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 2: April – June 2018

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June 2018

TABLE OF CONTENTS

LIST OF TABLES ii

LIST OF FIGURES ii

EXECUTIVE SUMMARY iv

1.0 GENERAL BACK GROUND 1

2.0 METHOD AND MATERIALS 3

2.1 Study area 3

2.2 Depth profiles and water transparency determination 4

2.3 Physico-chemical parameters 4

2.4 Nutrient and phytoplankton status 5

2.5 Zooplankton composition 5

2.6 Benthic macro invertebrate composition 6

2.7 Fish community 6

3.0 RESULTS AND DISCUSSION 7

3.1 Physico-chemical conditions and Nutrients 7

3.1.1 Physico-chemical conditions 7

3.2 Nutrients, Chlorophyll a, and Total suspended solids (TSS) 9

3.3 Phytoplankton species composition, abundance and distribution 11

3.4 Zooplankton abundance and species composition 16

3.4.1 Zooplankton abundance 16

3.4.2 Zooplankton species composition and distribution 18

3.5 Macro-benthic invertebrate community 21

3.5.1 Taxa composition and distribution 21

3.5.2 Macro-benthic invertebrate abundance 23

3.6 Fish species diversity, abundance and ecology 25

3.6.1 Fish Catch composition and abundance 25

3.6.2 Catch rates/biomass estimates 26

3.6.3 The haplochromines 26

3.6.4. Biology of common fish species 29

4.0 CONCLUSION 31

REFERENCES 32

Appendix: Percent composition of benthic macroinvertebrates, June 2018 35

LIST OF TABLES

Table 1. Physico-chemical variables at the sampling points, June 2018 7

Table 2. Concentrations of nutrients (µg/l), chlorophyll *a* (µg/l) and Total Suspended (mg/l), at SON cages and non-cage sites, during June 2018 9

Table 3. Distribution of phytoplankton species across sampled stations, March 2017 to June 2018 13

Table 4. Zooplankton species composition and distribution across study sites at SON fish farm, March 2017 to June 2018. 18

Table 5. Occurrence of benthic macro invertebrate taxa across the study sites at SON fish farm, June 2018. 22

Table 6. Catch rates (numbers) of fish species from SON cage area, Mar. 2016 – Jun. 2018. 25

Table 7. Catch rates by weight (g) of fish caught at SON Fish cage site, upstream and downstream of cages, March 2016 to June 2018. 27

Table 8. Catch rates (by numbers) of haplochromine species from SON Fish cage site. 28

Table 9. Basic biological parameters of fish species caught from SON Fish cage site, March 2016 to June 2018. 29

LIST OF FIGURES

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, BCS- between cage sites, and DSC- downstream of cages. 4

Figure 2. Monthly variation in mean levels of the physico-chemical parameters between cage and non-cage areas. Downstream (Stations BCS and DSC), Upstream (RPT and USC) and Within cages (WIC1 to WIC4) 8

Figure 3. Monthly variation in mean concentration of nutrients, and total suspended solids between cage and non-cage areas.. 10

Figure 4. Total abundance of phytoplankton (expressed as bio-volume, mm^3L^{-1}) at sampled stations: Reference point (RPT), Between cage sites 1 and 2 (BCS), Downstream (DSC), Upstream (USC) and Within (WIC1, WIC2, WIC3, WIC4) cages, June 2018..... 11

Figure 5. Relative abundance of different phytoplankton groups at: Reference point (RPT), Between cage sites (BCS), Downstream (DSC), Upstream (USC) and Within (WIC1, WIC2, WIC3, WIC4) cages, June 2018. 12

Figure 6: A) Abundance of different phytoplankton groups across months and B) their relative contribution per month, March 2017 to June 2018..... 13

Figure 7. Mean abundance of total zooplankton, copepods, cladocera and rotifers at cage (WIC1 – WIC4) and non-cage (RPT, USC, BCS and DSC) stations, June 2018..... 17

Figure 8. Monthly variation in mean abundance of total zooplankton, copepods, cladocera and rotifers at Upstream (RPT and USC stations), Within cages (WIC1 to WIC4) and Downstream of cages (BCS and DSC)..... 18

Figure 9. Numerical abundance of major benthic macroinvertebrate taxa recorded at SON during March and June 2018 periods.. 24

Figure 10. Monthly variation in total abundance (±SE) of macro invertebrates across study sites at SON fish farm, March 2017 to June 2018. Upstream (RPT and USC stations), Within cages (WIC1 to WIC4) and downstream (DSC station)..... 24

EXECUTIVE SUMMARY

The monitoring of water quality and biotic communities at Source of the Nile (SON) fish farm for quarter 2 (April to June 2018) was undertaken in June 2018. The activity aimed at assessing the status of the water environment at the farm 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 at all sampled stations. Water transparency measured as Secchi depth (SD) was above 1.0 m (range 1.3–1.63). Dissolved oxygen at all sites was above 6.0 mg/l suitable for fish such as catfish and Nile tilapia which require at least 4 mg/l to maintain good health and feed conversion. Temperatures at all sites was 25.5–26.5 ^{o} C and fell within the ranges typically observed in Lake Victoria. The lowest and highest values of pH were recorded at the reference (range 3.37 – 8.38), with the rest of the sites having a pH above 7.0, which was within the optimal range (6.0 – 9.0), suitable for the cultured fish. Conductivity varied within narrow margin (95.2–98.4 µS/cm) and was typical of Lake Victoria.

Nitrite-nitrogen concentration in the current month of June (range: 4.69–7.77 µg/l) was higher than previously recorded in March 2018 (about 2.60 µg/l) at all sites. Nitrate-nitrogen was lowest at the reference (9.75 µg/l) and highest at downstream (13.92 µg/l) similar to previous records of March 2018. For ammonium nitrogen, the lowest (10.2 µg/l) and highest (85.2 µg/l) values were recorded in the cages. The concentration of total nitrogen was lowest in the cages at WIC2 (398 µg/l) and highest at downstream (766.2 µg/l). Total phosphorus concentration recorded in the current survey (range: 38.63–41.13 µg/l) was lower than previously recorded in March 2018 (Range: 78.08–88.08 µg/l). Soluble reactive phosphorus varied within narrow margin (range: 9.38–11.88 µg/l). The concentration of chlorophyll *a* was in the range 4.17–9.73 µg/l while total suspended solids ranged 2.0–3.8 mg/l. At all sites, the concentrations of nutrients were within the acceptable standards for fish survival.

Phytoplankton community mainly comprised of blue-green, diatoms and green algae, with a total of 50 species (18 species of blue-green algae, 12 species of diatoms and 20 species of green algae). Diatoms made a significant contribution > 40% at majority of the sites, except at downstream of cage site 1 where the group contributed 30 %, and was superseded by blue-green

algae with 52 %. The highest contribution of green algae (>40%) to the total biovolume was in the upper cage site. Whereas the bio-volume of diatoms ranged between 30 and 70 %, that of blue-green algae and green algae ranged from 10 to 52 % and 6 to 34 % respectively.

The cage sites presented the lowest abundance and species richness of zooplankton in June 2018. Copepods were the most abundant (range: 582,861–654,809 ind.m^{-2} at upstream, 459,175–755,051 ind.m^{-2} at downstream, and 2,425–489,894 ind.m^{-2} within the cages). For rotifers, abundance was in the range 46,685–46,888 ind.m^{-2} at upstream, 26,677–194, 826 ind.m^{-2} at downstream and 11,318–55,780 ind.m^{-2} within the cages. Cladocerans were the least abundant (range: 3,638–4,850 ind.m^{-2} at upstream, 4,850–10,509 ind.m^{-2} downstream, and 0–11,318 ind.m^{-2} within the cages). Benthic macroinvertebrate community comprised of Molluscs (Bivalves and gastropods), Arthropods (May flies, caddis flies, dragon flies, and dipterans) and annelids (Oligochaetes and Hirudinea). Taxa richness ranged from 9 to 18 taxa in the non-cage stations and 5 to 16 taxa in the cages. Generally, total abundance of benthic macroinvertebrates recorded in June 2018 was less than that of March 2018. Molluscs were the numerically most abundant and well distributed benthos at all sites, with the abundance in the current survey higher than previously recorded in March 2018 and December 2017, while EPT indicated a decline at all sites.

One fish species, *Lates niloticus* (Nile perch) was recorded in the recent survey of June 2018 in all sites compared to six fish species (*Lates niloticus*, *Mormyrus kannume*, *Oreochromis niloticus, Synodontis afrofischeri, Barbus altianalis* and haplochromine as a single species) recorded in March 2018. Overall mean catch rates during the June 2018 survey were 0.3 fish/net/night and 53.2g/net/night compared to 0.5 fish/net/night and 208.5g/net/night recorded in March 2018. Catch rates in June 2018 were highest at the upstream of cages sites, both by weight (159.5g/net/night) and number (0.9 fish/net/night). The diet of *L. niloticus* comprised of Odonata (36.7%), *Caridina nilotica* (23.3%), haplochromine cichlids (35%) *and R. argentea* (5%), which are known natural foods of the species. Infection by fish parasites was not noticed in any fish specimen recorded from the experimental gillnets.

The overall observation on concentrations of nutrients and levels of physico-chemical variables in the water column, as well as abundance and distribution of biotic communities indicated minimal impact of cage operation on water quality.

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 is through a collaborative arrangement between SON fish farm and NaFIRRI and aims at assessing the status of the water environment at SON cage area. The fish rearing activity at SON fish farm involves keeping fish in cages 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 end up in 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 and 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 (Sanz-Lázaro and Marín 2011). Caged fish under crowded conditions is susceptible to water-borne diseases and could infect wild fish or vice versa. While disease outbreak 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 second quarter (April to June 2018) undertaken in June 2018. 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 has two cage sites (Figure 1) 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. The transect runs from the reference point (RPT) located upstream of upper cage site (site 2) through the two cage sites to the downstream site, incorporating both sites into the monitoring plan (Figure 1). Sampling was carried out at the following sampling stations: 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 cages in cage site 2 and cage site 1 respectively (Figure 1).

