Uganda Journal of Agricultural Sciences, 2013, 14 (2): 61 - 75 ISSN 1026-0919

Effects of cage fish culture on water quality and selected biological communities in northern Lake Victoria, Uganda

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Abstract

Growing of fish in cages is currently practiced in Uganda and was first introduced in northern Lake Victoria in 2010. An environment monitoring study was undertaken at Source of the Nile, a private cage fish farm, in Napoleon gulf, northern Lake Victoria. *In-situ* measurements of key environmental (temperature, dissolved oxygen, pH and conductivity) and biological (algae, zooplankton, macro-benthos) variables were made at three transects: Transect 1- the site with fish cages (WC); transect 2- upstream of the fish cages (USC-control) and Transect 3- downstream of the cages (DSC). Upstream and Downstream sites were located approximately 1.0 km from the fish cages. Environment parameters varied spatially and temporally but were generally within safe ranges for freshwater habitats. Higher concentrations of SRP (0.015-0.112 Mg/L) occurred at USC during February, September and at DSC in November; NO_2-N (0.217- 0.042 mg/L) at USC and DSC in February and November; NH_4-N (0.0054- 0.065 Mg/L) at WC and DSC in February, May and November. Algal bio-volumes were significantly higher at WC ($F_{(2,780)}$=4.619; P=0.010). Zooplankton species numbers were consistently lower at WC with a significant difference compared to the control site (P=0.032). Macro-benthos abundance was consistently higher at the site with cages where mollusks and low-oxygen and pollution-tolerant chironomids were the dominant group. Higher algal biomass, concentration of low-oxygen/pollution-tolerant macro-benthos and depressed zooplankton diversity at WC suggested impacts from the fish cages on aquatic biota.

Key words: Algae, cage fish, invertebrates, water quality

Introduction

Growing fish in cages is practiced in many parts of the world but has in the last 20 years become a popular fish farming practice in Africa specifically in Ghana, Kenya, Malawi, Uganda, Zambia and Zimbabwe (Blow and Leonard, 2007). In comparison to traditional pond culture systems, the advantage of cage fish culture technology is the possibility of growing a large amount of fish in a relatively small volume or area of water.

For example in 8-12 m^3 cage, one can raise one ton of fish in 8 months. In addition, cages can be easily fabricated from locally available materials such as netting mesh, steel bars or bamboo stem frames, plastic floaters, stone sinkers and ropes. Culturing of fish in cages affords greater production rates compared to yield in pond systems. High quality fry and formulated commercial feeds are fast becoming available on the open market as the number of private commercial

hatcheries and local feed manufacturers increase in Uganda.

In the East African region, cage fish farming has not been widely practiced despite a large market for fish in the region and known potential of the practice (Blow and Leonard, 2007). Cage fish farming is currently practiced by few commercial fish farmers and is a direct response to declining fish harvests from wild fish stocks and increasing market demand from local, regional and international markets. Uganda is promoting cage fish farming to improve household incomes and national food security (MAAIF, 2010). Production figures of the Source of the Nile (SON) fish farm in northern Lake Victoria indicate high potential for cage fish culture with increase in yield from 290 tons in 2011 to 402 tons in 2012 and 506 tons in 2013 corresponding to 147, 205 and 269 cages of approximately 15.625m^3 volume (SON Cage Fish farm records).

Fish rearing in cages in natural freshwater water bodies (lakes, rivers, reservoirs and dams) raises concerns of water quality and disease impacts from the caged fish (Pearson and Black, 2001; Veenstra *et al*., 2003; Mangaliso *et al*., 2011) despite the promise for high fish production over relatively short time periods.

Other concerns include impacts on biological communities especially in cases of intensive cage culture (Dias *et al.*, 2011). Water quality deterioration may result from release of solid wastes (Merrican and Phillips, 1985; Dias *et al.*, 2011) such as un-eaten feeds, faeces and mucus, soluble wastes especially phosphorus and nitrogen compounds. Overtime, these may cause environmental impacts such as eutrophication (Demir *et al*. 2001; Santiago *et al.* 2001), algal blooms and changes in zooplankton community structure (Dias *et al*., 2011) that may affect natural fish production. Mangaliso *et al.* (2011) predicted that intensive aquaculture is likely to become an important new source of nutrients on local and lake-wide scale. It is therefore important that all projects that involve intensification of aquaculture should be backed by a strong environmental monitoring program.

