A TECHNICAL REPORT ON SUSTAINABLE COMMUNITY-BASED CAGE AQUACULTURE IN LAKE VICTORIA, KENYA

Aquaculture Business Development Programme (ABDP)

MAY 2022

DECLARATION

We, Kenya Marine and Fisheries Research Institute (KMFRI), Aquaculture Business Development Programme (ABDP), Kenya Fisheries Service (KeFS) and State Department for Fisheries, Aquaculture and the Blue Economy (SDFA & BE) herein submit a technical report on sustainable community-based cage aquaculture in Lake Victoria. To the best of our knowledge, all the information contained in this report represents the accurate and truthful representation of the survey and findings as related to the report.

ACKNOWLEDGEMENT

We wish to thank the International Fund for Agricultural Development (IFAD) and The Government of Kenya through the ABDP for funding the expedition and development of this report. We also wish to thank all the KMFRI, KeFS and County Governments for their valuable contribution.

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CONTRIBUTORS

KMFRI: Christopher Mulanda Aura, Chrisphine S. Nyamweya, Collins Ongore, Fredrick Guya, Paul Orina, Kevin Obiero, Veronica Ombwa, Nicholas Gichuru, Monica Owili, Caleb Ogwai, Job Mwamburi, Joseph Nyaundi, Priscilla Boera, Venny Mziri, James Last Keyombe, Awuor F. Jane, Hilda Nyaboke, Safina Musa, Patrick W. Otuo, Jared Babu, Nathan Mrombo, George Basweti, Naftaly Mwirigi, Julia A. Obuya, Dennis Otieno, Hezron Awandu.

ABDP: Ruth Lewo Mwarabu, Grace Njagi, Kelly Owila

SDFA & BE: Samson Kidera, Stephen Lolel, Karen Mugambi

KeFS: Christine Etiegni, Zachary Ogari, Alice A. Hamisi, Ashford Maguta, Ann N Wangechi

Letter of Submission

KENYA MARINE AND FISHERIES RESEARCH INSTITUTE

Telephone 020-8021560/1
020-2353904
Mobile: 0712003853
FAX: 020-2353226
E-mail: director@kmfri.co.ke
When replying please quote
Ref: no:
and date:
If calling or telephoning ask
For:
Please address your reply to:
The DIRECTOR GENERAL

HEADQUARTERS
P.O. Box 81651
MOMBASA
KENYA

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The Programme Coordinator (PC)
AQUACULTURE BUSINESS DEVELOPMENT PROGRAMME (ABDP)
IFAD Building,
Kamakwa Road (Opp. Nyeri Club)
P.O. Box 904-10100,
Nyeri

RE: SUBMISSION OF FINALIZED TECHNICAL REPORTS AND FACTSHEETS ON CAGE CULTURE, AQUAPARK AND RESTOCKED SMALL WATER BODIES

The Government of Kenya (GoK) in partnership with the International Fund for Agricultural Development (IFAD) is implementing the Aquaculture Business Development Programme (ABDP) whose aim is to increase the incomes, food security and nutritional status of the wider communities of poor rural households involved in aquaculture in the fifteen targeted Counties in Kenya. As part of ABDP implementation activities, the programme is expected to undertake relevant studies that will form a basis of advising the relevant county governments and the State Department of Fisheries, Aquaculture & Blue Economy (SDFA & BE) on environmental and socio-economical sustainability aquaculture production in the country.

In-line with the aforementioned, Kenya Marine and Fisheries Research Institute (KMFRI) led participants from ABDP, Kenya Fisheries Service (KeFS), SDFA & BE in the development of following technical reports and their related briefs:

i) Sustainable Community-based cage aquaculture in Lake Victoria; and
ii) An end-line survey report of selected small water bodies (SWBs) stocked with Nile tilapia fingerlings.

The purpose of this letter is therefore to submit the aforementioned reports and briefs to your office for further actions.

Thank you.

Dr. Christopher M. Aura (PhD)
Director, Freshwater Systems Research
FOR: DIRECTOR GENERAL/CEO-KMFRI

Kenya Marine and Fisheries Research Institute ISO 9001:2015 CERTIFIED

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Executive Summary

Cage aquaculture is quickly expanding in the African Great Lakes Region, with the potential to boost fish output and act as a source of food security, poverty reduction, and job creation. However, there is growing concern that the proliferation of fish cages in Lake Victoria may have significant consequences on the lake's ecology. It is in this context that Aquaculture Business Development Programme (ABDP) supported a socioecological study across the five riparian counties of Lake Victoria, Kenya on sustainable community-based cage aquaculture, in close collaboration with stakeholders in the fisheries and aquaculture value chains. The study assessed the existing investment models, production levels, cage inventory, ecological integrity, fish condition, emerging issues and lessons learnt. The floating cage system is the technology adopted in the lake with square-metal frames dominating while the UV treated PVC frames is preferred by large producers. The survey recorded a total of 5242 cages across the five counties with Siaya County having the highest number of cages attributed to the special support from the Ministry of Devolution in 2018. Majority of the employees were men mainly due to the labor-intensive nature of cage production system. Women were mainly employed as casual laborers during harvesting while men were employed as feeders, security personnel, and managers. The cost of production and the gross margin for the various cage sizes indicate that cage aquaculture is an economically viable business. However, the profitability of the cages varied depending on the scale of operations with the 10 m diameter cage having the highest return on investment. The carrying capacity with best management practices is estimated to be more than 500% of the current cage culture production, which is estimated to be 21,000 mt. Major climate risks constraints to cage aquaculture operations included strong winds and waves, unpredicted movements of water hyacinth mats and algal blooms. Opportunities for cage investment were noted to include the availability of materials for cage structure, adequate labour, rising demand for fish and political goodwill. The water quality parameters were generally within the optimal levels recommended for aquaculture. However, there was no clear gradient on the concentration of the parameters in cage locations probably due to the dilution effect of the lake water which may deteriorate in the long run. Fish exhibited normal growth with uniform length and weight gain. Floating cage system was noted to be the most preferred technology by majority of cage investors who prefer metal frames due its sturdiness during operations such as changing fouled nets, grading, and harvesting. It was established that famers had no access to quality affordable seed and feed, and extension services thereby limiting cage productivity. Lack of quality feeds locally was the main reason for importing feeds. There is therefore need to monitor the certified hatcheries and feed manufacturers to ensure production standards are adhered to. Appropriate policies and regulations are required for improved lake and resource management, as well as to guide cage culture business, improve security, and facilitate resource usage dispute resolution procedures. Farmers should undertake regular monitoring of both physico-chemical parameters and microbiological parameters which are often not included in the monitoring of fish farm water quality.