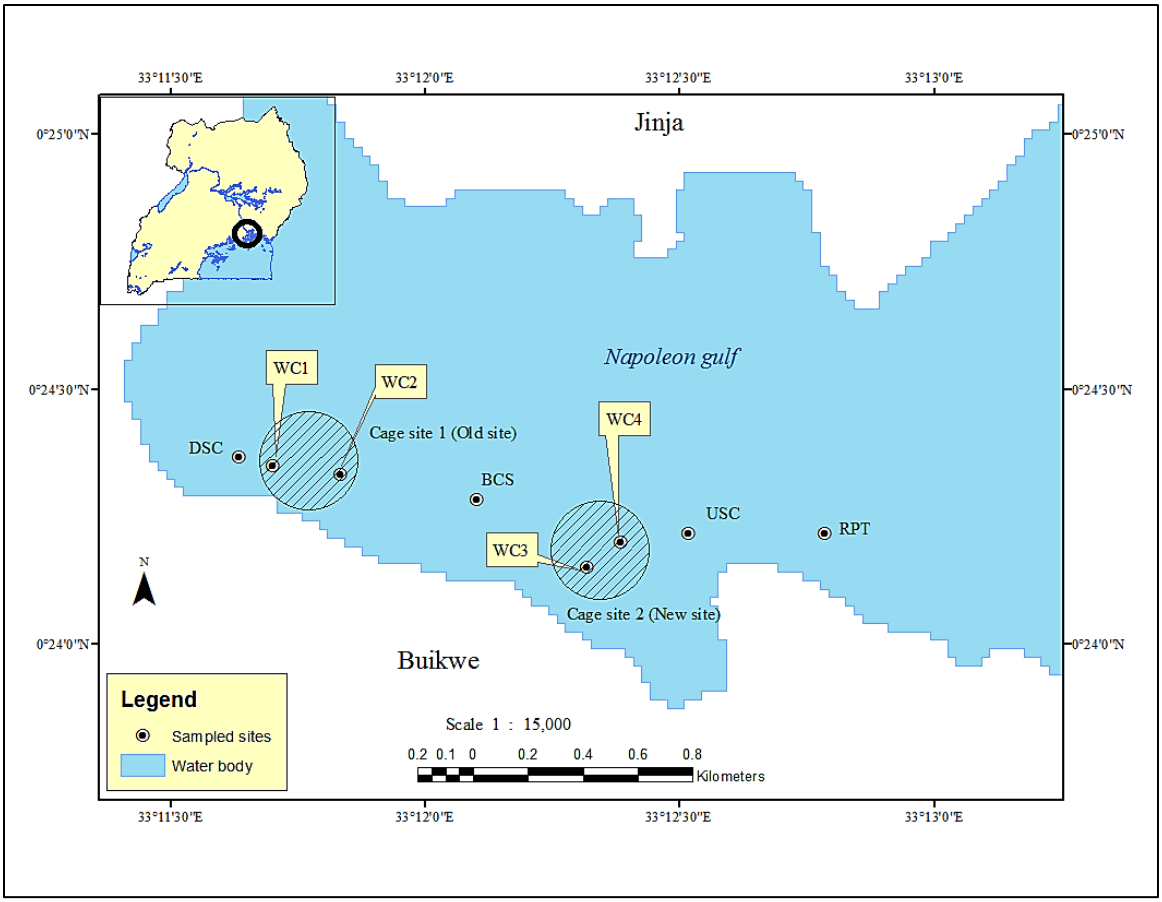

Figure 1. Schematic presentation of the study area showing location of SON Fish Farm sites and study sampling points: RPT- Reference point, USC- upstream of cages; WC- within cages, BCS- between cage sites, and DSC- downstream of cages.

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. For the purposes of assessing variation in each parameter at each sampling point, all in-situ measurements were made in triplicate.

2.4 Nutrient and phytoplankton status

Water samples for the analysis of nutrients and phytoplankton status were collected at 0.5 m below the water surface 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 preserved in Lugol's solution for laboratory analysis. In the laboratory, standard methods were used to analyse 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 and 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 X400 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 and 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 and Braide (1991), Korinek (1999) and Koste (1978). Members of each species were enumerated.

2.6 Benthic macro invertebrate composition

Three replicate benthic macro invertebrate hauls were taken using a Ponar grab (open jaw area, 238cm^2) at each sampling station and consolidated into one sample for each station. The bottom type and texture were determined by visual examination and feel between two fingers. Each consolidated sample was concentrated, placed in clean, labeled sample bottle, and preserved with 5% formalin solution. In the laboratory, each sample was rinsed with tap water and spread out on a white metallic tray. Macroinvertebrates were then sorted from the sediment using forceps and each sample examined under a dissecting binocular microscope at x40 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). 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 Physico-chemical conditions and Nutrients

3.1.1 Physico-chemical conditions

Water physico-chemical variables: dissolved oxygen (DO), temperature, pH, conductivity, total depth (TD), and secchi depth (SD) were recorded during June 2018 period. Total depth was above 5.0 m at all sampled stations (Table 1). Water transparency measured as Secchi depth (SD) was above 1.0 m (range 1.33 at DSC to 1.63 at USC). Dissolved oxygen in both cage and non-cage sites was above 6.0 mg/l suitable for warm water fish such as catfish and Nile tilapia which require at least 4 mg/l of DO (FAO 1989) to maintain good health and feed conversion. Temperatures at all sites ranged from 25.5 to 26.5 ^{o} C and fell within the ranges typically observed in Lake Victoria (Sitoki et al. 2010). Water temperature in the range of 27–31 ^{o} C is optimal for growth of most fish (FAO 1989) including tilapia whose optimal range is 29–31 ^{o} C (Popma and Masser 1999). The lowest and highest values of pH were recorded at RPT (range 3.37–8.38). The rest of the sites however, had a pH above 7.0 at all depth (Table 1) which was within the optimal range of 6.0–9.0, suitable for the cultured fish (Popma and Masser 1999, Kasozi et al. 2016, Devi et al. 2017). Conductivity varied within narrow margin for all sites (range: 95.2 – 98.4 uS/cm) and this was within the range typical of Lake Victoria (Sitoki et al. 2010).

Table 1. Physico-chemical variables at the sampling points, June 2018.

Station	Statistic	DO (mg/l	Temp (^{o}C)	pH	EC (uS/cm)	TD (m)	SD (m)
RPT	Mean	8.83	26.17±0.14	7.80±0.30	96.58±0.23	9.3	1.49
	Range		25.5 – 26.5	3.37 – 8.38	95.7 – 97.6		
USC	Mean	8.93	25.97±0.09	7.97±0.04	95.99±0.08	9.1	1.63
	Range		25.6 – 26.3	7.74 – 8.14	95.6 – 96.4		
WIC4	Mean	9.06	26.03±0.05	7.85±0.02	96.17±0.09	9.4	1.57
	Range		25.8 – 26.2	7.75 – 7.94	95.8 – 96.6		
WIC3	Mean	9.06	25.89±0.06	7.99±0.04	95.91±0.04	8.5	1.61
	Range		25.6 – 26.1	7.85 – 8.17	95.70 – 96		
BCS	Mean	8.57	25.94±0.04	7.87±0.04	96.35±0.22	8.3	1.53
	Range		25.8 – 26.1	7.71 – 8.04	95.3 – 97.0		
WIC2	Mean	8.90	25.96±0.016	8.07±0.05	97.47±0.316	7.3	1.49
	Range		25.9 – 26	7.82 – 8.25	96.1 – 98.4		
WIC1	Mean	9.39	25.98±0.04	7.786±0.03	95.78±0.169	6.9	1.61
	Range		25.8 – 26.1	7.62 – 7.9	95.2 – 96.7		
DSC	Mean	8.01	25.65±0.03	7.60±0.08	95.20±0.07	5.2	1.33

Range	25.6 – 25.8	7.08 – 7.8	95 – 96

The levels of physico-chemical parameters recorded in the current survey at the sites (upstream, cage and downstream) were also compared with that determined in the previous surveys or sampling months. The variation in levels of dissolved oxygen, pH, temperature and conductivity across sampled months indicated a similar pattern across sites for a given parameter (Figure 2). For all the parameters, the lowest mean values were recorded at the downstream of the cages (Figure 2). Temperature, pH and conductivity exhibited minimal variation among upstream, cage and downstream sites since June 2017 (Figure 2).

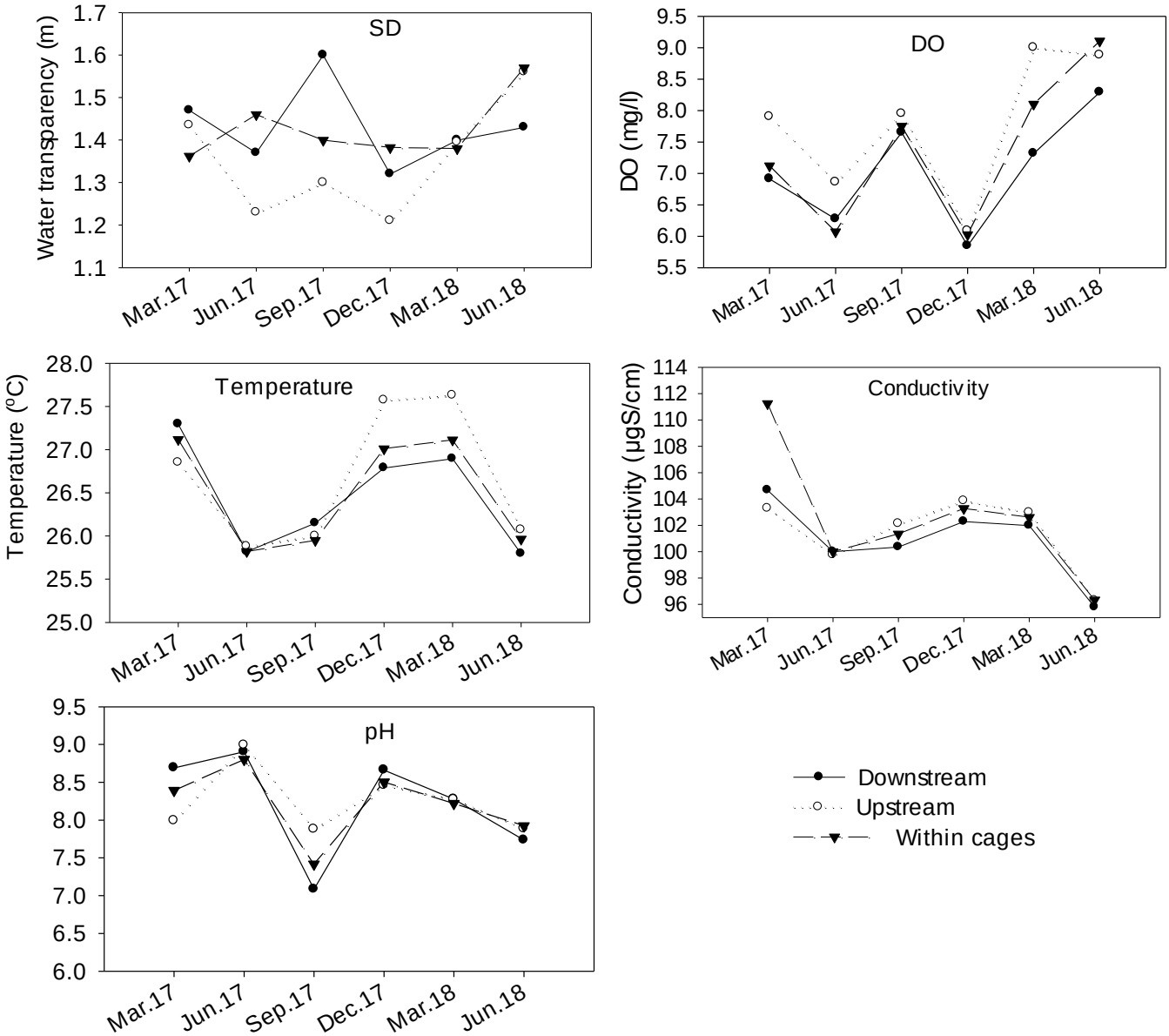

Figure 2. Monthly variation in mean levels of the physico-chemical parameters between cage and

non-cage areas. Downstream (Stations BCS and DSC), Upstream (RPT and USC) and Within cages (WIC1 to WIC4).

