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The evaluation of cage fish farming effects on water quality using selected benthic macro-invertebrate community parameters in the napoleon gulf, northern Lake Victoria

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Abstract
Since the proliferation of cage fish farming in Uganda has raised concern over water quality deterioration, a study of the effects of cage fish farming on water quality in the Napoleon Gulf, Northern Lake Victoria was conducted during October 2012 to February 2013. Selected water column physico-chemical parameters and benthic macro-invertebrates' community parameters (i.e. numerical abundance, Shannon-Weaver diversity Index and modified Hilsenhoff Biotic Index) were analyzed monthly at both cage and non-cage sites. No significant differences were observed in physico-chemical parameter values, benthic macro-invertebrates' numerical abundance and Hilsenhoff Biotic Index between cage and non-cage sites. On the other hand Benthic macro-invertebrate species diversity differed significantly between the reference site and cage site 2 ($P<0.05$). Pollution tolerant *Chironomus sp.* and *Melanoides tuberculata* Muller, 1774 were significantly higher at the cage sites than the non-cage sites ($P<0.05$). These results suggest that cage fish farming significantly changed water quality.

Keywords: Cage fish farming, Water quality, Benthic macro-invertebrates' species diversity, Physico-chemical parameters

1. Introduction

While traditional fish farming in Uganda has been based on pond production, the high fish demand today has led to diversification of fish farming methods, and cage fish farming (i.e. rearing of fish in net enclosures placed in a water body) is increasingly becoming popular. Since cage fish culture depends on the use of natural water (e.g. lakes, rivers) and natural food chains (Dosdat, 2001) [1], there is growing concern that water quality may be compromised in the process of popularizing cage fish culture.

Fish cages directly release large amounts of nutrient-rich wastes (feces, unconsumed feed and metabolic products) into the water and the underlying sediment (Temporetti *et al*., 2001) [2]. In high concentrations, the wastes may drastically alter water quality conditions through direct or indirect effects. These may be manifested as modification of benthic macro-invertebrates' community structure, phytoplankton blooming, fluctuations in pH, dissolved oxygen and increased turbidity (Pitta *et al*., 1999) [3]. Complete understanding of the actual effects of rearing fish in cages is necessary to facilitate the integration of cage fish culture within the production dynamics of water bodies and to avoid conflicts of interest. Despite the drive for increased farmed fish production, there is insufficient documented information to guide cage fish farming in Lake Victoria, a regional fish production system of great ecological and economic importance. This situation is in contrast to other areas where intensive cage fish culture is practiced, and where considerable field studies have been undertaken (Yucel-Gier *et al*., 2007; Neofitou and Klaoudatos, 2008) [4, 5], to provide environmental guidelines to investors and water managers.

The aim of this study was to determine the effects of cage fish culture on the water quality in Napoleon Gulf, northern Lake Victoria using benthic macro-invertebrates. Benthic macro-invertebrates provide a history of events of water pollution that affect their community structure; diversity, abundance and distribution (Mandaville, 2002) [6].

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2 Materials and Methods

2.1 Study area

The study was carried out at the Chinese cage fish farm in the Napoleon Gulf (Figure 1), north-western Lake Victoria. The Napoleon Gulf (0°25'34" N and 33°15'50" E) is located near Jinja town in Uganda and lies at an elevation of 1,133 meters above sea level (Mapcarta, 2013) [7].

The farm was composed of 50 cages of 5X5X2.5 meter dimensions spread over approximately 250 m^2. The fish (Nile Tilapia) were stocked at a density of 172 fish per cubic meter and fed manually three times a day (8 am, 12.30 pm and 5.30 pm) on formulated sinking pellet feeds.

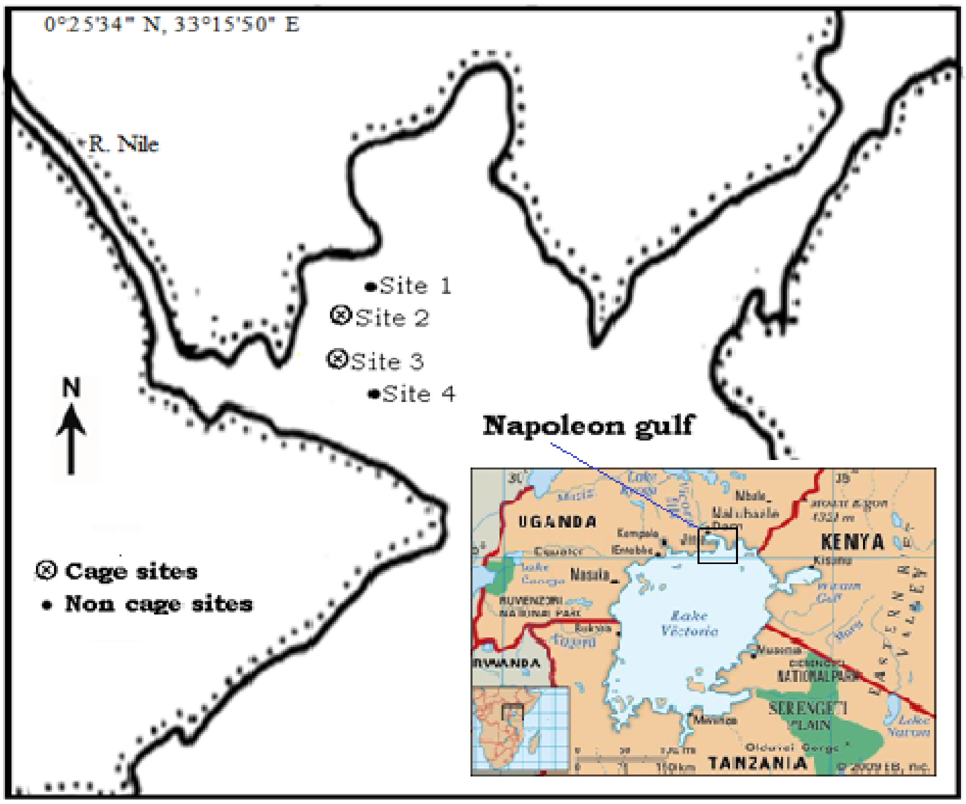


Fig 1: Location of Napoleon Gulf in Lake Victoria and the sampling sites (1-4) at the Chinese cage fish farm.