The overall objective of this study was therefore to evaluate the possible impacts of cage fish culture on water quality and biological communities in northern Lake Victoria. The specific research questions were: "Does cage fish operation influence key physical-chemical parameters of the water?", "Do fish cages have impacts on algal, zooplankton and macro-benthos communities within and around the cage operation areas?".

Materials and methods

Study area and field sampling

The study was undertaken at the Source of the Nile (SON) Fish Farm Ltd. located near the headwaters of the river Nile at the south western end of the Napoleon gulf, northern Lake Vitoria (Fig. 1). The farm had a total of 147 cages (each with 2.5x2.5x2.5 meters (long, wide and deep respectively) in an area of approximately 2,112.5 km^2 by the end of 2011 (SON Fish Farm records).

Three study transects were set up as follows: transect 1 (USC) was approximately 1 km upstream of the fish cages; transect 2 (WC) was located within the fish cage rows and transect 3 (DSC) was approximately 1 km downstream of the fish cages. Each transect contained three sampling points, at intervals of 50 meters apart.

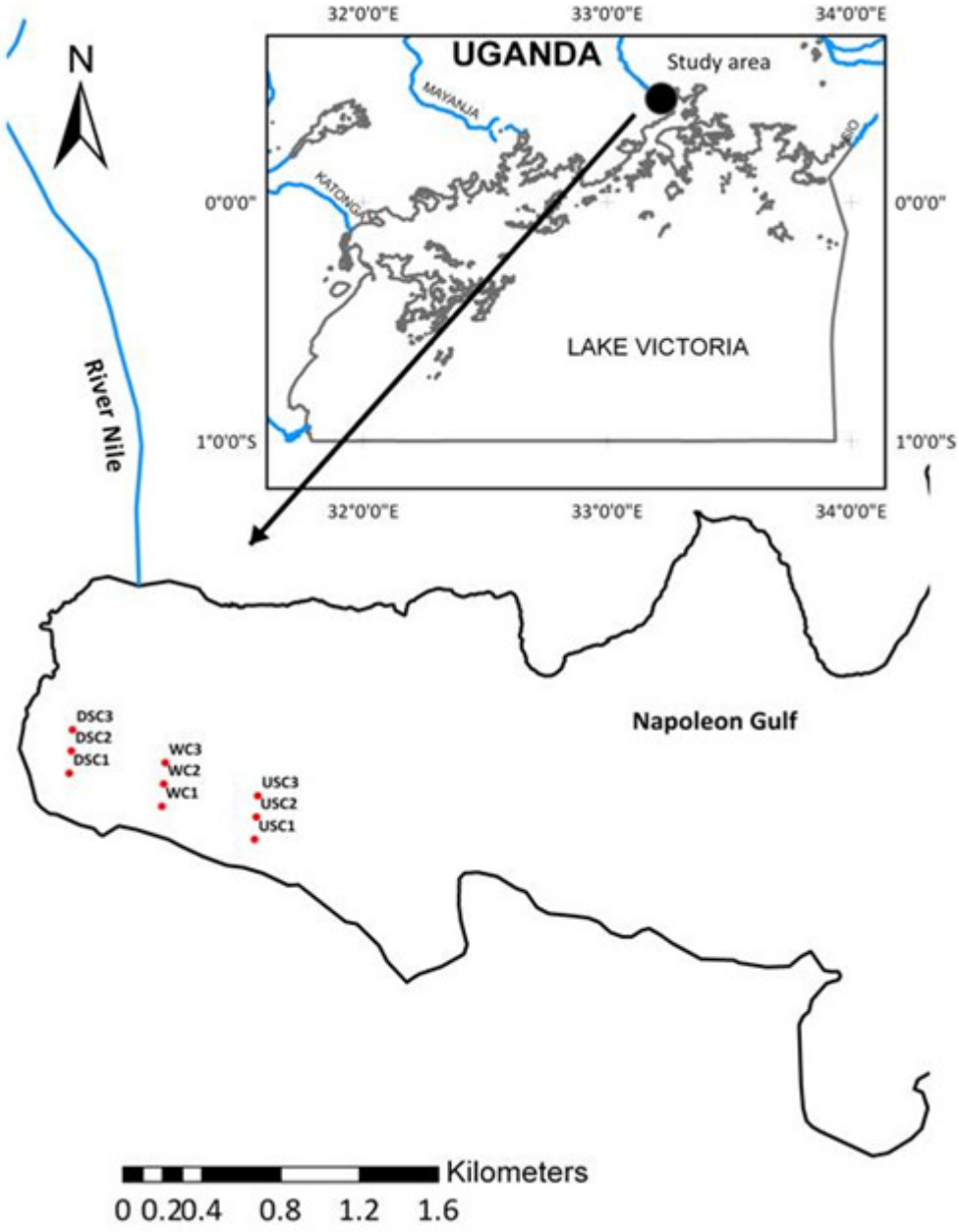

Figure 1. Study area and transect distribution in Napoleon Gulf, northern Lake Victoria. Transect 1: upstream of the cages (USC1-USC3), Transect 2: within the cage rows (WC1-WC3) and Transect 3: downstream of the cages (DSC1-DSC3).