3.2 Nutrients, Chlorophyll *a*, and Total suspended solids (TSS)

Table 2 shows the concentration of nutrients as measured in June 2018 at the farm. Nitrite-nitrogen (NO_2-N) concentration in the current month of June (range: 4.69–7.77 µg/l) was higher than previously recorded in March (about 2.60 µg/l) at all sites. The concentration of nitrite-nitrogen was slightly higher in the cages (Range 6.23–7.77 µg/l) than recorded upstream (5.46 µg/l) and downstream (4.69–7.0 µg/l). Nitrate-nitrogen (NO_3-N) was lowest at RPT (reference) and highest at DSC similar to previous records of March 2018. For ammonium-nitrogen (NH_4-N), the lowest and highest concentrations were recorded in the cage site 2 and 1 respectively (Table 2). The concentration of total nitrogen (TN) was >390 µg/l at all sites, being lowest at WIC2 (398 µg/l) and highest at DSC (766.2 µg/l).

At all sites, Total phosphorus (TP) concentration recorded in the current month of June 2018 (38.63–41.13 µg/l) was lower than previously recorded in March 2018 (78.08–88.08 µg/l). Soluble reactive phosphorus (SRP) varied within narrow margin, 9.38–11.88 µg/l at upstream stations, 9.38–10.63 µg/l within the cages (WIC 1 to WIC4) and 10.63–11.88 µg/l at the downstream stations. The concentration of chlorophyll *a* (Chl-*a*) ranged from 4.17 µg/l at DSC to 9.73 µg/l at BCS while total suspended solids (TSS) ranged 2.0–3.8 mg/l. The variation in nutrient concentration across sampling months indicated no major differences between cage and non-cage sites (Figure 3). At all sites, the concentrations of nutrients were within the acceptable standards for fish survival (FAO 1989).

Table 2. Concentrations of nutrients (µg/l), chlorophyll *a* (µg/l) and Total Suspended (mg/l), at SON cages and non-cage sites, during June 2018.

	Sampling sites and stations							
	Upstream		Cage site 2		Cage site 1		Downstream	
Variables	**RPT**	**USC**	**WIC4**	**WIC3**	**WIC2**	**WIC1**	**BCS**	**DSC**
NO_2-N	5.46	5.46	7.00	6.23	6.23	7.77	4.69	7.00
NO_3-N	9.75	12.25	12.25	12.25	13.08	13.08	13.92	13.92
NH_4-N	37.20	43.20	20.20	10.20	85.20	52.20	52.20	40.20
SRP	9.38	11.88	9.38	10.63	8.13	9.38	11.88	10.63
TN	642.20	722.20	674.20	749.20	398.0	569.20	715.20	766.20
TP	40.29	41.13	39.46	38.63	39.46	39.88	38.63	39.46
Chl-*a*	5.56	5.56	4.17	6.95	8.34	5.56	9.73	4.17

TSS	2.0	2.6	2.2	3.4	3.8	2.0	2.2	2.0

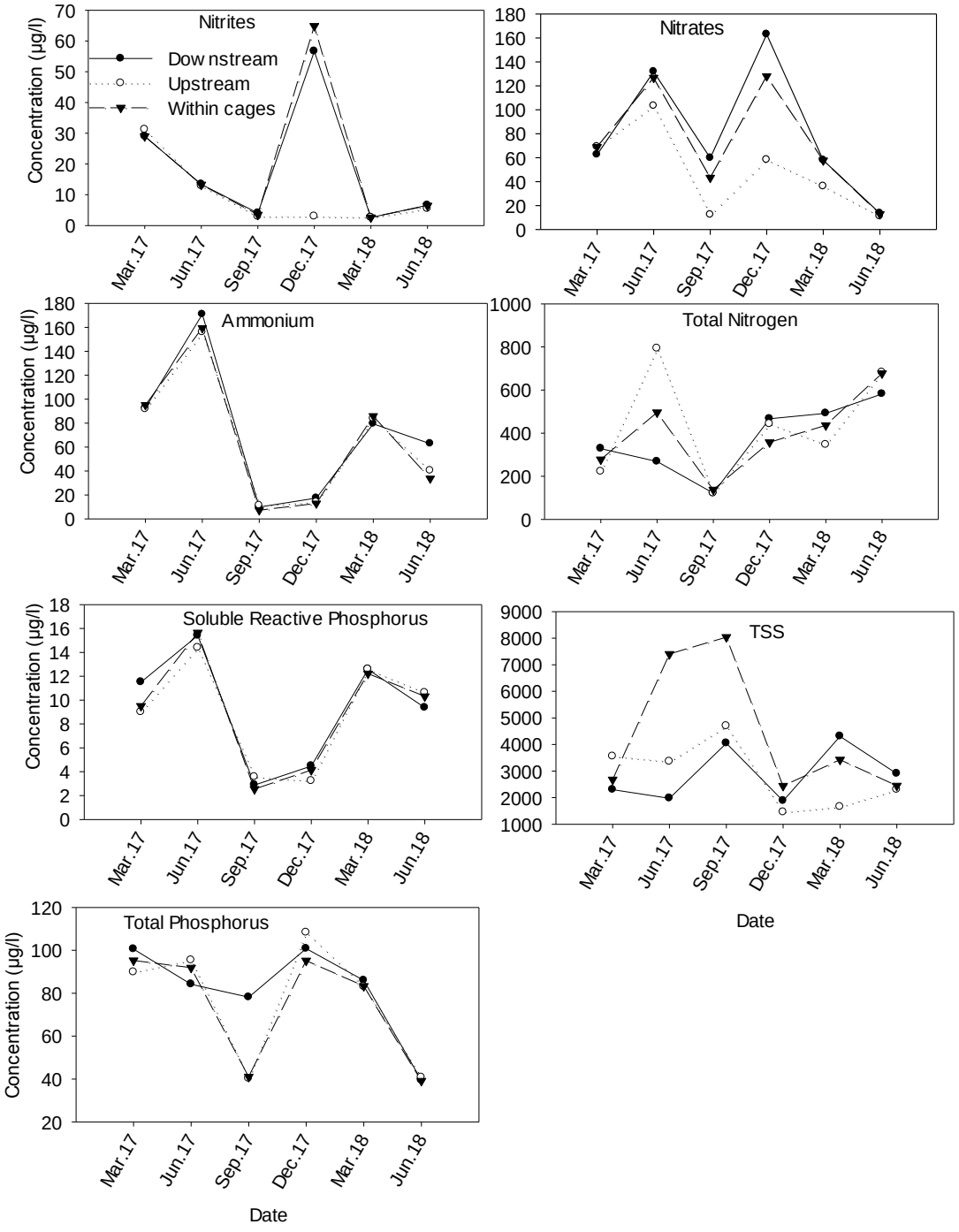

Figure 3. Monthly variation in mean concentration of nutrients, and total suspended solids between cage and non-cage areas. Downstream (Stations BCS and DSC), Upstream (RPT and USC) and Within cages (WIC1 to WIC4).

3.3 Phytoplankton species composition, abundance and distribution

Phytoplankton community mainly comprised three taxonomic groups: blue-green algae, diatoms and green algae, similar to the records from previous surveys. The total bio-volume of phytoplankton was highest at the reference (RPT) followed by WIC4 in cage site 2 and WIC1 in cage site 1 (Figure 4). Whereas the reference point (RPT) had the highest bio-volume, the least was recorded at BCS, a downstream station of the second cage site. Diatoms made a significant contribution > 40% at majority of the sites, except at DSC station, downstream of cage site 1 where the group contributed 30 %, and was superseded by blue-green algae with 52 % (Figure 5). The highest contribution of green algae (>40%) to the total biovolume was at WIC4 in cage site 2 (Figure 5). Whereas the bio-volume of diatoms ranged between 30 and 70 %, that of blue-green algae and green algae ranged from 10 to 52 % and 6 to 34 % respectively. Noteworthy, diatoms were the dominant group at majority of the stations both in cage and non-cage sites and in these stations, blue-green occurred with a negligible contribution (Figure 5).

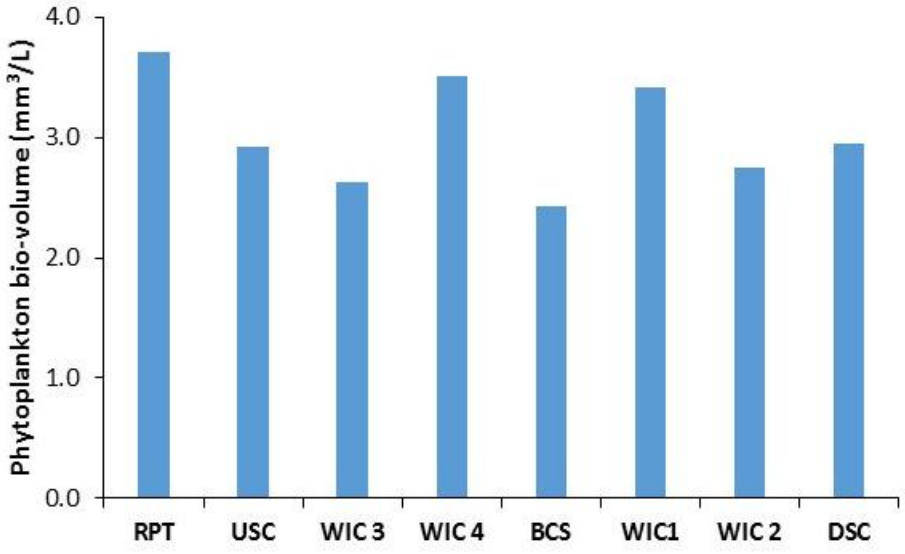

Figure 4. Total abundance of phytoplankton (expressed as bio-volume, mm^3L^{-1}) at sampled stations: Reference point (RPT), Between cage sites 1 and 2 (BCS), Downstream (DSC), Upstream (USC) and Within (WIC1, WIC2, WIC3, WIC4) cages, June 2018.