Four study sites (Figure 1) were selected on the basis of distance from the fish cages and location in relation to the fish cages. Site 1/reference site (00.40920^{0}N & 033.21362^{0}E) was located 1 km away from the fish cages, in a northeast direction presumed not to be affected by the fish cages. Site 2 (00.41331^{0}N & 033.20962^{0}E) and Site 3 (0.41324^{0}N & 033.20917^{0}E) were set up close to the cages, in the cage impact zone (cage sites). Site 4 (00.41286^{0}N & 033.20720^{0}E) was located at a 400 m distance away from the cages to the south. This site (Impact Verification Site) was used to verify whether any discharges by cage fish farming had an influence on sites away from the cages.

2.2 Sampling for macro-invertebrates

Sediment samples were collected monthly (i.e. mid-month) from each site from October 2012 to February 2013. Replicate samples were collected from each site using a ponar grab with an open area of 238cm^2. The grab was set and lowered from the boat to the lake bottom, given a jerk and retrieved to obtain sediment samples which were washed through a 0.4 mm mesh filtering bag. The retained samples were each placed in separate labeled bottles, fixed with 5% formalin and taken to the laboratory for examination and analysis. Each sediment sample was rinsed with tap water to remove the preservative (formalin) and spread out on white plastic trays. Macro-invertebrates were sorted from the sediment using forceps and individual taxa examined under a dissecting binocular microscope at x 400 magnification. Taxonomic identification was done to the lowest possible taxonomic level using manuals by Pennak (1953) [8] and Epler (1995) [9]. For each sample, macro-invertebrates of the same taxon were put together and counted.

2.3 Benthic macro-invertebrate community parameters

The community parameters; total numerical abundance, modified Hilsenhoff Biotic Index (HBI), and Shannon Weaver diversity Index (H') were calculated for each sampling site. Numerical abundances of the different taxa were estimated by counting individual macro-invertebrate taxa from each group and total numerical abundance was expressed as the total number of individuals (macro-invertebrates) per square meter using the following formula: total numerical abundance = N÷A, where N is total number of benthic macro-invertebrates per sample and A is mouth opening/jaw area (0.0238m^2) of the ponar grab.

Diversity at each sampling site was calculated by means of Shannon-Wiever Diversity Index (H') using the formula: $H' = -\Sigma pi \ln(pi)$, where H′ represents the Diversity Index and p_i the proportion of a particular taxon/species in a sample belonging to the i^{th} species. The index takes into account both species richness and evenness.

Hilsenhoff Biotic Index, a measure of the benthic macro-invertebrates' tolerance to organic (nutrient) enrichment (Zimmerman, 2014) [10] was used to evaluate the water quality status and the level of organic pollution for each sampling site. This index incorporates the tolerance values of the various taxa and the actual counts of each organism, and it's based on species level identification of most taxa. It was calculated

using the formula: HBI= $(\Sigma x_i t_i)/n$
Where: x_i = number of individuals in the i^{th} taxon, t_i = pollution tolerance value of the i^{th} taxon and n = total number of benthic macro-invertebrates in the sample

2.4 Water sampling and physical-chemical measurements

Water samples were collected monthly (i.e. mid-month) from each site between 08:00 am and 11:00 am, from October 2012 to February 2013. The samples at each site were taken in replicates (one meter distance randomly away from each other) at both the surface (0.5 m below the water surface) and the bottom (1 m above the lake bottom) using Van Dorn water sampler (model Alpha, Vertical PVC, opaque PVC, 2.2 L). The replicate samples were placed in separate well labeled acid-washed polyethylene bottles and taken to the laboratory to determine concentrations of Nitrate, Nitrite, Ammonia and Soluble Reactive Phosphorus.
In-situ measurements of selected environmental variables (temperature, dissolved oxygen, pH, water transparency, total depth and conductivity) were done in replicates from water column. Water temperature (°C), electrical conductivity (μScm^{-1}), dissolved oxygen (mg/L) and pH were determined using a portable multi-parameter water quality probe (model HQ40d). Water transparency was measured with a white and black 25-cm diameter secchi disk as the average depth at which the disk was no longer visible upon lowering and raising it in the water column from the shaded side of the boat. Total depth of the water column was determined using a digital echo sounder (model Plastimo Echotest 2).

2.5 Data analysis

Data was analyzed using SPSS 16.0 Software and 5 % significance level was used. Mann-Whitney U test was used to test differences in the Shannon-Wiever Diversity Index, and Hilsenhoff Family Biotic Index values between cage and non-cage sites. Differences in benthic macro-invertebrates' numerical abundance between cage and non-cage sites were tested using Kruskal-Wallis and Mann-Whitney U tests. The parameter values of the current study were compared with the parameter values obtained from previous baseline survey by NaFIRRI (2012) [11].