Field measurement (selected environmental parameters) and sampling of water, algae, zooplankton and macro-benthos was undertaken in February, May, September and November, 2011 at fixed points along each transect.

Physical-chemical parameters

Selected environmental parameters were measured *in-situ* with a CTD (Conductivity, Temperature, Dissolved oxygen) multi probe (Sea-Bird Electronics, Model 19-03 with depth range of 197 meters).

Nutrients, algae and total suspended solids (TSS)

Water samples for analysis of nutrients and algae were collected with a Van-Dorn sampler (Alpha, Vertical PVC, Opaque PVC, 2.2L) at 0.5m depth, and transferred to clean and labeled plastic bottles. In the laboratory, sub-samples of 100 ml were filtered using a hand pump (pressure ranging from 50 - 100 cent bars depending on water hardness) and the filtrate was used to analyze dissolved nutrients (Soluble Reactive Phosphorus (SRP), Ammonium-nitrogen (NH_4-N) and Nitrite-nitrogen (NO_2-N) by spectrophotometric methods (Stainton *et al.*, 1977). Sub-samples of 400 ml were filtered on to Whatman GF/C filter papers 47mm and the filtrate used for the determination of Total Suspended Solids (TSS) following APHA (1998) methods.

Sub-samples of 20 ml were transferred into clean, labeled glass scintillation vials, preserved with Lugol's solution. 2 ml of the sample were placed in Sedgewick counting chamber, allowed to settle for three hours and examined under an inverted microscope (Hund Wolvert s) at x400 magnification following the procedure of Utermohl as described by Lund *et al*. (1958). Algal cells were counted and their cell dimensions measured using an eye micrometer to generate bio-volume data.

Zooplankton and macro-benthos

Zooplanktons were sampled with a conical plankton net of 0.25M mouth diameter and 60 µm mesh as in Vincent *et al*. (2012). Concentrated samples were placed in clean, labeled plastic bottles and fixed with 4 % sugar formalin. 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. Sub-sample series of 2, 2, 5 and 10 ml were taken from a well agitated sample in a beaker using a calibrated automatic bulb pipette and introduced on to a plankton counting chamber.

For macro-benthos three hauls of bottom sediments were hauled from each sampling point using a Ponar grab (open jaw area, 238 cm^2). Each sediment haul was concentrated by sieving through a 400µm nitex mesh, placed in clean, labeled sample bottle, and preserved with 5 % formalin.

Zooplankton samples were examined under an inverted microscope at x40 and x100 magnification for counting and taxonomic identification respectively. Individual organisms were taxonomically identified to species level using published manuals by Boxshall and Braide (1991); Korinek (1999) and Koste (1978). Macro-benthos samples were examined under a dissecting binocular microscope at x 25 magnification and taxonomically identified using identification manuals by Pennak (1953), Mandhal-Barth, (1954) and Epler (1995). Invertebrate species taxa were tallied and recorded.

Distribution and abundance data generated were stored using Microsoft Excel 2007 and analyzed with SPSS (Version 12) while Sigmaplot (Version 11) was used for graphics. One-way ANOVA and LSD *post hoc* tests were used to compare mean values.

Results

Physical-chemical parameters

Observed ranges of selected water environment variables (Table 1) across the three sampling sites were compared with standards of the National Environment Management (NEMA) and desirable levels for cage culture from literature (Table 1).

Nutrient concentrations across sample sites and dates

NO_2-N, SRP and TSS all attained highest mean concentrations (0.2-0.25, 0. 1- 0.15 and 7.1 mg /L respectively) at the control site in February and remained at lower levels at other times and study sites. NH_4-N registered high and comparable concentrations (0.05-0.10 Mg/L) across all three study sites during November but remained at lower levels at other times and study sites.

Algal composition and bio-volumes

The algal community was composed of three major taxonomic groups, (blue-green algae, green algae and diatoms) but occasionally, dinoflagellates, euglenophytes and cryptophytes were also encountered. Most genera and species were encountered at all the three study sites. There was minimal variation of species numbers across the three study sites for the three major algal groups i.e. 30, 33, 34 at USC, WC and DSC respectively. The blue-green algal group contained higher average numbers of species at USC, WC and DSC with 14, 16, and 16 respectively compared to green algae and diatoms, which had 10, 12 and 12, 5 and 6, respectively.