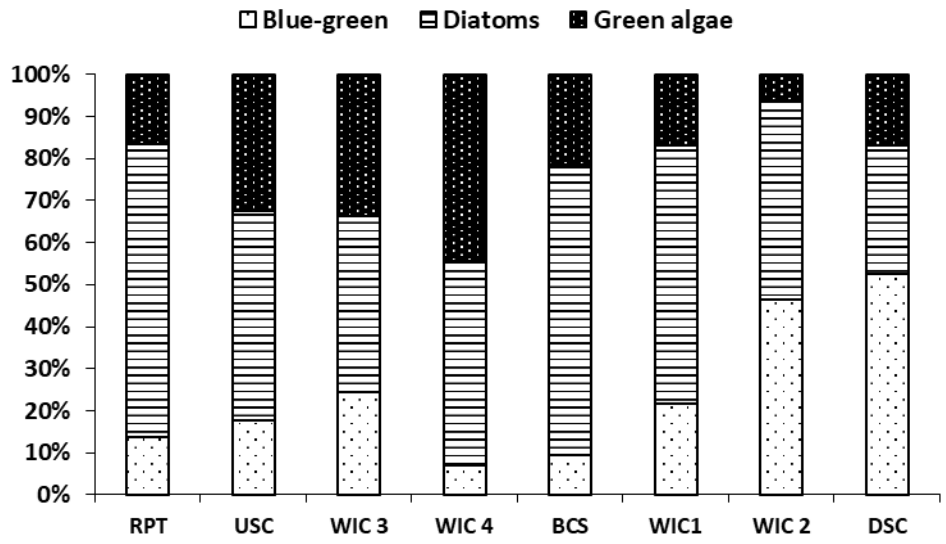

Figure 5. Relative abundance of different phytoplankton groups at: Reference point (RPT), Between cage sites (BCS), Downstream (DSC), Upstream (USC) and Within (WIC1, WIC2, WIC3, WIC4) cages, June 2018.

However, the phytoplankton bio-volume of June 2018 was lower than that recorded in the previous months. There also seems to be a phytoplankton succession between diatoms and cyanobacteria among months. For instance, whereas diatoms dominated in June 2018 and September 2017, blue-green algae dominated in March 2018, June 2017 and March 2017 (Figure 6). From March 2017, the highest bio-volume was measured in June 2017, and the least occurred in the current survey (June 2018). The difference in phytoplankton contribution could be attributed to changes in nutrient levels which were generally higher in June 2017 than recorded in June 2018 (Figure 3).

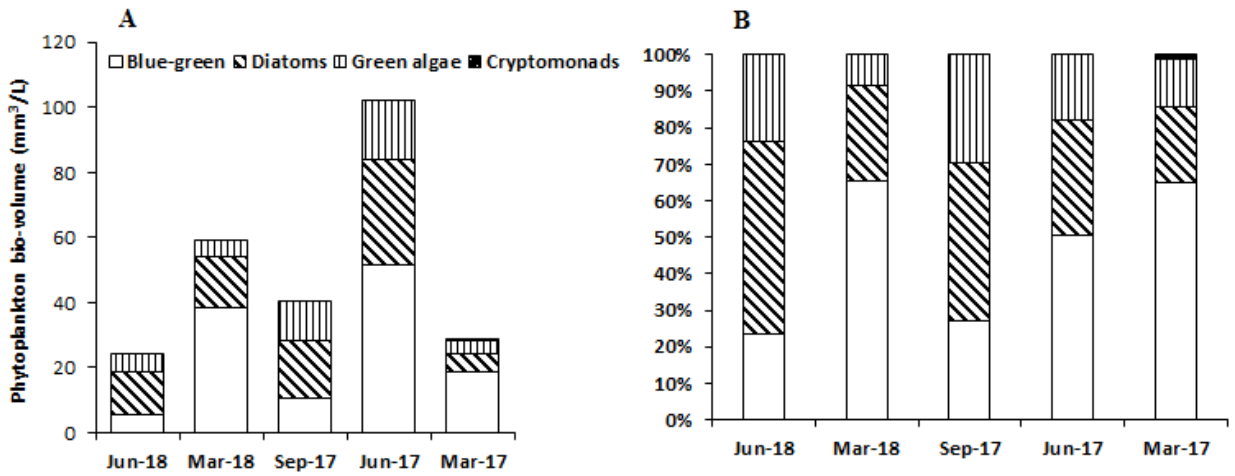

Figure 6: A) Abundance of different phytoplankton groups across months and B) their relative contribution per month, March 2017 to June 2018.

However, despite the low bio-volume recorded in June 2018, there was a higher occurrence of species compared to the previous survey. A total of 50 species were recorded, 18 belonging to blue-green algae, 12 to diatoms and 20 to green algae (Table 3). As reported previously, diatoms have been consistently dominated by *Nitzschia acicularis* (7 mm^3L^{-1}). Blue-green algae were dominated by *Microcystis flos-aquae* (1.5 mm^3L^{-1}) and *Planktolyngbya circumreta* (1.6 mm^3L^{-1}). All other species of these groups and green algae had a bio-volume less than 1 mm^3L^{-1}.

This general phenomenon of blue-green algae and diatoms dominance in the waters of Lake Victoria has been reported over time (Mugidde et al. 2003) and associated with eutrophication of the lake. This in turn has been linked with increased human population in the lake catchment which has significantly led to an increase in the phytoplankton productivity (Bootsma and Hecky 1993, Hecky 1993) and dominance by opportunistic colonial and filamentous blue-green algae such as *Microcystis* and *Planktolyngbya*. Species such as *Nitzschia acicularis* have been supported by a general reduction in silica concentration, causing a silica demand and proliferation of such non-heavily silicified diatoms.

Table 3. Distribution of phytoplankton species across sampled stations, March 2017 to June 2018.

	Sampling points							
Taxa	**RPT**	**USC**	**WIC4**	**WIC3**	**BCS**	**WIC2**	**WIC1**	**DSC**
Blue-green algae								
Anabaena circularis			---+-					

	Sampling points							
Taxa	**RPT**	**USC**	**WIC4**	**WIC3**	**BCS**	**WIC2**	**WIC1**	**DSC**
Anabaena circinalis	++++++	+--++-	++--++	++++++	++--+-	+--+++	++-+++	++-++-
Anabaena sp.		-+----			---+--			
Anabaenopsis tanganyikae		--+---	---+-+		++----			
Aphanocapsa delicatissima	-+-+-+	-+++-+	-+++--	-+++--	--++--	---+++	---+-+	--++-+
Aphanocapsa elachista	--++--	---++-	---+--	-++---	---+-+	+-++++	-+-+-+	---++-
Aphanocapsa holistica			--+---	+-----	---+--	----+-	--+---	
Aphanocapsa incerta	+-+++-	+---++	---+--	+-++--	-+-+--	---+++	---+--	+--++-
Aphanocapsa nubile	---++-	+--+-+	++++++	-++++-	--+-+-	-++++-	+--+-+	+++++-
Aphanocapsa sp.	---+--	-+-+--	-+-+--		--+---	--+++-	-+-+--	---++-
Chroococcus dispersus	---+++	---+--	-+++--	++-+-+	+--+--	+++++-	---+--	+--+++
Chroococcus limnetica	++++--	++++++	+-++++	++-++-	-+-+++	+--++-	---++-	+--+++
Chroococcus minutus		----+-	----+-	----+-	-----+	----+-		----++
Chroococcus turgidus	-++-+-	-+-+-+	-+---+	---+--	-++---	---+--	+--+-+	-+-++-
Chroococcus sp.		--+---					--++--	
Chroococcus trigonum								--+---
Coelastrum microporum	---+--							
Coelomoron pusillum	--+++-	---+-+	-+++--	--+++-	---+-+	---+-+	---++-	--+++-
Coelomoron species							---+--	
Coelomoron tropicale	---+--	--++--	---+--	--++--	---+--		-++---	---+--
Coelosphaerium kuetzingianum	+--+--	---+--		+-----			-+----	+--+--
Coelosphaerium sp.						---+--		
Cylindrospermopsis africana			--+---					
Cylindrospermopsis sp.					--+---	-+----		
Merismopedia tenuissima	+-++++	+--+++	---++-	++-++-	++++-+	-+++++	+++-++	-+++-+
Merismopedia elegans	+-+---	--+---		+-----		+-----	----+-	
Merismopedia glauca	-++---	---+--				--+---		--+---
Merismopedia sp.					---+--			
Microcystis aeruginosa	---+--	-+----		-+-+--	-+----	--+---	-+-+--	--++--
Microcystis elegans					---+--			
Microcystis flos-aqaue		--+++-	-+----		--++--	---++-	---+-+	-----+
Microcystis wesenbergii		-+--+-		----+-				
Planktolyngbya sp.	-+----				+-----			
Planktolyngbya circumreta	++++++	++++++	++++++	++++++	-+++++	++++++	++++++	++++++
Planktolyngbya contorta	-+----	---+--						
Planktolyngbya limnetica	++++++	++++++	++++++	++++++	++++++	++++++	++++++	++++++
Planktolyngbya tallingi	--+--+	-+++-+	--+-+-	-+--++		--++++	+-----	-+++--
Planktolyngbya undulata				+-----		-----+		
Pseudonabaena limnetica	-+----		--+---	-+----	-+-+--	--+---		---+-+
Pseudonabaena sp.					-+----			
Scenedesmus acuminatus	-+----							
Diatoms								
Aulacoseira ambigua	-++---							
Aulacoseira granulata	+----+	-++---	--+-+-	-++-++		-+---+	-----+	-++---
Centric diatom		----+-			-----+	--+---	-+++--	--+---
Cocconeis placentula				-+----				
Cocconeis sp.			-+----					
Cyclostephanodiscus Astraea								-+----
Cyclostephanodiscus sp.						-+----		