3 Results

3.1 Composition and abundance of benthic macro-invertebrates

Three phyla (Anellida, Mollusca and Arthropoda) were encountered from the study sites. Although Arthropoda contained the highest number of benthic macro-invertebrates (Figure 2), differences between cage and non-cage sites were not significant (Kruskal Wallis Test: P=0.1). Similarly, differences in numerical abundances of molluscs between cage and non-cage sites were not significant (Kruskal Wallis Test: P=0.6). Annelids were significantly higher at the reference site than at cage site 2 (Mann-Whitney Test; P=0.004).

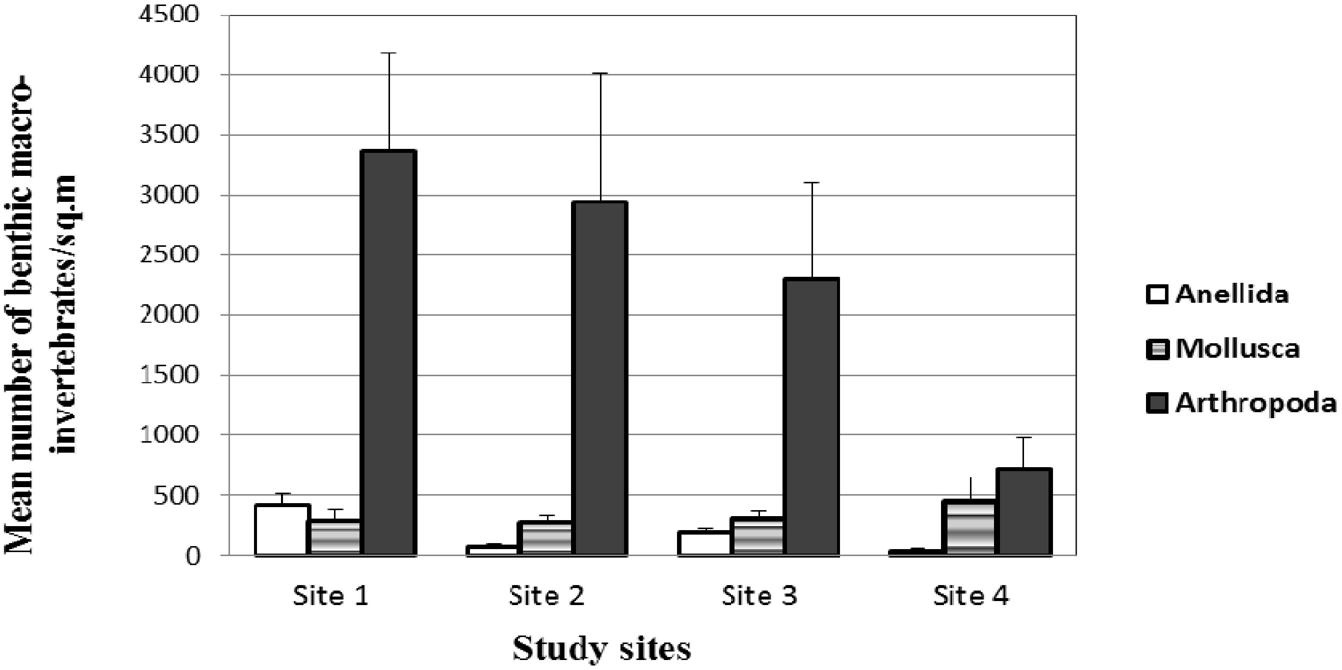


Fig 2: Average abundance of benthic macro-invertebrates per phyla at the study sites of the Chinese cage fish farm in the Napoleon Gulf, Lake Victoria.

Six classes of benthic macro-invertebrates (Oligochaeta, Hirudinea, Bivalvia, Gastropoda, Insecta and Malacostraca) were identified at the study sites (Figure 3). The most numerically abundant benthic organisms across the study sites belonged to class Insecta while the least abundant belonged to Malacostraca and was restricted to site 1 (reference). Although Oligochaeta, Bivalvia, Gastropoda and Insecta were encountered at both the cage and non-cage sites, only the Oligochaetes' and Gastropods' abundance were significantly different between cage and non-cage sites i.e. Oligochaetes were significantly higher at the reference site than at cage site 2 (Mann-Whitney Test, P=0.004) and Gastropods were significantly higher at the cage sites (2 and 3) than the non-cage sites (Kruskal Wallis Test: P=0.02).