Blue-green algae registered the highest mean bio-volumes in all three study transects, with the highest value at the site with cages (WC) and was closely followed diatoms (Fig. 3) in all study sites. One–way ANOVA indicated significantly higher algal bio-volumes at WC compared to UPS and DSC ($F_{(2,780)}$=4.619; P = 0.010). Post hoc LSD test, revealed no significant difference between USC and DSC (P = 0.39). Algal bio-volumes in USC and WC increased from February, through May to

Table 1. Ranges of selected physical-chemical parameters at Source of the Nile Fish Farm, northern Lake Victoria, 2011

Parameters	Observed range	NEMA Standards	Desirable levels for cage culture
Dissolved oxygen (mg/L)	3.4-6.2	Acceptable	> 3 (Delong *et al.,* 2009)
pH	7.2-8.7	6.5 - 8.5	6 – 9 (Nathan *et al.,* 2013)
Temperature °C	24.6-26.5	Acceptable	12 – 30 (Joseph *et al.,* 1993)
Conductivity (μSCm^{-1})	98.1-99.8		30 – 5000 (Nathan *et al.,* 2013)

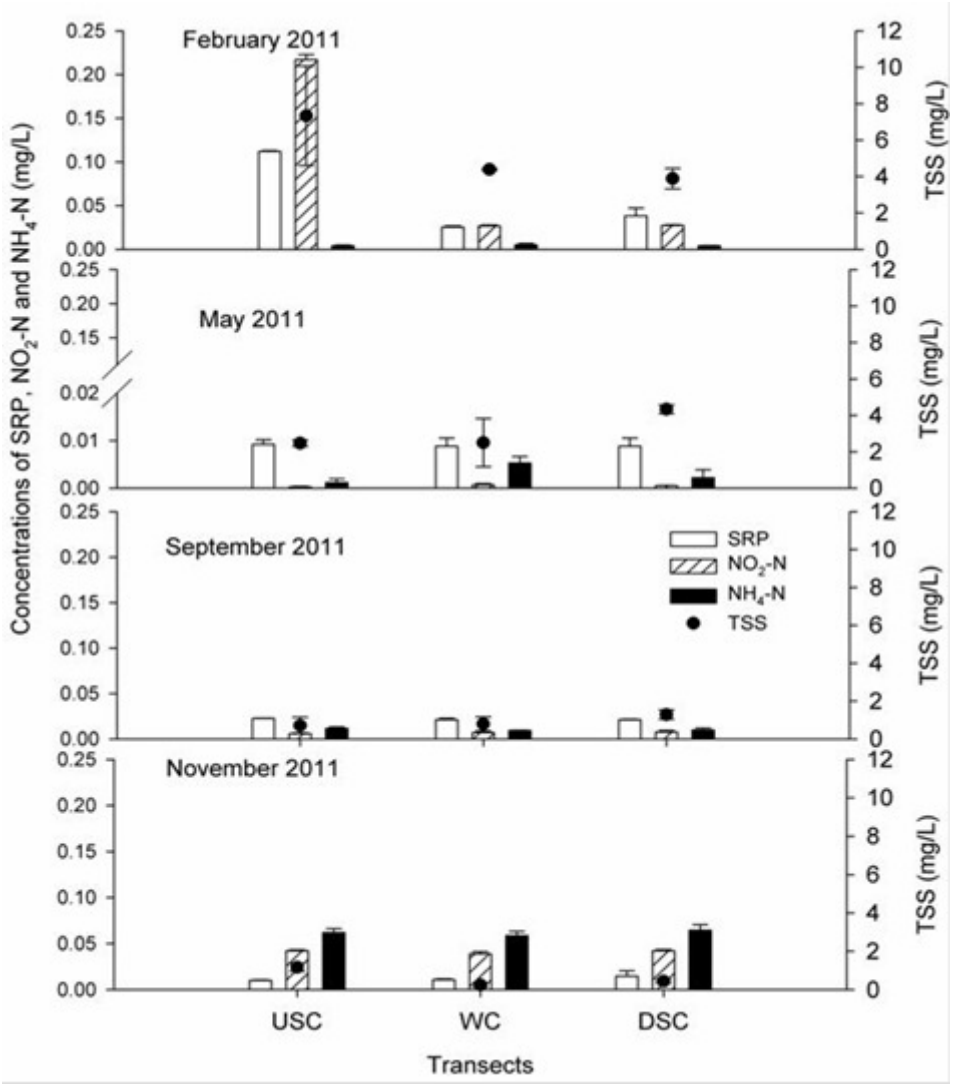

Figure 2. Spatial-temporal variation of mean nutrient concentrations (SRP, NO_2-N & NH_4-N) and Total Suspended Solids (TSS) in three transects (USC, WC and DSC) at SON cage fish farm, northern Lake Victoria, 2011.