1. Introduction

Lake Victoria is the largest tropical lake in the world and the largest in the African Great Lakes region. The basin is home to over 40 million people and sustains one of the world's most dense and impoverished rural populations, with densities of up to 1200 people per Sq. km. in parts of Kenya (Hoekstra and Corbett 1995; Aura et al., 2022). The vast majority of the basin's inhabitants live on less than $1.00 per day. The average population density in the basin is roughly 165 people per Sq. Km. This is owing to its advantageous agricultural, fishery, and other economic conditions (Aura et al., 2019).

The average population density on the Kenyan, Tanzanian, and Ugandan sides of the basin is 297 people per Sq. km., 97 people per Sq. km., and 635 people per Sq. km., respectively. The growing population puts increasing strain on Lake Victoria's natural resources, with an average yearly growth rate of 3.5 %, which is among the highest in the world. The exploitation of these resources is greatly influenced by the livelihood needs of the basin's population. Aside from population increase, other pressures affecting Lake Victoria aquatic resources include overfishing, poor fishing techniques, pollution, the introduction of invasive species, and, more recently, climate change (Hecky et. al., 2010). Multiple pressures have resulted in a significant drop in Lake Victoria fisheries, prompting many fishermen/investors to turn to cage culture as an alternative source of income (Aura et al., 2018; Musinguzi et al., 2019; Hamilton et al., 2020; Musa et al., 2021).

Cage aquaculture is the practice of growing fish in existing water resources while enclosed in a net cage that permits free passage of water (Aura et al., 2021). Cage culture activities were first documented in Southeast Asia in the late 1800s, specifically in Kampuchea's freshwater lakes and river systems. Marine fish farming in cages dates back to the 1950s in Japan, when fish farming research at Kinki University's Fisheries Laboratory resulted in the commercial culture of yellowtail (Seriola quinqueradiata) and grew into a large industry as early as 1960. Cage fish aquaculture is quickly developing across Africa. Since 1995, the production of farmed fish in Sub-Saharan Africa has expanded more than sixteenfold (FAO, 2018), mostly due to the expansion of tilapia cage aquaculture (Satia, 2011). Lake Victoria in Kenya (Aura et al., 2018), Lake Victoria in Uganda (Blow and Leonard, 2007), Lake Volta in Ghana (Asmah et al., 2016), Lake Kariba in Zimbabwe (Berg et al., 1996), and Lake Malawi in Malawi are all notable examples of rapid spread of cage fish farming in Sub-Saharan Africa (Blow and Leonard, 2007). Despite the region's enormous fish market and the practice's proven potential, cage fish farming has not been widely practiced in East Africa (Blow and Leonard, 2007). Few commercial fish farmers now practice cage fish farming, which is a direct response to decreased wild fish harvests and increased market demand from local, regional, and international markets.

Cage culture was pioneered in Kenya by the Lake Basin Development Authority (LBDA) with trials around Dunga Beach in 1988. In 2005, the Dominion Group of Companies harvested successfully from cages at its Yala wetland farm (Orina et al., 2018). Between 2008 and 2013, "BOMOSA," an EU-sponsored project, conducted trials on caging within small water bodies within the Lake Victoria basin. Cage culture techniques have grown in popularity on the beaches of Obenge and Dunga in Siaya and Kisumu counties, respectively, thanks to the efforts of the

Fisheries Cooperative Society and Beach Management Units (BMU) (Aura et al., 2017). Despite early setbacks, cage culture approach was subsequently selected in 2010 at Dunga Beach in Kisumu County through collaborative work between KMFRI and Dunga Beach Management Unit. Cage culture has emerged in recent years as a new livelihood in Lake Victoria, in addition to safeguarding diminishing wild fish species. The practice has since spread to Lake Victoria's five riparian counties, namely Busia, Siaya, Kisumu, Homa Bay, and Migori. For example, the total number of cages in the Kenyan section of Lake Victoria increased from 1663 to more than 4537 between 2016 and 2019, with further growth projected (Hamilton et al., 2020).

Fisheries and aquaculture are important change agents because they lower livelihood risks while also contributing to income generation and poverty alleviation. The concept of livelihood is central to the discussion about sustainable development, which seeks to promote "healthy lifestyles for all" by ensuring that everyone has access to inexpensive and nutritious food (United Nations, 2015). SDG 14 focuses on the role of fisheries and aquaculture in attaining food security, with a call to encourage fish stock renewal in order to maintain safe, diverse, and nutritious diets. The goal also encourages countries to protect and exploit oceans, seas, and marine resources in a sustainable manner in order to achieve sustainable development. This is consistent with the current blue economy concept, which emphasizes the proper evaluation and utilization of resources associated with rivers, lakes, and seas for economic growth and long-term development (FAO, 2014).

Sustainable cage culture requires strict adherence to proper husbandry procedures. Improper husbandry can cause ecological degradation, resulting in changes in water quality and biotic structure. In both cultured and capture fisheries, habitat change may result in poor fish health and, in some cases, widespread mortalities. The farmer may suffer financial losses as a result of this. The sustainability of cage culture practice will also be determined by the gross profit margin, which is calculated by deducting the farmer's profits from the costs of producing and distributing its products. Kenya Marine and Fisheries Research Institute (KMFRI) led Aquaculture Business and Development Program (ABDP) and Kenya Fisheries Service (KeFS) and and State Department for Fisheries, Aquaculture and the Blue Economy (SDFA & BE) participants in conducting a socioecological study across the five riparian counties of Lake Victoria in March 2022, on sustainable community-based cage aquaculture, in close collaboration with stakeholders in the fisheries and aquaculture value chains.