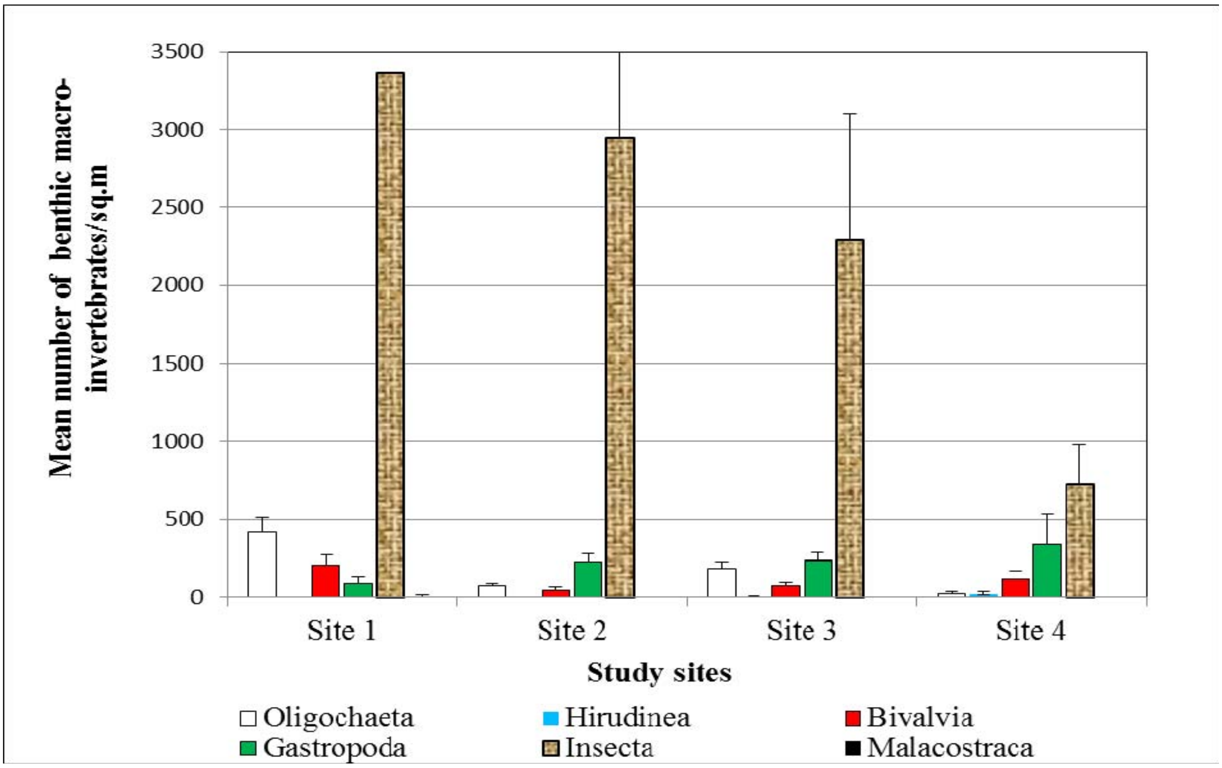


Fig 3: Average abundance of benthic macro-invertebrates per class at the study sites of the Chinese cage fish farm in the Napoleon Gulf, Lake Victoria.

Of the 25 species/genera of benthic macro-invertebrates identified in this study, *Chaoborus sp*., *M. tuberculata, Bellamya unicolor* Olivier, 1804, *Caelatura hauttecoeuri,* Bourguignat, 1883, *Corbicula africana* Krauss, 1848, *Byssanodonta parasitica* Deshayese, 1854, *Chironomus sp*., *Clinotanypus sp*. and *Ablabesmyia sp* occurred at both cage and non-cage sites (Table 1). *Chironomus sp.* were the most abundant genera and were significantly higher at the cage sites than the non-cage sites (Kruskal Wallis Test: P=0.02). *C. africana* was significantly lower at cage site 2 compared to the reference site (Mann-Whitney Test; P=0.04) and significantly higher at cage sites 2 and 3 compared to site 4 (Mann-Whitney Test; P=0.04 and 0.02 respectively). *B. parasitica* was significantly higher at the non-cage sites than at the cage sites (Kruskal Wallis Test; P=0.02). *M. tuberculata* was significantly higher at the cage sites than the non-cage sites (Kruskal Wallis Test; P=0.01). *Chaoborus sp.* was significantly higher at reference site than cage sites (Kruskal Wallis Test; P=0.03). There were no significant differences in numerical abundance of *B. unicolor* and *C. hauttecoeuri* between cage and non-cage sites (Kruskal Wallis Test; P=0.1 and P=0.3 respectively).

3.2 Benthic macro-invertebrates' species diversity

The species diversity calculated as the Shannon-Wiever diversity Index showed a range of 0.1 to 2.0 (Table 2). There was a significant difference in the diversity index values of the reference site and cage site 2 (Mann-Whitney Test; P= 0.02). The reference site had the highest diversity index, while cage site 2 had the lowest. The index values between cage sites and site 4 (impact verification site) were not significantly different (P=0.2).

Table 1: Average numerical abundance (ind./m^2) of benthic macro-invertebrates encountered at the study sites of the Chinese cage fish farm in the Napoleon Gulf, Lake Victoria.

Benthic Macro-invertebrates' Taxa	Non-cage sites		Cage sites	
	Site 1	Site 4	Site 2	Site 3
Bivalvia class				
C. hauttecoeuri	8±5	18±11	3±3	15±6
Caelatura monceti Bourguignat 1883	6±4	04±4	----	----
Mutera sp.	----	04±4	----	----
C. africana	134±46*	14±11*	42±20*	63±19*
B. parasitica	53±38*	77±42*	3±3*	----
Sphaerium sp.	3±3	----	----	----
Gastropoda class				
Bulinus sp.	----	7±7	----	18±10
Biomphalaria sp.	----	4±4	----	----
Lentorbis junodi sp.	----	4±4	----	----
Gyraulus sp.	----	11±11	----	----
Gabbia humerosa Mandahl-Barth 1954	3±3	196±185	----	----
M. tuberculata	42±19*	56±33*	126±33*	133±41*

Pila ovata Olivier 1804	----	----	----	3±3
B. unicolor Olivier 1804	45±24	60±30	105±29	93±25
Insecta class				
Chironomus sp.	1810±594*	77±33*	2696±1039*	2139±818*
Ablabesmyia sp.	6±6	14±6	3±3	----
Clinotanypus sp.	25±12	21±21	3±3	----
Cryptochironomus sp.	08	----	----	----
Procladius sp.	----	4±4	----	3±3
Tanypus sp.	8±6	----	----	12±7
Tanytarsus sp.	3±3	----	----	----
Chaoborus sp.	1226±392*	11±8	240±184*	144±68*
Caenis sp.	3±3	21±15	----	----
Povila adusta Navas 1912	----	266±171	----	----
Malacostraca class				
Caridina nilotica Roux 1833	08 ±8	----	----	----

*Indicates significant difference at P (0.05).