September before a drastic decline in November (Fig. 4).

Zooplankton composition and species richness

The zooplankton community was composed of three broad taxonomic groups: Copepoda, Cladocera and Rotifera (Table 2). Rotifers registered higher species numbers across sampling dates and study sites. WC registered lower mean species numbers (12-15) in May, September and November compared to other sites (Fig. 5A). While one-way ANOVA indicated no significant difference of species numbers between USC, WC and DSC ($F_{(2,8)}$=3.868; P=0.085) and across sampling dates

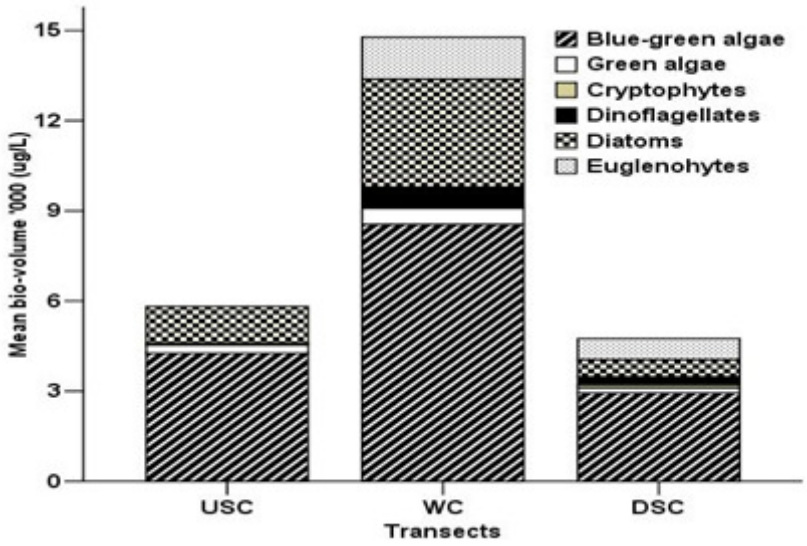

Figure 3. Comparison of bio-volumes of different broad algal taxa a cross study sites at SON cage fish farm, northern Lake Victoria, 2011.