2. Materials and Methods

2.1 Study area

The study was conducted in the five riparian counties of Lake Victoria (Busia, Siaya, Kisumu, Homa Bay, and Migori) in Kenya (Figure 1). Lake Victoria provides critical ecological services to roughly 40 million people in Kenya, Tanzania, and Uganda. These include fishing, transportation, and the use of water in households, agriculture, and industry (LVFO, 2015; Aura et al., 2019). Lake Victoria, with a surface area of 68,000 km^2, is the world's largest tropical and second-largest freshwater lake. It is shared by Uganda (43%), Tanzania (51%), and Kenya (6%). (Aura et al., 2013). The lake is situated 1134 meters above sea level.

In Kenya, it is the second largest inland water body after Lake Turkana, covering 4100 km^2 with an average depth of 6 - 8 m (inside the gulf) and a maximum depth of 70 m (in the open waters) (Odada et al., 2004). The lake is monomictic, with complete annual mixing occurring between June and August. Furthermore, the seasonal mixing wind generates significant shear at the lake bottom and vigorous vertical mixing in the gulf, notably in the Mid Gulf (Okely et al., 2010; Guya, 2013). As a result, the expansion of the cage culture industry in the lake could have a variety of fishery, socioeconomic, and limnological consequences that could affect the lake's limnological quality.

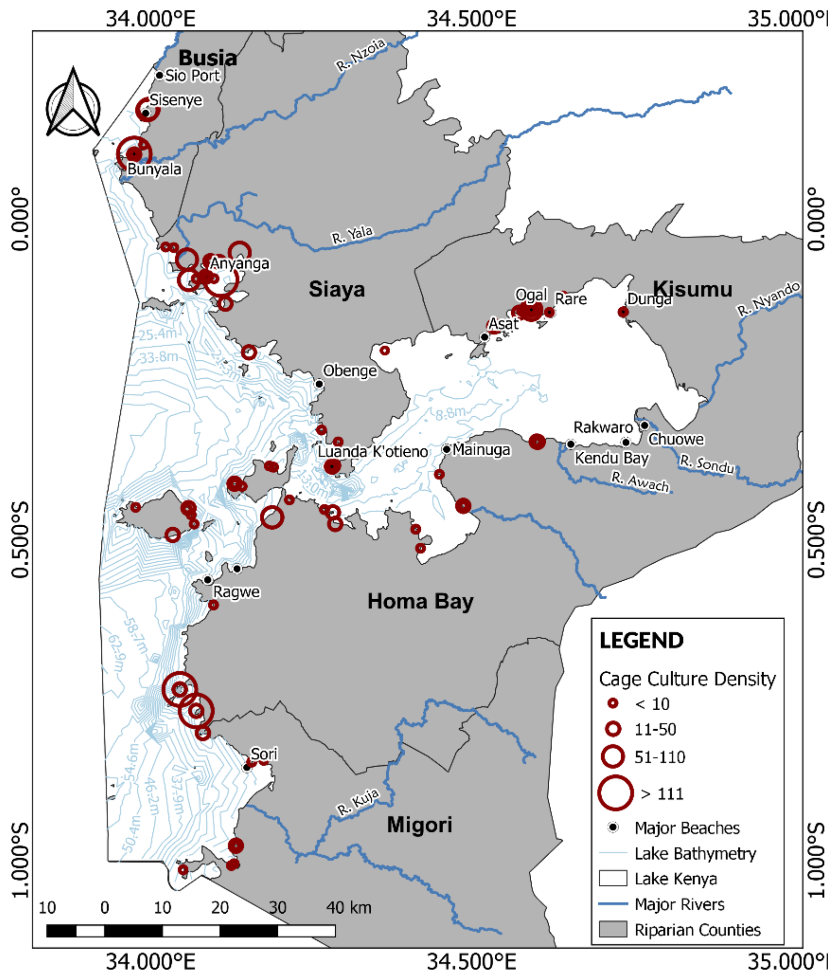


Figure 1. Map showing riparian counties of Lake Victoria, Kenya where the socio-ecological survey on community cage culture was conducted.

2.2 Data collection and analysis

2.2.1 Socio-economics

In March 2022, the survey was carried out in the Kenyan waters of Lake Victoria. Survey teams sought and interviewed all cage culture producers who were either proprietors or managers of cage facilities. The study used semi-structured questionnaires to collect information on various aspects of the survey, such as cage specifics, socio-demographic characteristics, and farm operations and investments. GPS coordinates were also used to map cage culture stations and the total number of cages at all stations. The questionnaire was administered electronically via the Kobo collect application. This module improved data capturing accuracy, as well as real-time data transfer.

Carrying capacity scenarios were created using the International Futures (IFs) Model. The IFs platform is a broad platform with a large variety of levers that may be used to mimic scenarios like those experienced in the lake ecosystem. A foresight exercise with important stakeholders was conducted to gain insights into the various variables to be considered in the estimation of the carrying capacity. The simulation revealed a number of potential carrying capacity scenarios. The best scenario in this case was to employ suitable areas from the KMFRI assessment (zoning) (190 km^2) and combined with typical density at harvest, culture duration, cage depth, and a precautionary factor for zoning to account for the distance of the constraints from the shoreline and the potential impact on the lake ecosystem.

Survey data from online submissions was extracted from the Kobo database and entered into Ms. Excel files for descriptive analyses. The dataset was cleaned several times to ensure that it was error-free and internally consistent. Descriptive analyses were performed in order to identify significant connections among the study's variables. Thematic analysis of qualitative data was performed using deductive and inductive coding as suggested by Braun and Clarke (2006). On a five-point Likert scale, a series of responses to the various indicators were measured. Following that, frequencies for various levels of agreement were obtained and multiplied by their appropriate weights for each indicator under consideration. Tables and graphs have been used to display the quantitative data when suitable.