3.4 Modified Hilsenhoff Biotic Index (HBI) of benthic macro-invertebrates

The HBI was higher at cage site 2 (Table 2), although the Kruskal Wallis Test showed no significant differences between cage sites and the reference site (P=0.9). Index values of the cage sites were however significantly higher than those of non-cage site 4 (P=0.01).

3.5 Benthic macro-invertebrates – Water quality relationship

According to the Shannon-Wiever diversity and Hilsenhoff Biotic Index values obtained in this study, the study sites were categorized as either moderately polluted or highly polluted (Table 2).

Table 2: Values of biological indices and implications for water quality for the study sites of the Chinese cage fish farm in the Napoleon Gulf, Lake Victoria.

Biological Indices	**Non-cage sites**		**Cage sites**	
	Reference	**Site 4**	**Site 2**	**Site 3**
Shannon-Wiever diversity index (H')	1.1±0.1	1.2±0.2	0.7 ±0.1	1.0±0.2
Degree of organic pollution**	Moderately polluted	Moderately polluted	Highly polluted	Moderately polluted
HBI(Mean ± SE)	8.4 ± 0.2	6.7 ± 0.6	8.6 ± 0.3	8.5 ± 0.3
Water quality classes	Poor	Fairly poor	Very poor	Poor
Degree of organic pollution**	Very significant organic pollution	Significant organic pollution	Severe organic pollution	Very significant organic pollution

**Implications on water quality based on Wilhm and Dorris (1968) [12] and Hilsenhoff (1982) [13].

3.6 Physical and chemical characteristics of the water column

Mean depth was significantly different between the cage sites (2 and 3) and non-cage sites (1 and 4) ($F_{3, 8}=0.6$; $P<0.05$); with site 1 being the deepest and site 4 the shallowest (Figure 4).

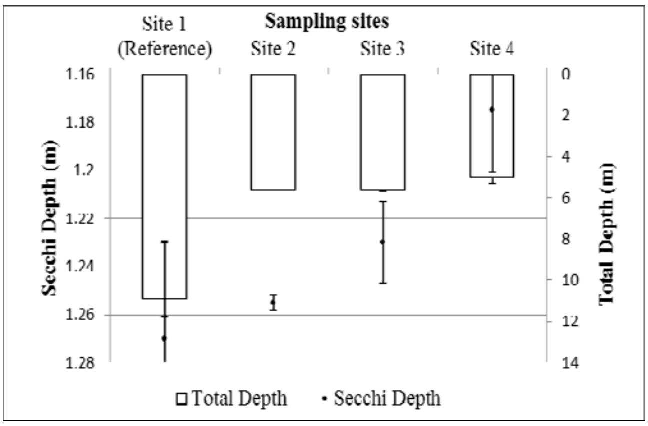


Fig 4: Variations in secchi depth and total depth in the water column at the study sites of the Chinese cage fish farm in the Napoleon Gulf, Lake Victoria.

Mean secchi depth (water transparency) ranged from 1.18 m to 1.27 m; electrical conductivity from 101.2 to 102.1 µS/cm, water temperature ranged from 26.5 to 27.1°C; dissolved oxygen from 5.6 to 6.4 mg/L and pH from 7.5 to 8.1. No significant differences between cage and non- cage sites were found for secchi depth, electrical conductivity, water temperature, dissolved oxygen and pH ($F_{3, 8}=2.6$, P = 0.1; $F_{3, 28}=0.5$, P=0.7; $F_{3, 28}=0.8$, P=0.5; $F_{3, 28}=0.3$, P=0.8 and $F_{3, 28}=0.4$, P=0.8 respectively) (Figures 4, 5).

Mean concentrations of nutrients for both cage (2 and 3) and non-cage sites (1 and 4) shown in Figure 6 show that Nitrite-Nitrogen and Nitrate-Nitrogen ranged from 2.8 to 3.9 µg/L and 33.3 to 56.2 µg/L respectively and were not significantly different between cage sites and non-cage sites ($F_{3, 24}=0.7$, P=0.6). Ammonia-Nitrogen and Soluble Reactive Phosphorus ranged from 11.7 to 24.3 µg/L and 7.9 to 9.4 µg/L respectively and differences between cage and non-cage sites were not significant ($F_{3, 24}=1.6$, P=0.2 and $F_{3, 24}=0.1$, P=0.9 respectively).