	Sampling points							
Taxa	**RPT**	**USC**	**WIC4**	**WIC3**	**BCS**	**WIC2**	**WIC1**	**DSC**
Cyclotella kuetzingiana	-+----				-+----			
Cyclotella sp.	--+---	---+--		-+----	--+---	----+-	---+--	
Cyclotella meneghiniana			-----+			---+--		-----+
Cymbella cistula	-+----							
Epithemia argus			+-----					
Fragilaria sp.		-+----						
Navicula gastrum	--+--+	+++---	-++-++	--+---	++--+-	++----		--+-+-
Navicula granulate				---+--				
Navicula radiosa	---+++			----++	-----+	-----+	----+-	-----+
Navicula sp.	--+---				-++---			
Nitzschia acicularis	+++++-	+++-++	++++++	++++++	++++++	++++++	++++++	++++++
Nitzschia closterium						-+----	-+----	
Nitzschia fonticola	+-+---	--+---	-++---	-+----	-+----	++++--	-+---+	-+---+
Nitzschia sp.			-+----					
Stephanodiscus Astraea	----++	-----+		-----+	---+--	-----+	-----+	
Surirella linearis					-----+			
Surirella robusta						-----+		
Synedra cunningtonii	----++	-+++++	----++	-++--+	+-+-++	-----+	-----+	-----+
Synedra sp.			-+----					
Synedra ulna					-+----	-+----	-----+	
Green algae								
Actinastrum hantzschii	--++--	--+---	--+---	---+--	-+----	---+--		
Ankistrodesmus falcatus	+-++++	--++++	-+++++	+-+-++	+-++++	+-++--	--++++	++++--
Ankistrodesmus fusiformis								+----
Ankistrodesmus setigerus		---++-	--+---	+-+---				
Anthrodesmus sp.						--+---		
Chlorella vulgaris		++----	-----+	+-----	-+----	+-----	-----+	+--+--
Chlorella sp.		---+--						
Chodatela sp.								---+--
Closterium aciculare						+-+---		
Closterium acutum	-----+						-----+	
Closterium Kuetzingii			--+---		--+---	--+---		
Closterium spp.	-+----	--+---	----+-	-----+	---+--		---+--	-+++--
Coelastrum costatum					-+----			
Coelastrum microporun					--+---			
Cosmarium sp.		-----+				-+----	-+----	-+----
Crucigenia fenestrate			-+--+-	---+--		+-----	-----+	-----+
Crucigenia tetrapedia				-+----	-++---			
Didymocystis tuberculata		---+--	---+--					--+---
Kirchneriella obesa	--+---	--+---	+-+---	----++	-++-+-		++----	-++---
kirchneriella subsoltaria	---+--				---+--			
Kirchneriella sp.		----++	----+-		--+--+			
Monoraphidium contortum	++-+-+	-++-+-	-+-+++	+++-++	--+-+-	-+--++	--+---	-+----
Monoraphidium sp.		-----+			--+---	--+---	-+----	
Oocystis gigas	+-++-+	--++--	-----+	+-----			-+----	+-+---
Oocystis lacustris						+-----		
Oocystis sp.			----+-		--++--		---+--	
Pediastrum duplex	-+-+--					--+---		
Pediastrum simplex	--+--+	----++	++---+	-----+	+----+	++----	-+--+-	-----+
Pediastrum tetras		-----+		-----+				

	Sampling points							
Taxa	**RPT**	**USC**	**WIC4**	**WIC3**	**BCS**	**WIC2**	**WIC1**	**DSC**
Scenedesmus arcuatus			--++--					
Scenedesmus acuminatus	-+--++	----+-		-+---	--+-++	--+-++	--+---	
Scenedesmus armatus		-----+	+-+---					+-----
Scenedesmus perfolatus	-+++--	+++-++	--+-++	+---++	--+-+-	+---+-	-++---	--+---
Scenedesmus quadricauda				---+--	--++--			
Scenedesmus sp.		--++--			---++-			
Selenestrum bibraianum		--+---		--+---				
Selenestrum sp.		--+---		-+----	-++---		--+---	
Staurastrum cheatoceras				--+---				
Staurastrum cunningtonii					-----+			
Staurastrum gracile	---+-+		-+----	-----+			--+--+	
Staurastrum longiradiatum								-----+
Staurastrum sp.					-+----			
Tetraedron trigonum			---+--		+-----		--+---	-++---
Cryptophytes								
Cryptomonas marssonii							+-----	
Cryptomonas sp.						+-----		+-----

Note: '+' indicates presence of taxon and '–' indicates absence of taxon, in the order of March 2017, June 2017, September, 2017, December 2017, March and June 2018.

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. These taxa are important to the fishery as they are an important food source for larval and pelagic fish. Total zooplankton abundance and the abundance of copepods and rotifers were highest at BCS station located between the two cage sites and therefore downstream of upper cage site (Figure 7). Cladocera abundance was highest at WIC4 station in the upper cage site (cage site 2) and lowest in the lower cage site (cage site 1, WIC1 and WIC2) where no cladocerans were recorded (Figure 7). The cage sites presented the lowest abundance of zooplankton in the present survey of June 2018 (Figures 7 and 8). Total zooplankton abundance and the abundance of copepods were lowest in cage site 2 (WIC3 and WIC4 stations) while rotifer and cladocera abundance were lowest in cage site 1 (WIC1 and WIC2) as seen in figure 7. Copepods which are known to be the numerically dominant zooplankton in Lake Victoria (Mwebaza-Ndawula 1994) were the most abundant at all sites (range: 2,425–755,051 ind.m^{-2}), followed by rotifers (11,318–194, 826 ind.m^{-2}) with the cladocerans contributing <12,000 ind.m^{-2}, being absent at WIC1 and WIC2 (Figure 7).

The abundance of copepods was 582,861–654,809 ind.m^{-2} at upstream (RPT and USC), 459,175–755,051 ind.m^{-2} at downstream (DSC and BCS), and 2,425–489,894 ind.m^{-2} within the cages (WIC1 To WIC4). For cladocerans, the abundance was 3,638–4,850 ind.m^{-2} at upstream, 4,850–10,509 ind.m^{-2} downstream, and 0–11,318 ind.m^{-2} within the cages. The abundance of rotifers was 46,685–46,888 ind.m^{-2} at upstream, 26,677–194, 826 ind.m^{-2} at downstream and 11,318–55,780 ind.m^{-2} within the cages. Generally, zooplankton abundance was higher in the non-cage sites than was recorded in the cage sites (Figure 8).

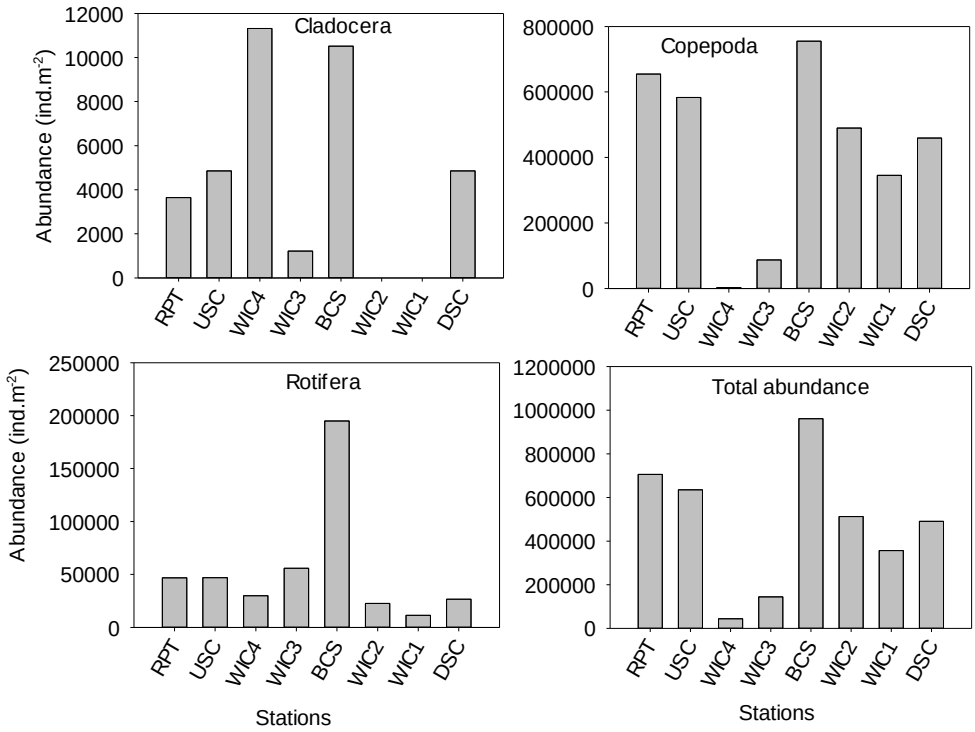

Figure 7. Mean abundance of total zooplankton, copepods, cladocera and rotifers at cage (WIC1 – WIC4) and non-cage (RPT, USC, BCS and DSC) stations, June 2018.

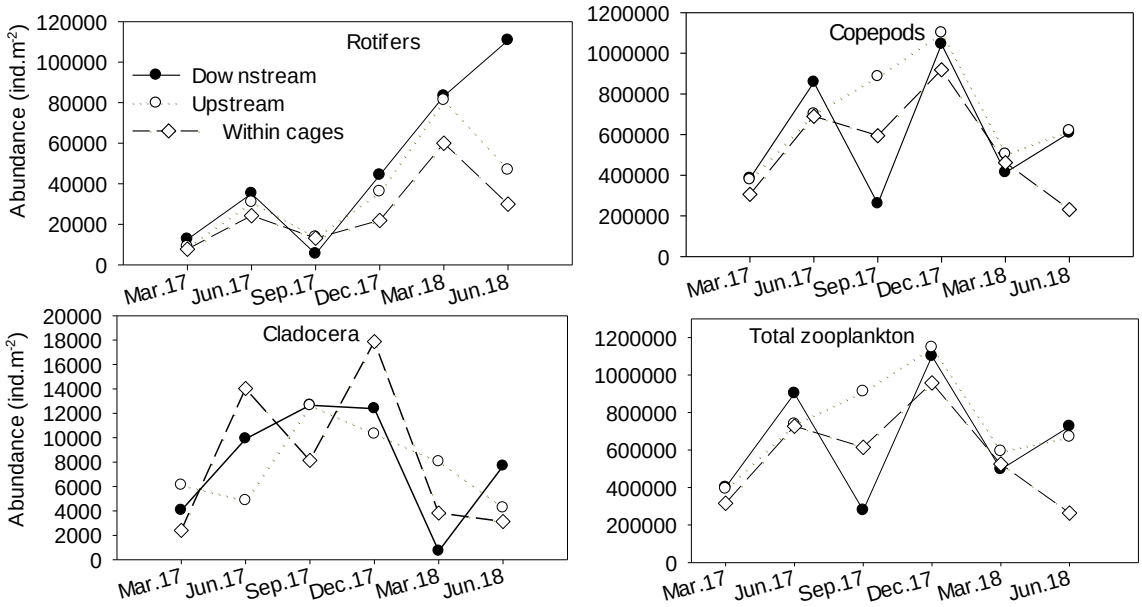

Figure 8. Monthly variation in mean abundance of total zooplankton, copepods, cladocera and rotifers at Upstream (RPT and USC stations), Within cages (WIC1 to WIC4) and Downstream of cages (BCS and DSC).