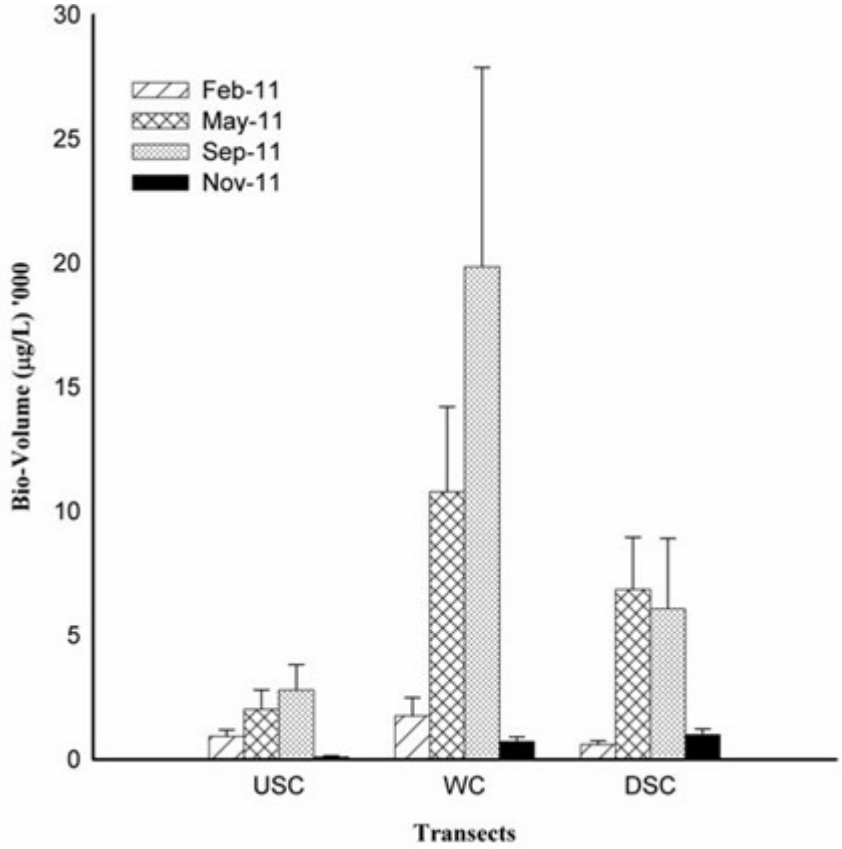

Figure 4. Spatial-temporal variation of mean (±SE) algal bio-volumes at SON cage fish farm, northern Lake Victoria, 2011.

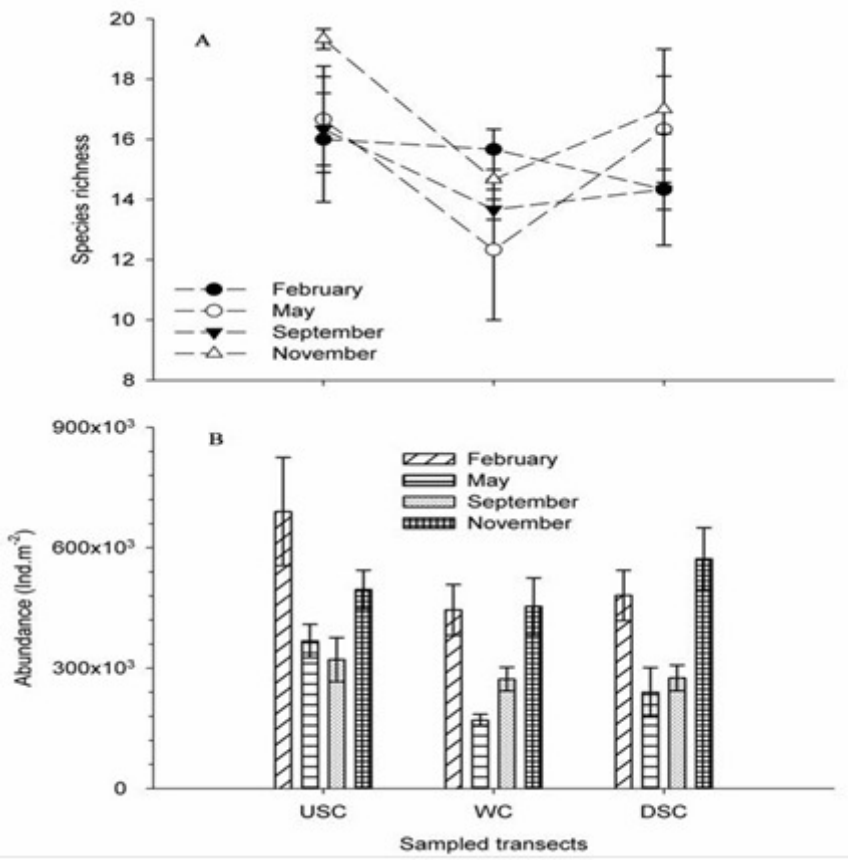

Figure 5. Spatial-temporal variation (mean±SE) of species richness (A) and numerical abundance (B) of zooplankton across study sites at SON cage fish farm, northern Lake Victoria, 2011.

($F_{(2,32)}$=1.173; P=0.335), a *post hoc* LSD test revealed a significant difference between USC (control) and WC during November (P = 0.032).

Zooplankton abundance

Estimates of numerical abundance indicated higher values during February and November at all study sites (Fig. 5B). One-way ANOVA, however indicated no significant differences of abundance between study sites $F_{(3,33)}$ = 0.171, P > 0.05 although significant variation occurred between sampling dates ($F_{(3,33)}$ = 12.226; P < 0.05). A *post hoc* LSD test revealed significant difference between February May and September (P < 0.05).

Copepods constituted the bulk of total zooplankton abundance throughout the four survey dates with total density estimates between 490,000 and 2,030,000 ind. m^{-2}; followed by rotifers with 17,000 - 280,000 ind. m^{-2} compared to cladocerans with 1,000 -15,000 ind. m^{-2} (Table 2). The three groups showed no consistent abundance patterns across the study sites (USC, WC and DSC) on different sampling dates. Copepod and rotifer densities differed significantly

Table 2. Zooplankton composition and abundance (Indiv. m^{-2}) patterns across study sites at the SON cage fish farm, northern Lake Victoria, 2011.