2.2.2 Water quality

At each cage site, in situ measurements and sampling for nutrients, plankton, and benthic macroinvertebrates were taken at three different points along a transect. A control site was identified far away from the cages. At each sampling/cage culture site, depth profile measurements were taken using portable water physicochemical electronic sensor-based probes. Data was promptly recorded on field data sheets and sent to the online Kobo Collect system for transmission and storage. Column depth (m), temperature (^oC), dissolved oxygen (mgL^{-1}), conductivity ($\mu S\ cm^{-1}$), pH, turbidity (Formazin Turbidity Units -FTU), salinity (ppt), Oxidation-Reduction Potential (ORP), and Total Dissolved Solids (TDS) were the key physical and chemical parameters assessed (mgL^{-1}). A conventional Secchi disk of 20 cm diameter was used to evaluate water transparency as Secchi depth (photic depth).

For each study site, nitrogen (ammonium-NH4+-N; nitrite-NO2—N; nitrate-NO3-- N; total nitrogen-TN), phosphorus (soluble reactive phosphorus-SRP; total phosphorus-TP), silicate species, Chlorophyll-a, and total suspended solids (TSS) concentrations were measured. Water properties were assessed using recognized standard methodologies for aquatic environmental studies (APHA, 2012).

Chlorophyll-a determination required gentle vacuum filtration of a certain amount of water sample via a Whatmann GF/C or Ederol BM/C filter, followed by acetone extraction. The filter and seston were folded and then wrapped in aluminum foil before being placed in the freezer overnight to aid in cell bursting. The seston and filter were homogenized in a tissue grinder at 5000 rpm for about 1 minute before being covered with 5 cc of 90% aqueous acetone. The samples were placed in screw-cap vials/centrifuge tubes, the grinder was washed with 90% acetone (note volume used), and the rinse was added to the extraction slurry. The volume was adjusted to 10 ml with 90% acetone, and the sample was placed in the dark at 4°C for at least 8 hours for the chl-a extraction. Following incubation, the material was centrifuged at 2500 g for 10 minutes. Decanting the cleared extract into a clean test tube. The light absorbance of the Chl-a extract was measured using a spectrophotometer in 1-cm cell cuvettes at 750 nm and 663 nm. To account for turbidity and other colors, absorption at 750 nm was removed from 663 nm data. The Chl-a concentration was estimated using the Talling and Driver (1961) equations.

2.2.3 Phytoplankton

The boat was anchored at specific sampling sites to collect water samples for analysis. The bottle was submerged and slowly dragged towards the current (the direction the boat is headed) until it was completely filled. The standard depths for "surface" water samples are 0.1 and 0.5 meters. 1-3 mL of Lugol's solution was used to preserve the material (1-3 mL per 1 litre of sample). Varied water chemistry and algal material density necessitate different preservative concentrations. A typical rule of thumb is that there should be enough Lugol's to turn the sample the color of weak tea (deep yellow colour). Plankton nets are not suggested for quantitative phytoplankton sampling. They are size selective and qualitative in nature. They can, however, be utilized to identify the species present because the higher density assists in taxonomic studies, particularly for rarer species.

2.2.4 Zooplankton

Zooplankton samples were collected using a cone-shaped 1-meter-long net with a mesh size of 50 or 60 m. The net was lowered as close to the bottom as possible with a graded rope and vertically hauled while noting the depth of the haul. The net's contents were then gently rinsed (with a wash bottle) into clear plastic bottles. These samples were then stored in a 5% formaldehyde solution before being delivered to the lab for analysis. Using a graduated beaker, a fresh volume was formed for each sample in the laboratory based on the sample concentration.

The sample was aggressively swirled just before taking a sub-sample for inspection from the beaker, and consecutive aliquots of each sample were studied and tallied in a counting chamber under a binocular dissecting microscope at 40X magnification. After placing the sub-sample, the counting chambers should be placed on a flat surface and allowed to settle for at least 30 minutes. Tiny rotifers were further separated into slides with glycerin mixed with distilled water using a fine glass capillary tube and viewed under a compound microscope at 100X. Using appropriate taxonomic literature, zooplankton was identified to the genus level and, where feasible, to the species level. Identification keys developed by Dussart and Defaye (1995) were employed for copepods. The keys by Korovchinsky (1992) and Smirnov (1996) were utilized for Cladocera identification, whereas the keys by Koste (1978), Koste and Shiel (1987), and Segers (1995) were employed for rotifer identification.

2.2.5 Microbiology

Water samples were collected directly into 500 mL aseptic plastic bottles for bacteriological quality testing. Each bottle was corked and labeled with the location, time, and date of collection before being transported in a cooler box to the KMFRI Kisumu laboratory for analysis. Total coliforms and fecal coliforms were the bacteriological measures of water quality examined. 1ml of the sample water was combined with 9ml of saline solution, and 0.1ml of the inoculum was incubated in this solution. All water quality measurements, sample collection, and analyses were carried out using conventional methods for water and wastewater examination (APHA, 2012).

R program v4.1.2 was used to analyze the gathered data. The mean and range of the individual parameters were determined using descriptive statistics. The Pearson correlation factor was utilized to determine the relationship between total coliform concentration and fecal coliform concentration. The results were compared to the appropriate ranges/values established by the Water Resources and Management Authority (WARMA).

2.2.6 Macroinvertebrates

Triplicate samples from the shoreline and the bottom were taken from each sampling site. The samples were washed with a sieve with a mesh size of 500 mm. Sorting took place in a white tray, which was then stored in ethanol (70%). The samples were then transferred to the laboratory, objectively separated, and macro-organisms were counted and classified to genus level using several keys (Merritt and Cummins, 2006), Gerber and Gabriel, 2002; Samways, 2008; and http://extension.usu.edu/water quality). The stomach contents of the organisms were analyzed further to identify eating habits, and the feeding guilds were assigned according to Gerber and Gabriel (2002) and Chesire et al. (2005).

The number of genera per station, relative abundance, numerical abundance, evenness, dominance, variety, species richness, and functional feeding guilds of all taxa were used to describe macroinvertebrate community structure and functional composition. The numerical abundance of the various FFGs was used to compute the ratios. The primary criteria of water quality indicators used to measure ecological integrity and production at each sampling/cage culture site are shown in Table 1.