3.4.2 Zooplankton species composition and distribution

A total of 28 species (6 copepods, 5 cladocera and 17 rotifers) were recorded in June 2018 survey (Table 4) and this was lower than recorded in March 2018 (34 species: 7 copepods, 7 cladocerans and 20 rotifers). In all the sampling periods, rotifers were the most species rich (Table 4). In the current survey, the number of species was highest in the non-cage sites (range: 8 to 18 species and lowest in the cages (5 to 14 species). None of the species including the juveniles of copepods were recorded in all stations sampled during the current survey of June 2018. In the previous survey of March 2018, the young copepod stages (calanoid copepodites, cyclopoid copepodites and nauplius larvae), as well as adult stages (*Thermodiaptomus galeboides* and *Tropocyclops tenellus*), rotifers such as *Keratella cochlearis*, *Synchaeta* spp. and *Trichocerca cylindrica* were recorded at all stations.

Table 4. Zooplankton species composition and distribution across study sites at SON fish farm, March 2017 to June 2018.

Sampling points	RPT	USC	WIC4	WIC3	BCS	WIC2	WIC1	DSC
COPEPODA	**5,6,6,5,5,6**	**6,5,6,4,6,4**	**5,6,6,6,6,1**	**4,5,5,6,7,3**	**5,6,4,7,6,4**	**4,7,5,7,5,2**	**4,6,5,5,3,0**	**3,5,4,6,5,2**
Mesocyclops sp.	-++--++		-++++-	+-+++-	-+-+--	-+++--	++---	---++++

Sampling points	RPT	USC	WIC4	WIC3	BCS	WIC2	WIC1	DSC
Thermocyclops incisus	+----+	+++-+-	+-+-+-	-+--+-	++-++-	-+-+--	--+---	
Thermocyclops emini	-+++-+	+-+-++	+++++-	-+-++-	---+++	++-++-	-+++--	-+-+--
Thermocyclops neglectus	+++++-	+++++-	+++++-	+-+++-	+++++-	-++++-	-+++--	-++++-
Thermodiaptomus galeboides	++++++	+++++ +	-+-+++	- +++++	++++++	+++++-	++-++-	+++++ -
Tropocyclops confinnis	++++++	+++++ +	++++--	+++++ +	++++++	++++++	+++++ -	+++++ +
Tropocyclops tenellus	++++++	+++++ +	+++++ -	+++++ +	++++++	++++++	+++++ -	+++++ -
Calanoid copepodites	++++++	+- ++++	+++++ -	+++++ +	++++++	++++++	-++-++	- +++++
Cyclopoid copepodite	++++++	+++++ +	+++++ -	+++++ +	++++++	++++++	+++++ +	+++++ +
Nauplius larvae	++++++	+++++ +	+++++ -	+++++ -	++++++	++++++	+++++ +	++- +++
CLADOCERA	**3,2,3,4,4, 2**	**2,2,4,3,4, 2**	**3,5,4,4,3, 2**	**1,4,3,4,3, 1**	**4,2,5,3,1, 4**	**1,3,6,4,2, 0**	**1,4,3,4,1, 0**	**2,3,3,3,0, 1**
Bosmina longirostris	++++-+	+++++ +	++++- +	- +++++	++++-+	-+++--	-+++--	--+--+
Ceriodaphnia cornuta	--++++	+-+-+-	++++--	-+++--	+-+--+	-+++--	-+-+--	-+++--
Chydorus spp.					--+---			
Daphnia lumholtzi		----+	----+-			--+---		
Daphnia lumholtzi(helm)	----+-			-+-+--	-----+	--+++-	--+---	---+--
Diaphanosoma excisum	+-+++-	--++--	+++++ +	+++++ -	+++++-	--+---	-+-+--	++-+--
Moina micrura	++-++-	- +++++	-++++-		+-++-+	+++++-	+++++ -	+++---
Macrothrix sp.			-+----					
Daphnia longispina				----+-				
ROTIFERA	**2,10,6,6,9 ,9**	**4,8,3,8,9, 9**	**2,3,5,4,4, 8**	**2,9,5,9,9, 9**	**2,7,3,6,13 ,8**	**1,9,6,8,13 ,6**	**5,3,9,5,9, 4**	**6,9,2,6,7, 4**
Ascomorpha sp.	-+---+			----+-	----+-	----+-		
Asplanchna spp.	--+---		-----+	--+-+-	----+-	-++-+-	--+---	--+-+-
Brachionus angularis	-+++++	++++- +	-+----	++-+-+	----++	-+--++	- +++++	+--++
Brachionus bidentatus				---+--	---+--	---++-	---+--	---+--
Brachionus caudatus				----+-				
Brachionus calyciflorus	-+----	----++		-+--++	-+----	-++--	-----+	-+----
Brachionus falcatus	---+--	+-----		-+-+--		---+--	+-+++-	---+--
Brachionus forficula		---+--	-----+					

Sampling points	RPT	USC	WIC4	WIC3	BCS	WIC2	WIC1	DSC
Brachionus budapstinensis					----+-			
Cephlodella sp.	-----+	-----+	--+--+	-+---+	---++-	---+--		-----+
Euclanis sp	++--++	-+--++	-----+	-+--+-	-+----	-+--+-	+---+-	++----
Filinia longiseta		---+--	-----+		----+-	-----+		+-----
Filinia opoliensis	----+--	-+-----	--+---	-----+	----++	--+---	--++--	
Hexathra		----++		--+---		--+++-		
Keratella cochlearis	-+-++-	-+-+++	---++-	-+-+++	--+++-	-++++-	--+-+-	-+-++-
Keratella tropica	-+++++	+++++ +	+-+++-	+--+++	++---+	-+---+	--+-++	-+-+-+
Lecane bulla	-++-++	+++---	-+++-+	-+++-+	-+++++	++-+++	-++-++	+++++ -
Lecane luna		---+---			----+-	----+-		
Polyarthra vulgaris.	-+----	-+--+-		----+-	--+-++	----+-	+---+-	-+----
Synchaeta spp.	++++++	---+++	+-+++	-++++	-++++	-++++	+-+++-	++-++
Synchaeta pectinata	----++	----+-			-----+	----+-		----+-
Trichocerca cylindrica	-+++++	-+-+++	-+--++	- +++++	++-+++	-+-+++	+++-+-	++--+-

Note: '+' indicates presence of taxon and '–' indicates absence of taxon, in the order of March 2017, June 2017, September 2017, December 2017, March 2018 and June 2018.

3.5 Macro-benthic invertebrate community

3.5.1 Taxa composition and distribution

Benthic macroinvertebrate community comprised of Molluscs (Bivalves and gastropods), Arthropods and annelids. Taxa richness ranged from 9 to 18 taxa in the non-cage stations (RPT, USC and DSC) and 5 to 16 taxa in the cages (WIC1 to WIC4), with the lowest number of taxa recorded at WIC4. Arthropods comprised of members of the order Ephemeroptera (may flies), Trichoptera (caddis flies), Odonata (dragon flies), and Diptera (flies). The annelids comprised of the classes Oligochaeta and Hirudinea (Table 5). Nine species of molluscs (4 Bivalve and 5 gastropod species) were recorded during the survey, with the highest number of species (7 species) recorded at the reference followed by USC (6 species) and the lowest number at WIC4 (3 species). The bivalve, *Corbicula africana* and the gastropods, *Bellamya unicolor* and *Melanoides tuberculata* were the most widely distributed mollusc species, being present at all stations sampled *Byssanodonta parasitica* was only absent at WIC4 but present in the rest of the stations (Table 5).

The order Ephemeroptera which is sensitive to pollution comprised of three species: *Caenis* sp., *Povilla adusta* and *Euthraulus* sp. *Caenis* sp. and *P. adusta* were recorded in majority of the stations except WIC4 and DSC while *Euthraulus* sp. was only recorded at the reference station (RPT). The order Trichoptera (caddis flies) comprised of two species: *Ecnomus* sp. and *Dipsuedopsis* sp. and these were recorded at the reference (RPT), USC and WIC2. Among Diptera species, only *Chironomus* spp. were recorded in 6 stations. *Procladius* sp. was only recorded at the reference while *Chaoborus* sp. was recorded at WIC2 and DSC. Among annelids, oligochaetes were the most widely distributed, being recorded in all stations sampled. Hirudinea were mostly recorded in the cages and at the reference (RPT). *Caridina nilotica* which is the main food for Nile perch (*Lates niloticus*) was not encountered at any station although it was part of the diet of this species in specimens examined during the current survey of June 2018 (section 3.6.4).

Table 5. Occurrence of benthic macro invertebrate taxa across the study sites at SON fish farm, March 2017 to June 2018.

	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	++--++	+-+--+	++-+++	++---+	+++++	++---	++++++	+++-++
Anisus natalensis	----+-							
Bulinus sp.	-----+							
Cleopatra pirothi	-----+							
Ephemeroptera								
Caenis sp.	+++-++	+++-++	+---+-	--+-++	+---+	++---+	--+-++	++----
Ephemerella sp.		+----						
Povilla adusta	+++-++	-+--++		--+--+	+++-+	++--++	-+--++	
Baetis sp.	+-----		+-----				+--++-	
Leptophlebidae	+-----							
Euthraulus sp.	-+--++	-+----			----+-	-+----		
Hyalophlebia sp.	----+-							
Plecoptera								
Perlidae	----+-							+-----
Odonata								
Phyllomacromia sp.	-+----	-----+				-----+		
Libellulidae	-----+		--+-+-	+----+			-----+	
Ictinogomphus sp.		-----+						
Diptera								
Ablabesmyia sp.	+-+-+-	+-----	+-+---		+----	+-+-++	-----+	--+---
Chironomus spp.	+-++-+	++-+-+	+++-+-	++++++	++-++	++++++	---+++	++++++
Clinotanypus sp.		+-++-+	+++-+-	++++-+	--+--	-+---+	-----+	++++-+
Cryptochironomus sp.	-----+	--+---		+----+	+----	-+---+	----++	
Procladius sp.	-----+	---+--					+-----	-+----
Tanypus sp.			--+---	-+-+--				++++--
Tarnytarsus sp.							+-----	
Ceratopogonidae	--+--+	-+--++	--+---	---+-+	----+	-----+	-----+	---+--

	Sampling points							
	RPT	**USC**	**WIC4**	**WIC3**	**BCS**	**WIC2**	**WIC1**	**DSC**
Chaoborus sp.	+-++--	-++---	+++++-	+++++-	--+++	--++++	+-+---	++++++
Trichoptera								
Leptoceridae		--+---				----+-		+-----
Polycentropodidae	+++---	--+---				-+----	--+---	
Dipsuedopsis sp.		--+--+				--+---	-+----	
Ecnomus sp.	-----+	----++			----+	----++	----+-	
Decapoda								
Caridina nilotica	--+---			----+-		--+---		
Hemiptera								
Naucorids			--+---					
Annelida								
Hirudinea	-+-+-+		-----+	-----+			----++	
Oligochaetes	-+++-+	++-+-+	++++++	++++++	+-+++	++++++	+-+-++	+++++

Note: '+' indicates presence of taxon and '–' indicates absence of taxon, in the order of March 2017, June 2017, September 2017, December, 2017, March and June 2018.