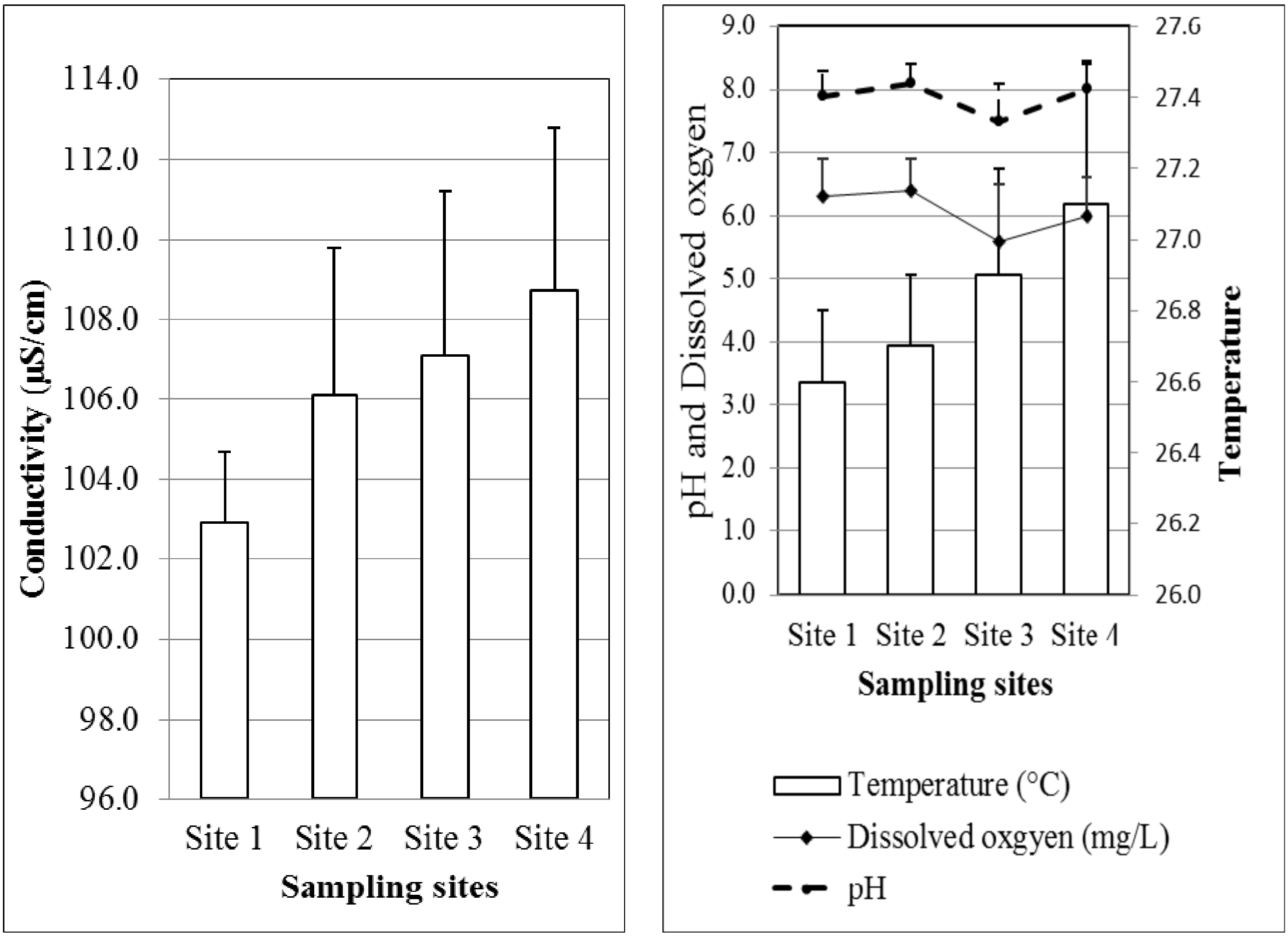
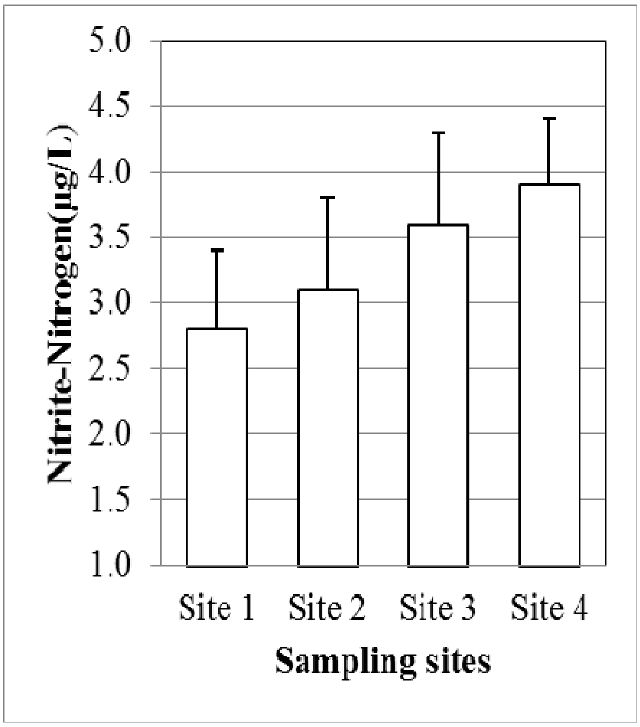
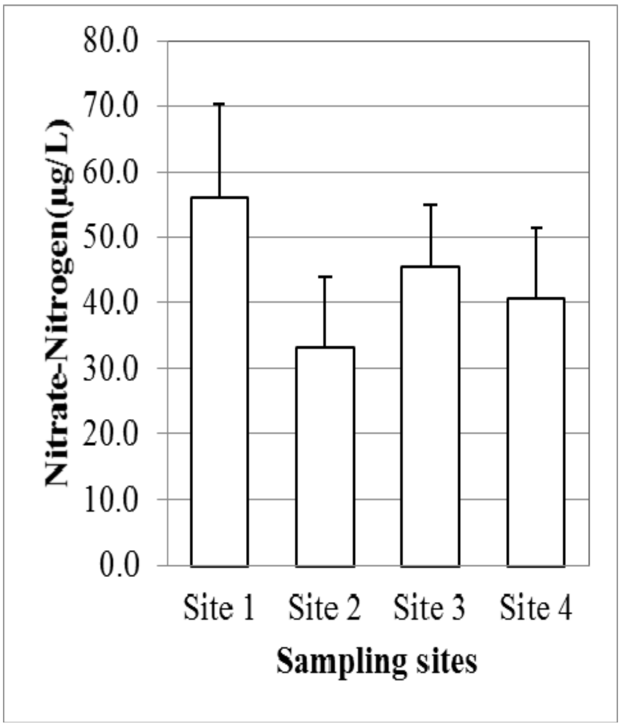


Fig 5: Variations in conductivity, pH, dissolved oxgyen and temperature in the water column at the study sites of the Chinese cage fish farm in the Napoleon Gulf, Lake Victoria.