Copepoda:	February-11			May-11			September-11			November-11		
	USC	WC	DSC	USC	WC	DSC	USC	WC	DSC	USC	WC	DSC
Number of species	6	6	6	7	6	6	6	6	6	7	5	6
Densities ('000)	2,030	1,307	1,418	1,047	490	669	933	798	803	1,192	1,189	1,605
Cladocera:												
Number of Species	5	3	5	4	4	4	5	3	2	5	2	3
Densities ('000)	8	9	5	6	1	12	6	2	2	15	5	5
Rotifera:												
Number of Species	12	12	11	14	11	10	12	12	10	10	9	13
Densities ('000)	33	19	21	50	21	39	25	17	21	280	167	107
Total number of species	23	21	22	25	21	20	23	21	18	22	16	22
Total Densities ('000)	2,070	1,335	1,443	1,103	511	720	964	818	827	1,487	1,361	1,717

among sample dates (F (3,32) = 10.056; P<0.05 and F (3,32) = 18.714; P<0.05).

Macro-benthos diversity and abundance

The macro-benthos community was constituted by four taxa: Bivalvia, Gastropoda (freshwater snails), Diptera (lakefly larvae), Trichoptera (caddisfly nymphs), and Ephemeroptera (mayfly nymphs). As a consistent pattern across the four study dates, higher numerical abundance (840-3907 ind. m^2) and species richness (4-15) of macro-benthos occurred at WC (Fig. 6). One way ANOVA showed that total macro-benthos densities across study sites were significantly different ($F_{(2.33)}$ = 12.495, P<0.05) while taxa richness was not significant ($F_{(2,33)}$ = 12.111, P>0.05). Organisms that constituted high abundance at WC were *Chironomus* sp., *Bellamya unicolor* and *Melanoides tuberculata*.

Discussion

Measured ranges of selected physical-chemical variables were generally within acceptable levels of NEMA, cage culture and freshwater habitats in general. There was no evidence of impact of fish cages on any of the measured parameters.

Observations on spatial-temporal variation of nutrient species and total suspended solids suggested minimal impacts from the fish cages despite an increase in the number of cages from 6 in to147 by November 2011. Zanatta *et al.* (2010) found comparable results in Jurumirim Reservoir in Brazil although the number of cages was low (30) and remained constant throughout the investigation. Guo and Li (2003) working in Niushanhu Lake, China observed that most environmental impacts in cage fish farm areas are associated with increased nutrient inputs although the contribution from other sources such as soil erosion may also be important. Results of the present study appear to have been influenced by water currents constantly sweeping across the study area given the location of SON fish farm near the headwaters of the River Nile; hence the importance of undertaking site suitability studies before cage fish culture investments are made. It is also important to note that released soluble nutrients may be readily taken up by green micro-plants (algae) in the water.

Variability data on algal bio-volume across the three study sites indicated much higher values at the site with cages (WC) compared to the control (USC) and downstream (DSC) sites. Given that algal growth largely depends on nutrient concentrations (Guo and Li, 2003), results of this study suggest that the fish cages at WC may have been associated with higher nutrient concentrations, which upon being taken up by the algal community resulted into higher algal biomass/bio-volume recorded at this site.

Excess algae are known to cause drastic reduction in dissolved oxygen levels after their collapse due to the ensuing oxygen-demanding decomposition process (WHO/EC, 2002). High algal bio-volumes at WC may thus explain the observed abundance of low-oxygen and pollution-tolerant macro-benthos such as *Chironomus* sp. at the site with cages also observed by other workers (Holmer, 2010; Hatami *et al.* 2011) and non-occurrence of oxygen and pollution-sensitive forms such Ephemeroptera and Trichoptera at WC. Nonetheless day-time dissolved oxygen measurements at the study sites did not show low dissolved oxygen levels at WC, although the situation could be different at night time when no

photosynthetic oxygen production is possible.

The zooplankton community composition and abundance patterns at the studied cage fish farm were comparable to those recorded elsewhere in Lake Victoria (Mwebaza-Ndawula *et al*., 2003, 2004; Semyalo *et al*., 2009; Ngupula *et al*., 2012; Vincent *et al*., 2012) with numerical dominance and wide spatial dispersion of copepods, paucity of cladocerans and diverse occurrence of rotifers in shallow near-shore areas.

Consistent lower zooplankton species numbers observed at the site with cages (WC) on all sampling dates was presumed to be an impact from the fish cages. The numerical superiority of rotifer species richness in all the three study transects was in agreement with Mwebaza-Ndawula *et al.* (2004) who associated rotifer prominence with eutrophic conditions in most near-shore areas of Lake Victoria. There was no significant difference in total mean densities of zooplankton across the study sites for the four sampling dates, suggesting minimal or no impacts on abundance so far from the fish cages even when the number of cage units increased tremendously from 6 to 147 by November 2011.