3.5.2 Macro-benthic invertebrate abundance

Generally, total abundance of benthic macroinvertebrates recorded in the current sampling period (June 2018) was less than recorded in the previous month of March 2018, except at USC and WIC2 where it was higher than previously recorded (Figure 9). Total abundance was highest at WIC1 and lowest at WIC4 within the cage area. Molluscs were the numerically most abundant and well distributed benthos at all sites. Notable species such as *C. africana* contributed >15% of the total abundance at majority of the stations sampled. At WIC4, *M. tuberculata* contributed 31.8% of the total abundance (Appendix). The reference point (RPT) and WIC1 were numerically dominated by the Ephemeroptera species *Povilla adusta* which contributed >21% of the total abundance of the benthos at these stations. The pollution tolerant *Chironomus* spp. (Dobrowolski 1987, Miserendino and Pizzolon 2000) dominated at WIC1 station (10.4% of the total abundance). The Oligochaetes which are also tolerant to poor water quality were highly abundant at RPT and WIC2 where the numerical abundance was 126 ind.m^{-2} for each station. Comparison of cage (WIC1 to WIC4), upstream (RPT and USC) and downstream (DSC) stations indicated minimal difference in the numerical abundance of the fauna (Figure 10). The abundance of molluscs at all sites was higher than previously recorded in March 2018 and December 2017, while EPT indicated a decline at all sites.

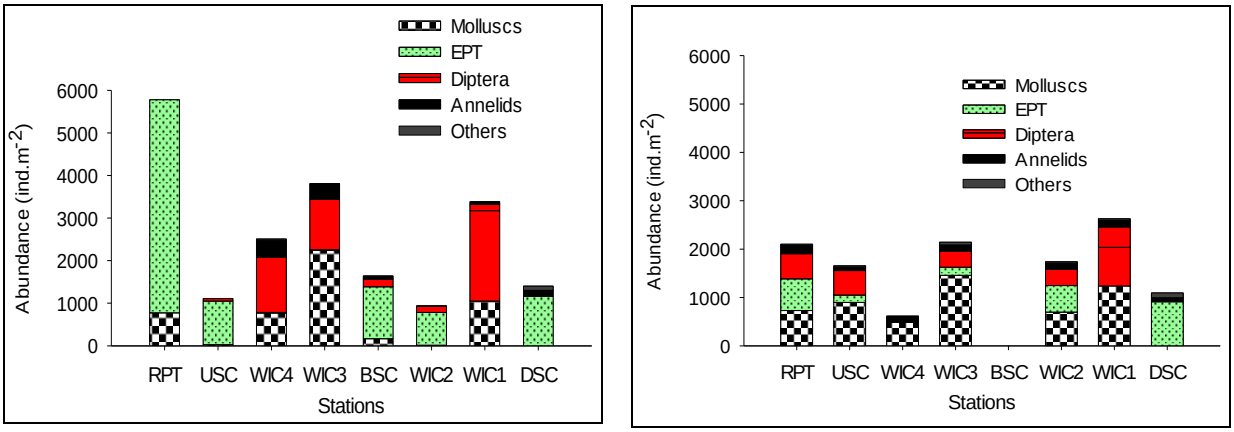

Figure 9. Numerical abundance of major benthic macroinvertebrate taxa recorded at SON during March and June 2018 periods. No sample was obtained at BCS and therefore no analysis at the site during June 2018 period.

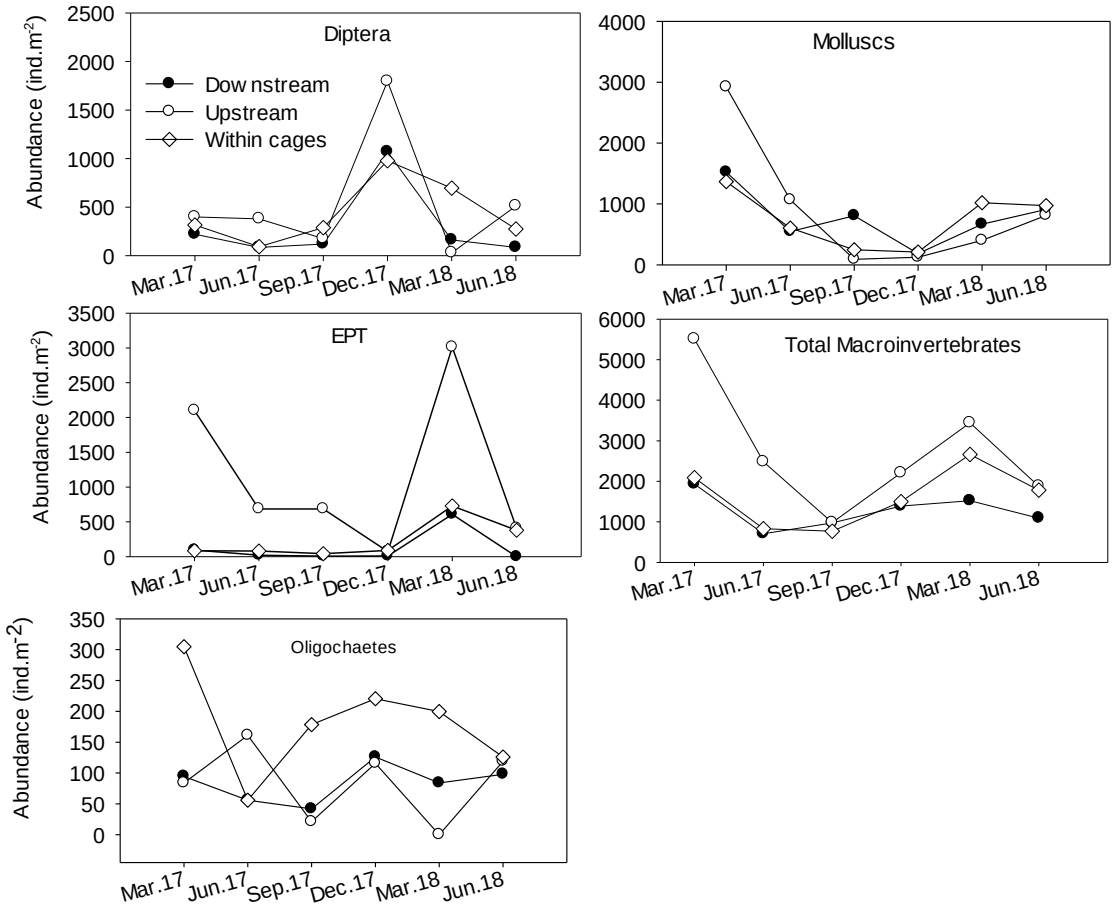

Figure 10. Monthly variation in total abundance (±SE) of macro invertebrates across study sites at SON fish farm, March 2017 to June 2018. Upstream (RPT and USC stations), Within cages (WIC1 to WIC4) and downstream (DSC station).

3.6 Fish species diversity, abundance and ecology

3.6.1 Fish Catch composition and abundance

Only one fish species, *Lates niloticus*, was recorded in the vicinity of the cages during the survey of June 2018 compared to six fish species recorded in the previous survey of March 2018 and December 2017 (Table 6). Fish abundance was highest Upstream and Downstream the cage site (41.7%), and lowest Within the cage site (16.7%). The highest biomass (Table 7) was recorded from Upstream the cages site (71.6%), followed by Within the cages site (18.2%) and the Downstream site (10.1%).

Table 6. Catch rates (numbers) of fish species from SON cage area, Mar. 2016 – Jun. 2018.

Family	Species	Site	Sampling months									
			March 2016	June 2016	Sept. 2016	Dec. 2016	March 2017	June 2017	Sept. 2017	Dec. 2017	Mar. 2018	Jun. 2018
Mormyridae	*Mormyrus kannume*	USC	0.1	0.1			9		0.1		0.2	
		WIC				0.1	0.3			0.1	0.2	
		DSC										
		All	0.01	0.03		0.03	0.1		0.02	0.02	0.2	
Clariidae	*Clarias gariepinus*	USC										
		WIC										
		DSC		0.1								
		All		0.02								
Cyprinidae	*Barbus altianalis*	USC									0.1	
		WIC										
		DSC										
		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	0.1	
		DSC										
		All	0.1		0.03	0.4			0.1	0.9	0.04	
Centropomidae	*Lates niloticus*	USC	0.5	0.3			0.3	0.1	0.8	0.4	0.3	0.9
		WIC		0.2	0.2	0.2	0.5	0.2	0.6	0.1	0.2	0.2
		DSC	0.2	0.1		0.1			0.2	0.2	0.2	0.4
		All	0.3		0,1	0.1	0.3	0.1	0.5	0.2	0.2	0.3
Cichlidae	*Tilapia zillii*	USC								0.1		
		WIC										
		DSC				0.1						
		All				0.04				0.04		
	Oreochromis niloticus	USC										
		WIC										
		DSC			0.1						0.1	
		All			0.03						0.02	

Family	Species	Site	Sampling months									
			March 2016	June 2016	Sept. 2016	Dec. 2016	March 2017	June 2017	Sept. 2017	Dec. 2017	Mar. 2018	Jun. 2018
	Haplochromines	USC	0.5				0.3			4.3		
		WIC		1.5	0.5	0.3		1.3	4.0		0.3	
		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	0.1	
Overall Rates		USC	0.8	0.4			0.4	0.1	1.1	3.1	0.6	0.9
		WIC		0.2	0.4	0.7	0.8	0.5	1.8	1.8	0.6	0.2
		DSC	0.3	0.2	0.1	0.2		0.4	2.1	0.4	0.2	0.4
		All	0.6		0.2	0.3	0.4	0.3	1.7	1.8	0.5	0.3
No of species recovered		USC	4	2	0	0	2	1	3	5	3	1
		WIC	0	2	3	4	2	2	2	4	4	1
		DSC	2	2	1	3	0	1	2	2	2	1
		All	4	4	4	5	3	2	4	6	6	1

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 June 2018, fish catch rates by weight were highest Upstream the cages 159.5g/net/night), followed by Within the cage site (29.1g/net/night) and Downstream the cage site (16.2/net/night) (Table 7). By numbers, the catch rates were highest Upstream the cage site (0.9 fish/net/night), followed by the Downstream site (0.4 fish/net/night) and the Within the cage site (0.2 fish/net/night) as indicated in Table 6. Overall mean catch rates during the recent survey of June 2018 were 0.3 fish/net/night and 53.2g/net/night compared to 0.5 fish/net/night and 208.5g/net/night recorded in the previous survey of March 2018 and 1.8 fish/net/night and 148.6g/net/night recorded in December 2017. Thus, the fish catch rates by numbers and weight were lower in June 2018 compared to the previous survey of March 2018.