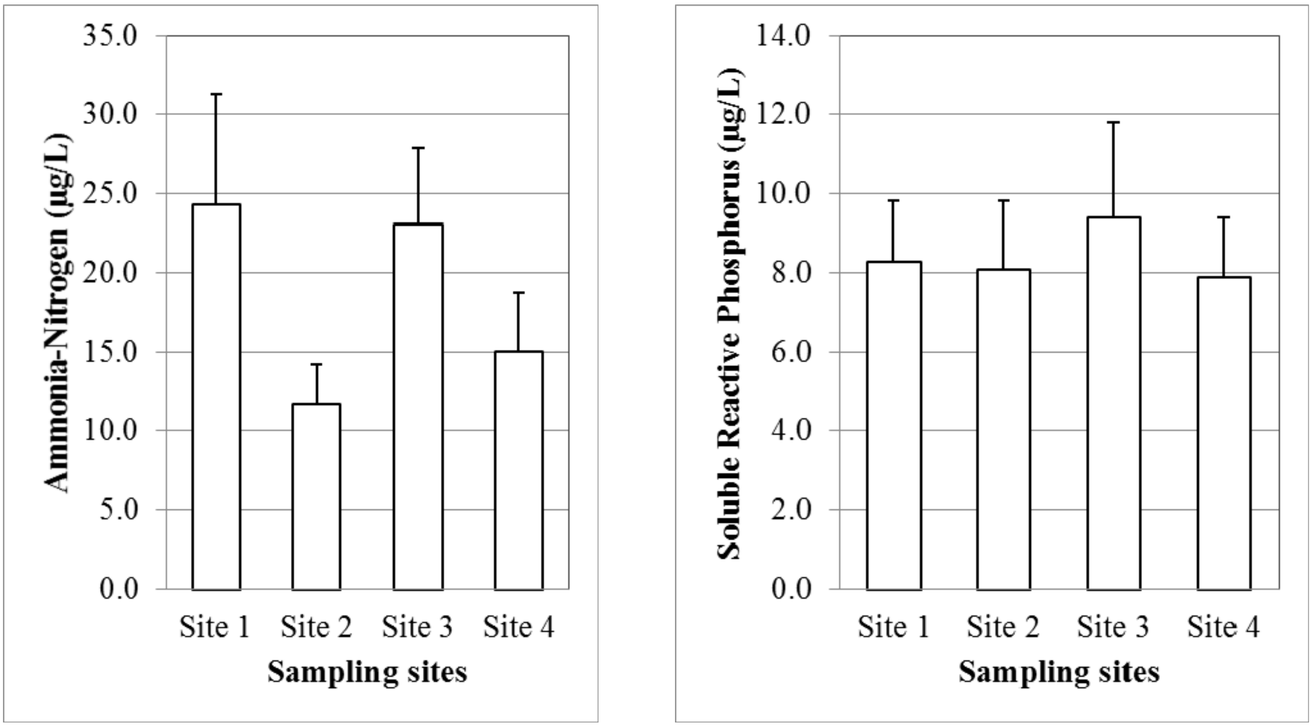


Fig 6: Variations (mean ± SE) in Nitrite-Nitrogen in the water column at the study sites of the Chinese cage fish farm in the Napoleon Gulf, Lake Victoria.

4 Discussion

4.1 Benthic macro-invertebrate community parameters

A comparison of the numerical abundances of the major pollution tolerant and non tolerant macro-invertebrate taxa between cage and non-cage sites suggested that some taxa were affected by the fish cage culture practices. The observed significantly higher numerical abundance of *Chironomus sp.* and *M. tuberculata* at the cage sites and the significantly lower abundance of *C. africana* at cage site 2 (compared to the reference site) and *B. parasitica* at both cage sites may have been influenced by presence of fish cages. The high abundance of the gastropod, *M. tuberculata* and *Chironomus sp.* indicate an input of organic matter, given that these organisms are known for their very high tolerance to pollution (Zimmerman, 1993; Mandaville, 2002) [10, 6]. Consistent with results of the present study, Karaca and Pulatsu, (2003) [14] and Ndaruga *et al*., (2004) [15], found increased abundances of *Chironomus sp.* in the vicinity of fish cages.

Similar to this study, results by Doughty and McPhail, (1995) [16] found significantly lower abundance of oligochaetes and chaoborids at fish cage sites, probably influenced by hydrological characteristics, substrate type, predation pressure and natural or anthropogenic disturbances. Both oligochaetes and chaoborids are reported to be opportunistic groups that mobilize available food resources for growth and are thus very tolerant to pollution (Miserendino and Pizzolon, 2000) [17].

A comparison of the benthic macro-invertebrates' results from this study and those from the baseline survey by NaFIRRI, (2012) [11] showed that: Some taxa such as *Pisidium sp.* (bivalve), Leptophlebidae (Ephemeroptera) and Psychomyiids (Trichoptera) reported in the NaFIRRI baseline survey were not encountered in this study. The latter two taxa are known to be sensitive to pollution (Mwebaza-Ndawula *et al*., 2013) [18]. On the other hand, taxa such as, *Caelatura monceti, Mutera sp., Sphaerium sp., Bulinus sp. Biomphalaria sp., Lentorbis junodi sp., Gyraulus sp., Pila ovata, Cryptochironomus sp., Cryptochironomus sp. Tanypus sp., Tanytarsus sp.,* Ceratopogonidae and *Caridina nilotica* encountered in this study were not reported in the 2012 NaFIRRI survey. These observations suggest that some changes in the macro-invertebrates' community structure have occurred probably due disturbances such as cage fish farming (Karalis *et al*., 2003) [19]. From results of this study, it is evident that differences in composition and abundance of benthic macro-invertebrates may have occurred following the establishment of cage fish farming activities at the study site, but this is subject to confirmation by future surveys to establish consistency of this observation. Differences in composition could also have been as a result of the differences in the duration of study because unlike the baseline survey, which was accomplished in a few days, the present study was carried out over a longer period of time.