Table 1. Water quality parameters used in assessing the ecosystem health status in Lake Victoria, Kenya.

	Parameter	**Purpose**
1.	Dissolved oxygen	Health and growth of the fish
2.	Temperature	Determines feeding, growth and reproduction of fish and plankton
3.	pH	Determines health of fish

4.	Transparency	Determines the depth to which phytoplankton and aquatic plants can grow, dissolved oxygen content, and water temperature
5.	Water depth	Determines the psychochemical parameters of the SWB and suitability of other culture systems such as cages
6.	ORP	Determines the ability of a SWB to cleanse itself or break down waste products such as contaminants
7.	Nitrogen Species (Ammonium-NH_4^+-N; nitrite-NO_2^--N; nitrate-NO_3^--N; total nitrogen-TN)	Support the growth of phytoplankton and aquatic plants, which provide food and habitat for fish
8.	Phosphorus species (soluble reactive phosphorus-SRP; total phosphorus-TP)	Support the growth of phytoplankton and aquatic plants, which provide food and habitat for fish
9.	Chlorophyll-*a*	To determine the level of primary productivity
10.	Phytoplankton abundance, composition and diversity	Are a food source to the fish and influence fish habits
11.	Zooplankton abundance, composition and diversity	Are a food source to the fish and influence fish habits
12.	Macroinvertebrate abundance, composition and diversity	Are a food source to the fish, indicates water quality and trophic structure?

2.2.7 Fisheries, Aquaculture and Investments

Using scoop nets, fish samples were obtained from several cages. The fish were identified to species level, and their total/fork and standard lengths were measured to the nearest cm and gram using a digital weighing scale. The fish were then gutted to reveal their sex and stage of maturation. The stomachs were carefully removed and kept in the lab for later stomach content research. The health of the fish was evaluated using established fish health diagnostic procedures (Aloo, 2012). Table 2 shows the primary research needs for fish biological sampling and the strategies employed to satisfy them.

Table 2. Parameters used in assessing fish condition in Lake Victoria, Kenya

	Parameters	**Purpose**
1.	Fish species composition; diversity indices; and stock abundance in the cages	Fish distribution; species composition; to address possible interaction between cultured species
2.	Stocking density, fish biomass,	Assess the population status; the stock abundance and environmental change
3.	Fish growth; length frequency, sex, and maturity; gonad somatic indices	Measure growth performance; establish key fish population parameters
4.	Stomach fullness and stomach contents assessment	Determine the trophic relationships

5.	Fish health assessment	Establish the health status of the fish; stocked

3.0 Results and Discussion

3.1 Socio-economic aspects of cage fish farming in Lake Victoria, Kenya

3.1.1 Socio-demographic characteristics of cage investors in Lake Victoria, Kenya

The majority of the cages are owned by Kenyans (n = 115; 95%) while the remaining are owned by nationals of various countries including; India (n = 2; 2%), China (n = 1; 1%), and Europe (n = 2; 2%). This indicates that the cage aquaculture venture is lucrative, attracting interest not only from locals, but also from foreign investors. The managers were mainly Kenyans (n = 112; 93%) with a few managers from India (n = 3; 3%), Uganda (n = 2; 2%), Zimbabwe (n = 1; 1%), and Germany (n = 1; 1%). The majority of the managers were aged between 36-45 years (n = 38; 32%) (Table 4) which is the most productive age of the Kenyan public workforce (KNBS, 2018). Most of the cage managers had O level education (n = 48; 40%). Those with tertiary level education were 34% (n = 40) while the rest had elementary education (n = 31; 26%). Management position in cage culture was male-dominated (n = 113; 94%), Managers who were full time fish farmers were (n = 36; 31%), the rest were part time fish farmers (n = 83; 69%). This is an indication that cage fish farming is not a full-time venture to the majority. The monthly household income of the cage managers varied with the majority earning between KES. 10,001-25,001 (n = 44; 37%) and supporting an average household size of 7 individuals.

Table 3. Socio-demographic characteristics of cage fish managers in Lake Victoria, Kenya in March 2022

Variable	Parameter	Proportion
Gender (118)	Female	6%
	Male	94%
Age (117)	18-35	33%
	36-53	48%
	54-71	15%
	72-89	3%
Marital status (120)	Married	83%
	Separated	1%
	Single	16%
	Widow/er	1%
Household size (120)	0	4%
	>10	13%
	1-3	17%
	4-5	18%
	6-7	29%
	8-10	19%
Level of Education (120)	Elementary	26%

	O'Level	40%
	Tertiary	34%
Main Occupation (120)	Full-time farmer	30%
	Part-time farmer	70%
Income level (120)	>200,000	3%
	10,001-25,000	37%
	100,001-200,000	1%
	1-10,000	34%
	25,001-50,000	14%
	50,001-100,000	8%
	Nil~~1~~	3%

3.1.2 Distribution of cages in Lake Victoria, Kenya

A total of 5, 242 cages were documented in the study (Table 3). The majority of the cage investors reported that cages started to operate in the waters in the year 2016. Siaya county recorded the highest number of cages (n = 3,838; 73.2%). The main reason for higher cage culture investment in Siaya County could be attributed to the adoption of cage culture technology from Dominion farm in Siaya County. In addition, the county's modest coverage of water hyacinth (*P*) may have given the room for the establishment of cages without worrying about the destruction of cages by the weed (Aura et al., 2018). Based on the survey conducted by KMFRI in 2018, the current survey revealed an increase in the number of cages in all the counties with Migori County recorded the highest percentage increase (310.5%). This rapid increase could have been caused by the uptake of cage fish farming technology as a result of the dwindling catches from capture fisheries.