3.6.3 The haplochromines

No species of haplochromine cichlids was *recorded* in the recent survey of June 2018 compared to one species recorded during the previous survey of March 2018 and four species recorded in the survey of December 2017 (Table 8).

Table 7. Catch rates by weight (g) of fish caught at SON Fish cage site, upstream and downstream of cages, March 2016 to June 2018.

Species	Site	Sampling months									
		March 2016	June 2016	Sept. 2016	Dec. 2016	March 2017	June 2017	Sept. 2017	Dec. 2017	Mar. 2018	Jun. 2018
Mormyrus kannume	USC	61.7	89.5					5.4		110.4	
	WIC				28.9	17.2			5.1	105.4	
	DSC										
	All	31	31.4		9.6	5.7		1.8	1.7	71.9	
Clarias gariepinus	USC										
	WIC										
	DSC		272.7								
	All		81.1								
Barbus altianalis	USC									62.7	
	WIC										
	DSC										
	All									20.9	
Synodontis afrofischeri	USC	12						8.1	25.8		
	WIC			5	52				67.8	3.8	
	DSC										
	All	6		2.5	17.3			2.7	31.2	1.3	
Synodontis victoriae	USC								38.6		
	WIC								48.2		
	DSC										
	All								62.3		
Lates niloticus	USC	191	7.4			4.5	166.6	187.5	188.0	57.3	159.5
	WIC		3.2	76.6	82.7	320.1	34.2	262.8	4.9	37.3	29.1
	DSC	5.4	0.9		1.6			8.2	48.6	63.8	16.2
	All	96		38.3	28.1	108.2	66.9	152.8	80.5	52.8	53.2
Tilapia zillii	USC								1.6		
	WIC										
	DSC										
	All				2				0.5		
Oreochromis niloticus	USC										
	WIC										
	DSC			0.1						185.0	
	All			0.03						61.7	
Haplochromines	USC	6.6				2.3			71.3		
	WIC		16	3.7	2.3		17.3	87.3		3.8	
	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	1.3	
Overall Rates	USC	262	96.8			5.2	166.6	197.8	312.1	230.4	159.5
	WIC		2.7	80.8	128.3	337.3	39.5	289.6	81.5	146.2	29.1
	DSC	6.3	278.6	5.8	6.5		4.8	38.8	52.2	248.8	16.2
	All	135		43.3	39.8	114.2	70.3	175.4	148.6	208.5	53.2
No of species recovered	USC	4	2	0	0	2	1	3	5	3	1
	WIC	0	2	3	4	2	2	2	4	4	1
	DSC	2	2	1	3	0	1	2	2	2	1
	All	4	4	4	5	3	2	4	6	6	1

Table 8. Catch rates (by numbers) of haplochromine species from SON Fish cage site.

Species	Site	Sampling months									
		Mar. 2016	June 2016	Sept. 2016	Dec. 2016	Mar. 2017	June 2017	Sept. 2017	Dec. 2017	Mar. 2018	Jun. 2018
A. Alluaudi	USC										
	WIC										
	DSC							0.5			
	All							0.2			
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			
P. "blackpara"	USC										
	WIC									0.3	
	DSC										
	All									0.1	
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		
P. sauvagei	USC										
	WIC										
	DSC						0.5	0.5	0.3		
	All						0.2	0.2	0.1		
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		12.5	
	DSC	33			33.3		100	92.6	50		
	All	21.4	40	33.3	16.7	6.1	76.9	63.1	28.2	5.3	

3.6.4. Biology of common fish species

The stomach content of 12 Nile perch (*Lates niloticus*) caught were examined so as to determine the type of food being consumed by the fish. The diet of the fish specimens examined comprised of Odonata nymphs (36.7%), *Caridina nilotica* (23.3%), haplochromine cichlids (35%) and *R. argentea* (5%), which are known natural foods of the species. There were no parasites on all the fish caught and examined (Table 9).

Table 9. Basic biological parameters of fish species caught from SON Fish cage site, March 2016 to June 2018.

Species/ Parameters	Sampled months									
	Mar. 2016	**June 2016**	**Sept. 2016**	**Dec. 2016**	**Mar. 2017**	**July 2017**	**Sept. 2017**	**Dec. 2017**	**Mar. 2018**	**Jun. 2018**
Clarias gariepinus										
Size range - TL (cm)		77								
% mature		100								
Main food type		Odt								
Parasites found										
Number examined		1								
Barbus altianalis										
Size range - TL (cm)										
% mature										
Main food type									E	
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	23-37	14.0 – 37.5
% mature	33.3			33.3	36.0	33.3	5.0	20		
Main food type	Haps	Fish	Car	Haps	Haps	Haps	Haps	Ras	Car	Fish
Parasites found										
Number examined	6	7	2	3	10	3	21	9	9	12
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	9.7	
% mature	100	50	0	100		96	77.4	87.5		
Main food type	Ins	Ins	Ins	E	E	Ins	Ins	Ins	E	
Parasites found (% infection)										
No examined	3	5	2	2	1	10	31	14	1	
Tilapia zillii										
Size range (cm)				13.0				9.2		
% mature				M						
Main food type				PM				E		
Parasites found										
No examined				1				1		

Species/ Parameters	Sampled months									
	Mar. 2016	**June 2016**	**Sept. 2016**	**Dec. 2016**	**Mar. 2017**	**July 2017**	**Sept. 2017**	**Dec. 2017**	**Mar. 2018**	**Jun. 2018**
Mormyrus kannume										
Size range (cm)	45	49		34	17.5 - 19.9		19.7	19.2	17.3 – 42.3	
% mature	100	100		100			100		50	
Main food type	Pov	Pov		Pov	Ins		Pov	Pov	Chir	
Parasites found										
No examined	1	1		1	4		1	1	4	
Oreochromis niloticus										
Size range (cm)			16.5						49.0	
% mature									100	
Main food type			Det						BG algae	
Parasites found										
No examined			1						1	
Synodontis afrofischeri										
Size range (cm)	13 – 14		13.0	10 – 16			11.5 - 11.7	9.1- 14.6	12.4	
% Mature	100		100	100			100	100	100	
Main food type	Ins		Moll	Ras			Ins	Chir	Chir	
Parasites found										
No examined	1		1	5			2	19	1	
Synodontis victoriae										
Size range (cm)								15.5 - 20.0		
% mature								100		
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

In this report, the levels of water physico-chemical conditions, concentrations of nutrients, and composition and abundance of biological communities (algae, invertebrates and fish) within and around SON cage fish farm were evaluated. The physico-chemical and nutrient parameters varied within narrow margin among cage and non-cage sites, were comparable across cage and non-cage sites, and were within the recommended ranges for the cultured fish.

At majority of the sites, the phytoplankton community was dominated by diatoms in terms of abundance although no particular trend was observed between cage and non-cage sites. The cage sites however, presented the lowest abundance and number of zooplankton species. In addition, the lowest abundance and number of benthic macroinvertebrate taxa was also recorded in a within-cage station, with the total abundance recorded in June 2018 being less than that of March 2018 for all sites. Catch rates by numbers and weight were lower in June 2018 when compared to those recorded in March 2018. In June 2018, all the fish specimens examined had fed on naturally occurring food organisms that included fish, *Caridina*, and aquatic insect larvae. Thus, cage fish farming had not impacted the feeding behavior of wild fish.

The overall observations on concentrations of nutrients and levels of physico-chemical variables in the water column, as well as abundance and distribution of biotic communities indicated minimal impact of cage operation on water quality.

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Appendix: Percent composition of benthic macroinvertebrates, June 2018

Higher level	Lowest possible taxa	RPT	UPT	WIC4	WIC3	BCS	WIC2	WIC1	DSC
Bivalvia	*Byssanodonta parasitica*	4.67	13.56		21.57		6.45	6.40	8.97
Bivalvia	*Caelatura hauttecoeuri*		0.85				1.61	1.60	
Bivalvia	*Corbicula africana*	15.33	17.80	25.00	22.22		20.16	22.40	23.08
Bivalvia	*Aspatheria sp.*		0.85						
Gastropoda	*Bellamya unicolor*	5.33	16.95	22.73	14.38		8.06	14.40	35.90
Gastropoda	*Biomphalaria sp.*	0.67							1.28
Gastropoda	*Bulinus sp.*	0.67							
Gastropoda	*Cleopatra pirothi*	2.00							
Gastropoda	*Melanoides tuberculata*	6.00	4.24	31.82	9.80		4.03	2.40	14.10
Ephemeroptera	*Caenis sp.*	1.33	1.69		3.27		8.87	0.80	
Ephemeroptera	*Povilla adusta*	21.33	5.08		4.58		19.35	29.60	
Ephemeroptera	*Euthraulus sp.*	3.33							
Trichoptera	*Ecnomus sp.*	5.33	0.85				3.23		
Trichoptera	*Dipsuedopsis sp.*		1.69						
Odonata	*Phyllomacomia*		0.85				1.61		
Odonata	*Libellulidae*	1.33			2.61			1.60	
Odonata	*Ictinogomphus sp.*		0.85						
		1.33	1.69		2.61		1.61	1.60	
Diptera	*Ablabesmyia sp*						4.03	2.40	
Diptera	*Chironomus spp.*	13.33	18.64		3.27		4.03	10.40	2.56
Diptera	*Clinotanypus sp.*		10.17		9.15		6.45	1.60	2.56
Diptera	*Cryptochironomus sp.*	1.33			0.65		0.81	0.80	
Diptera	*Procladius sp.*	9.33							
Diptera	*Ceratopogonidea*	0.67	1.69		2.61		0.81	0.80	
Diptera	*Chaoborus sp.*						3.23		2.56
Annelida	*Hirudinea*	2.00		18.18	0.65			0.80	
Annelida	*Oligochaetes*	6.00	4.24	2.27	5.23		7.26	4.00	8.97
Total abundance (ind./m2)		100.00	100.00	100.00	100.00		100.00	100.00	100.00