The modified HBI and Shannon-Weaver Index were used to classify both cage and non-cage sites according to their water quality status. The results (Table 2) indicated that cage site 2 showed the worst water quality status, and was likely affected by cage fish farming. Similar to common observations elsewhere (Edgar *et al*., 2010) [20], cage fish farming activities resulted into increases (though not significant) in the HBI index values and significant decreases in species diversity index of benthic macro-invertebrates at cage site 2. High HBI values as observed at this site are indicative of organic pollution while lower values at other sites are indicative of cleaner water environment (Zimmerman, 2014; Mandaville, 1999) [10, 21]. The increase in HBI index value at cage site 2 was due to the presence in large numbers of macro-invertebrates that are most tolerant to organic enrichment. The numerical abundance of tolerant benthic macro-invertebrate taxa is known to increase with increase in pollution (Doughty and McPhail, 1995; Mandaville, 2002) [16, 6].

The diversity patterns of macro-invertebrate community derived from fish farming have been widely studied (Kutti *et al*., 2007; Edgar *et al*., 2010) [22, 20]. The species diversity of benthic macro-invertebrates is reported to decrease with increased organic enrichment (Brown *et al*., 1987) [23]. Thus, the significant reduction in species diversity at cage site 2 suggested probable organic matter accumulation as a result of culturing fish in cages. Following gradients of increasing organic enrichment, benthic macro-invertebrate communities are known to become less diverse, exhibit a lower biomass and a higher proportion of deposit feeders (Pearson and Rosenberg, 1978) [24]. This is because as oxygen concentration decreases in the sediment, there is a shift towards few opportunistic/tolerant species (Diaz and Rosenberg, 1995) [25]. Since the Mann-Whitney test showed that species diversity at the reference site was only significantly higher when compared to cage site 2, the present study indicates that the effects of fish cages on the benthic macro-invertebrates population may have been localized at this fish cage site as observed elsewhere (Costa-Pierce, 2002) [26]. Several studies have shown that effects of cages on macro-invertebrate diversity are found between 25 and 80 meters away from the fish cages (Mente *et al*., 2006; Heinig, 2014) [28, 27].

4.2 Physico-chemical parameters

The present study shows that physico-chemical parameters (i.e. water temperature, dissolved oxygen, electrical conductivity, pH, water transparency, Ammonia-Nitrogen, Nitrite-Nitrogen, Nitrate-Nitrogen and Soluble Reactive Phosphorus) were unaffected by the fish cage culture practices. This could have been due to relatively low total weight of fish per unit volume of water. These results are in agreement with some of the data reported from other geographical areas (Soto and Norambuena, 2004, Maldonado *et al*., 2005; Jihani *et al*., 2012) [29, 30, 31].

According to Gowen *et al.* (1983) [32], the highly dynamic physical environment of cage fish farms is a key reason why effects may sometimes not be observed in their vicinity. Soto and Norambuena (2004) [29] suggested that increased nutrient concentrations may not usually occur in the vicinity of fish cages not only because of dilution process but also because they pass through the food chain very rapidly, from phytoplankton to higher levels as also observed by Mwebaza-Ndawula *et al*. (2013) [18] at SON fish farm near Jinja. Recent results by Machias *et al*. (2005) [33], showed increased wild fish biomass in response to the presence of fish farming zones.

Values reported in the present study for the selected physico-chemical parameters were within ranges reported normal for freshwater ecosystems, and within acceptable limits for drinking water purposes as well as sustaining aquatic life (Horne and Goldman, 1994; Hayashi, 2004; Mallya, 2013; WHO, 2014) [34, 35, 36, 37]. These values are comparable to previous records for Napoleon Gulf (Okello *et al*., 2009; Muyodi and Kapiyo, 2012; NaFIRRI, 2012) [38, 339, 11].

5 Conclusion

Cage fish farming affected water quality based on the numerical abundance of benthic macro-invertebrates, modified Hilsenhoff Biotic Index, and Shannon Weaver diversity Index. This study showed that cage fish farming can cause localized and significant changes on macro-invertebrate community structure as manifested in the observed reduction of species diversity and increased abundance of pollution-tolerant forms such as *Chironomus sp.* and *Melanoides tuberculata.* The modified HBI and Shannon-Weaver Index indicated severe organic/pollution highly polluted at a cage site 2. The results on selected physico-chemical parameters and nutrients indicated no significant effects from cage fish culture.

6 Recommendations

Since cage fish farming of mainly Tilapia is expected to be rolled out to all water bodies including ponds in Uganda to increase the supply of fish, water quality effects associated with fish cage culture may be avoided or reduced by careful cage siting and adherence to best management practices (e.g. improved feed formulation).

Although the results of this study indicated satisfactory water quality in terms of physico-chemical parameters, long term studies on the effects of fish cages on the physico-chemical parameters are still needed in order to determine future management options for fish farming in Ugandan water bodies. This is a necessary requirement because of the open-access nature of the water bodies where pressure from fish cage fish farms may cause negative impacts on water quality.

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