Table 4. Distribution of cage culture establishments in the five riparian counties of Lake Victoria, Kenya with their respective number of establishments in March 2022 (Active Cages = Stocked cages as at the time of the survey; Inactive = Abandoned, Awaiting restocking and Undergoing repairs)

County	Beach of operation/No.	Number of cage establishments	Total No. of Cages	Total No. of Active Cages
Busia	**3**	**13**	**478**	**313**
	Rudacho	1	8	5
	Mulukhoba	9	273	195
	Bumbe	3	197	113
Homa Bay	**23**	**42**	**719**	**594**
	Litare	3	11	10
	Lwanda Nyamasare	1	21	8
	Nyandiwa	3	111	78
	Obaria	4	13	12
	Roo	1	300	300
	Alum	2	18	6
	Nyagwethe	1	8	5
	Kaimbo/Akungo	1	2	0
	Kamolo	10	35	22

	Kisaka	1	2	2
	Nyachebe	1	78	60
	Kolunga	1	15	7
	Luanda Rombo	1	5	5
	Uyoga kombe	1	2	2
	Wayando	1	6	4
	Kaugege	2	9	9
	Wakula	2	2	2
	Kitawi	1	13	12
	Mrongo	1	8	8
	Rasira	1	23	18
	Ndhuru	1	9	0
	Likungu	1	26	22
	Kisaka	1	2	2
Kisumu	**8**	**30**	**219**	**199**
	Paga	3	7	7
	Ogal	14	157	140
	Kaloka	2	11	11
	Othany	6	14	11
	Nyamaruaka	1	4	3
	Dunga	2	14	18
	Achuodho	1	9	9
	Rare	1	3	0
Migori	**4**	**14**	**78**	**22**
	Sori	4	9	6
	Matoso	7	22	8
	Oodi	2	46	7
	Bamgot	1	1	1
Siaya	**13**	**28**	**3838**	**3796**
	Nyenye Got Agulu	1	5	5
	Uwaria	4	47	44
	Anyanga	11	3538	3530
	Luanda Disi	1	33	10
	Usenge	1	106	103
	Ugambe	1	6	4
	Utonga	1	11	9
	Kowang'e	1	1	1
	Midori	1	3	3
	Luanda Kotieno	3	43	43
	Kadiala	1	10	10
	Siungu	1	8	7
	Uyawi	1	27	27
Total	**51**	**127**	**5242**	**4824**

About 8% (n = 418) of the cages were dormant at the time of the survey. This was mainly attributed to the recent harvesting of fish in the cages, some cages undergoing repair as part of the regular monitoring plans, abandoned cages and those awaiting restocking. Some of the abandoned cages are shown in figure 2 below.

Figure 2. Plate (a) and (b) showing the abandoned cages in one of the beaches in Lake Victoria, Kenya

3.1.3 General farm operations

The floating cage system is the dominant technology for tilapia production in Lake Victoria with square-metal (n = 95; 79%) and circular-plastic (n = 25; 21%) frames as the major structures reported. The majority of cage investors prefer metal frames due to the improved physical access and more stable working conditions for operations such as changing fouled nets, reducing mortalities, grading, and harvesting. The cages and net materials are locally fabricated (n = 118; 98%) and sourced mainly from Monasa and Kavirondo companies in Kisumu with a few (n = 2; 2%) materials outsourced from China and the Philippines. Cage investment is mainly by individuals (n = 87; 73%) while the remaining are invested by community groups (n = 18; 15%), BMU (n = 5; 4%), Company (n = 5; 4%), Family (n = 4; 3%), and Cooperative (n = 1; 1%).

The only species being cultured was Nile Tilapia, because of its high consumer preference (Musa et al., 2014, Obiero et al., 2014). This could also be attributed to its feeding lower in the food chain, faster growth rate, high disease resistance and high tolerance to varied environmental conditions (Siddick et al., 2014, Amin et al., 2019 and Mahmoud et al., 2021). Most of the tilapia farmers stocked mono-sex fingerlings (n = 104; 88%) with a few reporting mixed sex, suggesting inefficient sex reversal. This could also be as a result of cages attracting wild fish who forage and breed around these areas. The cage fish farmers mainly sourced their seed from Jewlet (62.7%). The respondents attributed this to high quality seeds from the farm. The other hatcheries which provided seeds included Wakhungu hatchery, Hydro-fish farm, Lake View, Victory, George Muga farm, Elvis farm, Ogal, Great Lakes, and Dominion. Some farms owned hatcheries hence produced their own seeds while other farmers sourced fingerlings directly from the lake mainly due to insufficient financial resources.

3.1.4 Types and sources of feeds

Cage farmers relied mainly on three different categories of feeds: floating, sinking, and slowly sinking. Some farmers were unsure of the feed types they were using in the cages. Floating feeds are highly recommended for feeding tilapia since they are easier for the fish to pick (Aura et al., 2018). Fish feeds were mainly bought from Unga feeds (n = 72; 60%), Jewlet (n = 15; 12.4%), and Great Lakes (n = 8; 6.3%). The high preference of feeds from Unga feed was due to high quality of feeds. Other sources of feeds included KMFRI, Sigma, National Growers limited company, and Livestock feed company. Some farms like Victory, Global Tilapia, and Rio farms imported some of their feeds from Aller Aqua feed company in Zambia, Skretting in Egypt and Laguna feeds in Brazil. These farms cited a lack of quality feeds locally as the main reason for importing their feeds. Also, some mentioned that due to the increased number of farmers, the feed supplying companies could not keep up with the feed production pace hence delays in getting timely feeds. Other small-scale farmers opted to use home-made feeds such as dried freshwater shrimp (*Caridina*) citing high feed prices. The feeds had protein content ranging from 40% - 28% with varying average prices at KES. 122.45 to 173.90 per Kg from starter to grow-out feeds (Table 5).

Table 5. Average prices per kilogram (kg) for different feed types used in cage fish farming as at March 2022.