While the results of this study are comparable to those of Santos *et al.* (2009) who found that farming of tilapia in net tanks caused only small differences in zooplankton levels, they are in contrast to those of Dias (2008) cited in Zanatta *et al.*, 2010) who reported higher rotifer and Cladocera abundance at a site next to the fish cages and attributed this to nutrient enrichment and food availability.

Given that zooplankton communities are primary consumers from algae, the marked departure of zooplankton abundance from that of algal bio-volumes was unexpected. However it is noted that the bulk of algae were blue-green algae, whose nutritional value is widely known to be low (Moriarty and Moriarty 1973; www.dep.state.fl.us/water/bgalgae/faq.htm) Besides, it is known that blue-green algae or cyanobacteria, which were the leading contributor to the algal bio-volume (Fig. 3), contain species that produce toxins (Fulton and Pearl, 1987; Okello *et al.* 2012).

It is thus possible that zooplankton abundance patterns may not have been wholly driven by the cyanobacteria-dominated algal abundance (Fig. 3) but also by other environmental factors (Arndt, 2003). Observed significant density variation of zooplankton among sampling dates may, to some extent, have been due to seasonal influences in Lake Victoria (Mwebaza-Ndawula *et al*., 2004). Marked depression of the mean zooplankton abundance in May and September was at variance with the annual zooplankton pattern for offshore waters in Lake Victoria showing attainment of peak abundance during May, which coincides with the onset of the annual mixing period in the lake (Mwebaza-Ndawula, 2003).

Some zooplankton species including a number of copepods are known to avoid ingestion of endotoxic and nutritionally inadequate cyanobacteria (Fulton and Pearl, 1987; DeMott, 1989; Ahlgren *et al.,* 1990; Ahlgren, 1993) and this may to some extent explain the density trough during May and September (Fig.5B).

The dominant status of copepod community, which in Lake Victoria is dominated by medium-sized cyclopoids is in agreement with earlier records by Mwebaza-Ndawula, (1998); Mwebaza-Ndawula *et al.* 2003; 2004 and Ngupula *et al*. 2010. Results of this study suggest

that the cage set-up at the studied fish farm has so far not caused major changes in the zooplankton composition and abundance patterns.

The observed dominance of the copepods (490,000-2,030,000 ind. m^{-2}) recorded at the studied cage fish farm is in agreement with densities reported elsewhere in Lake Victoria (Ngupula *et al*., 2010; Vincent *et al*., 2010) and represent a rich food environment for the pelagic zooplanktivorous fishes especially the silverfish, "Mukene" (*Rastrineobola argentea*), which in the short run, are not likely to be affected by the cage fish culture operations of the scale currently set up at the studied cage fish farm.

As some elements of the zooplankton community are commonly used as bio-indicators of aquatic environments (Rogozin, 2000; Sukran *et al*., 2007; Yildz *et al*., 2007), it is expected that drastic changes in the environment quality resulting from cage fish operations would quickly be reflected in the zooplankton community structure. Some macro-benthos taxa are as well useful bio-indicators of water quality as manifested by abundant occurrence of well known stress-tolerant forms at the site with fish cages in this study.

Conclusions

Results from the study showed no discernible effects of the fish cage facility on selected physical-chemical parameters but do indicate possible influence of the fish cages on the nutrient status and inherently on the algal as well as zooplankton and macro-benthos communities in the studied cage fish farm. Nutrient-driven high algal bio-volumes, depressed zooplankton species diversity and numerical abundance of low-oxygen and pollution-tolerant dipteran larvae at the site with fish cages suggest influences from the fish cages.

Therefore, current efforts to promote commercial cage fish culture enterprises in Lake Victoria and other water bodies must proceed with caution especially regarding site location and concentration of cages at any one site; in order not to compromise the water environment quality, which can cause undesirable changes in natural biological productivity processes. In any case, regular environmental monitoring programs must be strictly enforced for all cage fish culture enterprises.

Acknowledgement

This study was financially supported by Source of the Nile (SON) Fish Farm to which the authors are very grateful. The Director of the National Fisheries Resources Research institute (NaFIRRI) is appreciated for logistical support, laboratory and field facilities. Drs. John Balirwa, Richard Ogutu-Ohwayo and two anonymous manuscript reviewers provided valuable comments and suggestions.

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