Feed type	Growth Stage	Crude Protein	Price (KES) per Kg
Starter (Powder)			
Marsh	Fingerlings	39.5	173.9
Grower (Pellets)			
2mm	Post fingerlings	35.2	146.07
3mm	Juveniles	32.4	131.75
4mm	Mature	28.36	122.45

3.1.5 Cage farm employees

Cages have employed different kinds of workers including youths, males, females, and the vulnerable and marginalized groups (VMGs) (Figure 2). The majority of the employees were men probably due to the labor-intensive system required in cage management. The women were mainly employed as casual laborers during fish harvesting. Men and youth were employed as feeders, security personnel, and managers. Very few marginalized and vulnerable groups were considered as employees in cages which raises concerns over the inclusivity of such groups in modern industries. VMGs are still susceptible to unemployment and underemployment which calls for innovative pathways to employ these minority groups in cages aquaculture.

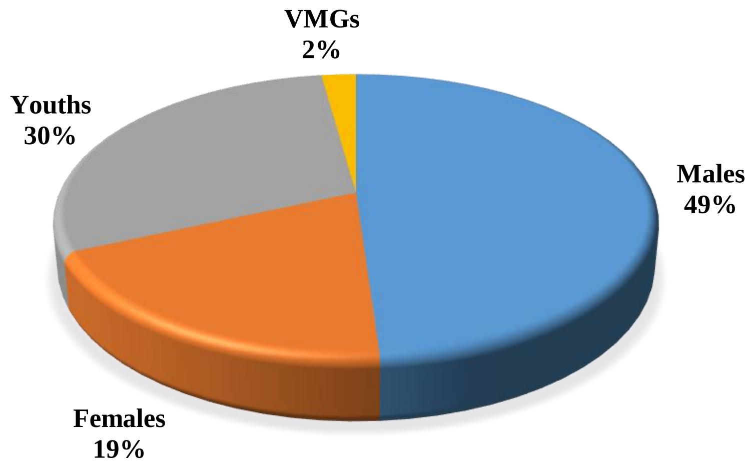


Figure 3. Cage culture employee dynamics in Lake Victoria, Kenya.

3.1.6 Carrying capacity and estimated annual production of cage culture

Based on the estimated most suitable site for cage culture of approximately 190 km^2 (Aura et al., 2021), this area can produce 109,000 mt on a sustainable basis (Table 6). To account for the distance of the constraints from the shoreline and the potential impact on the lake ecosystem, a precautionary of 0.05 percent was used. The carrying capacity is estimated to be more than 500% of the current cage culture production, which is estimated to be 21,000 mt (Table 7). Notably, best management practices, as well as regular monitoring and research, as well as adherence to regulatory mechanisms alongside commercialized systems, are required to reach the estimated carrying capacity.

Table 6. Calculations towards the estimated carrying capacity of Lake Victoria, Kenya

Demand side	**Without accounting for population growth**			
	Units	**Ballpark**	**Notes**	**Actual**
Population of Kenya	Millions	50000000	Wikipedia	53770000
Fish consumption per capita	kg ind-1 y-1	5	FAO	
Food security target	kg ind-1 y-1	20	FAO world average	
Shortfall	kg ind-1 y-1	15		
Total annual need	ton y-1	750000		
Supply side				Bottom up
KMFRI assessment (zoning)	km2	190	Available for aquaculture	Lake area
Typical density at harvest (tilapia)	ind m-3	20	Reported by farms	% Kenya
Typical harvest weight	g per fish	350	Reported by farms	% Aquaculture within Kenya
Culture duration	days	180	Reported by farms	Aquaculture area
Cage depth	m	8.1	Average cage depth	
Harvest weight per unit area	kg m-2 y-1	114.975		
Precautionary factor for zoning	no units	0.005	0.5% precautionary factor	
Potential total annual harvest	ton y-1	**109,226.25**		
Mass balance				
Food security	extra kg ind-1 y-1	2.184525	Raw production biomass	
		0.6	40% losses	
		1.310715		

Table 7. Estimated annual production of cage culture in Lake Victoria as at May 2022.

Item	Units	Value
Largest firm production per week	mt	60
Per week	days	5
Weeks in a month	week	4
Months	months	12
Annual production	mt	14400
Production by large firms (80% of total)	%	1.2
Total production by large firms		17280
Production by small firms (20% of large)	%	1.2
Annual production estimate	mt	**20,736**

3.1.7 Financial implications and commercialization concept of cage fish farming

Depending on the scale of operation, the dimensions of the cages varied greatly among investors (Table 6). The metal frame cages ranged from [2x2x4] meters to [10x10x4] meters while plastic cages ranged from 10meters to 18meters in diameter. Various cage farmers prefer different cage sizes and materials due to individual financial capacities for cage investment. In freshwater systems, cage systems are typically limited to 15m^2 (metallic) frames to allow for more access and control as well as more extensive husbandry practices like grading, fish movement, vaccination, and net change (Halwart et al., 2007). The stocking density varied depending on the size of the cage. At harvesting time, the fish stock density was relatively lower due to the effects of prevailing conditions that could lead to fish mortalities and escapees during the cycle. However, some farmers reported increased number of fish during harvesting as a result of influx of wild tilapia who breed around the cage areas. The estimated cost of production and the gross margin for the various cage sizes in the current study suggest that cage aquaculture is an economically viable business.

Table 8. Perceptions of cage culture farmers on initial capital investment per production cycle in Lake Victoria Kenya in March 2022. Asterix (*) means related cost for establishment.

Cage size	**2*2*2**	**3*3*2**	**3*3*2.5**	**5*5*2.5**	**6*6*4**	**6*6*6**	**10*10*4**	**10m diameter**	**18m diameter**
No. of fish stocked per cage	1793	1742	3000	5100	10246	7513	13750	36500	15400
Average price of fingerlings at stocking	4.5	5.0	3.9	4.7	4.6	4.6	6.3	6.8	6.7
Size of the fingerling (g) at stocking	2.0	1.4	1.1	2.8	3.0	3.4	1.6	5.2	0.6
Survival Rate (%)	50	75	80	88	91	91	88	91	95
Time taken to harvest (months)	10	10	11	9	9	9	9	8	10
Amortized cage – cost of construction *	69,285.71	53,000.00	158,000.00	134,507.50	269,892.00	268,453.13	305,000.00	800,000.00	176,666.67
Cost of fingerlings	11,980.77	7,100.00	11,812.50	24,175.00	50,233.95	37,991.79	68,500.00	249,750.00	117,133.33
Cost of feeds	53,392.31	35,200.00	84,675.00	14,4605.00	257,567.70	228,722.92	450,000.00	1,350,000.00	143,333.33
Cost of labor	38,111.11	35,600.00	61,500.00	69,031.58	60,317.10	58,697.43	98,500.00	59,500.00	75,000.00
Cost of transport	8,322.22	23,133.33	30,850.00	47,889.41	28,052.27	25,226.19	20,000.00	22,500.00	18,000.00
Cost of security	15,400.00	5,000.00	4,833.33	31,797.22	38,826.42	12,859.09	15,062.50	8,800.00	122,000.00
Other input e.g extension	13,200.00			11,950.00	15,563.16	8,094.44	3,000.00		
Total Production Cost	171,625.00	147,780.00	350,662.50	440,581.00	62,9114.13	60,1945.22	95,7812.50	2,490,550.00	611,466.67
Quantity (Number) of fish harvested	893	1300	2400	4465	9331	6822	12138	33250	14667
Price per kilo of fish	314.17	300.00	295.00	302.50	339.58	294.32	337.50	325.00	333.33
Total weight at Harvest (Kg)	886.5	841.2	1,682.5	2,474.2	4,939.2	4,897.3	7,237.5	16,500.0	12,000.0
Value of fish per harvest (Ksh)	268,490.83	252,360.00	467,000.00	746,370.00	1,585,207.17	1,456,429.30	2,401,875.00	5,400,000.00	3,933,333.33
Net profit	64,349.29	104,580.00	116,337.50	305,789.00	920,690.67	828,416.68	1,444,062.50	2,909,450.00	3,321,866.67

3.1.8 Cage fish Marketing

The harvesting cycle for cage fish was 1 year per cage. At harvesting, the preferred fish market size was 0.35 kg although the sizes ranged between 0.1 kg and 0.8 kg depending on the prevailing market demand. The average weight of fish at harvesting was 0.5 kg, but ranged from 0.2 kg to 1 kg with an average market price ranging from KES. 81.25 per kg for size 2 (0.2 - 0.25 kg) to KES. 353.00 for size 10 (> 1 kg). The harvested fish was mainly sold as fresh and whole to small-scale traders (n = 50; 43%) and directly to consumers (n = 28; 24%) with few being sold to hotels (n = 15; 13%), large-scale traders (n =14; 12%), and companies (n = 9; 8%). Fish consumers preferred fresh and whole fish (n = 94; 78%) to other forms (gutted, discaled, fried), although some investors like victory farms opted to sell their fish as fresh descaled and gutted to promote fish consumption. The bio-waste from gutted fish was disposed off by burying in the ground a few meters from the farm. The main market destinations for the harvested fish were major towns within the riparian counties including; Kisumu, Homa Bay, Kisii, Bondo, Bumala, Migori, Sori, Mbita, Busia, Oyugis, and far markets in Nairobi and its environs. The farmers also indicated that the harvested fish was sold to the local communities at affordable prices depending on preferred fish sizes. Some of the established farms mainly transported the harvested fish to market outlets using vehicles (trucks) while a majority of small-scale traders used motorbikes and foot as shown in figure 4.

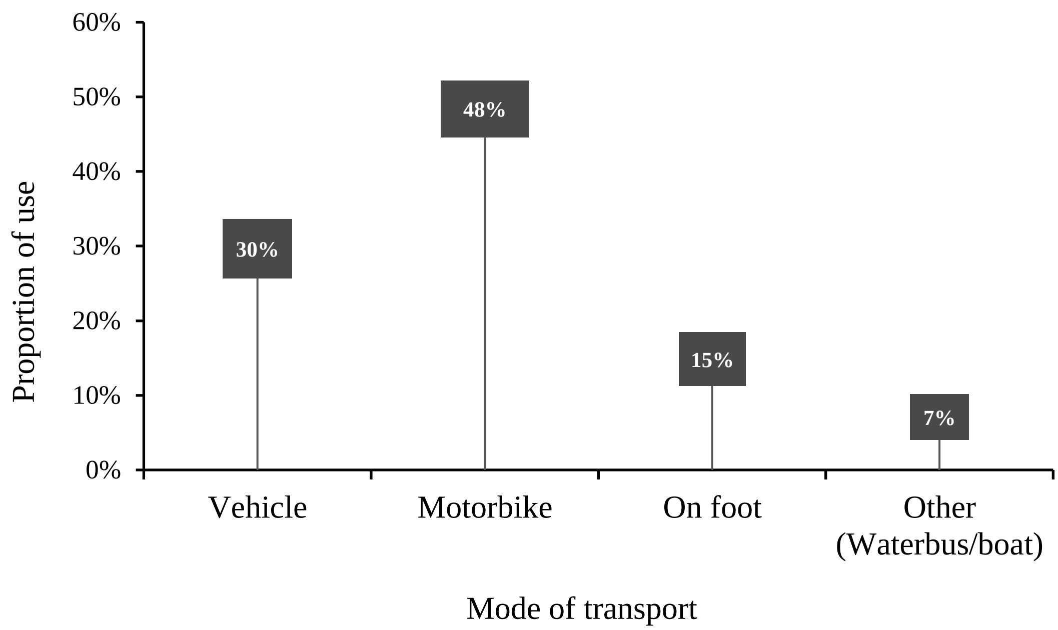


Figure 4. The major modes of transport used for the transportation of fish harvested from cages in Lake Victoria, Kenya.

3.1.9 Cage monitoring

Water quality monitoring was carried out by 37% (n = 22) of cage fish farmers. Monitoring was done daily (27%), weekly (14%), or monthly basis (59%). Farmers monitor the water to determine the current PH, temperature, and turbidity levels for improved fish performance. The main equipment and methods used for monitoring water quality included thermometers, watercolor observation, and PH probes. Approximately 80% (n = 48) of cage fish farmers sampled their fish monthly (85%), annually (6%), quarterly (4%), or weekly (4%). Fish sampling was mainly done to monitor fish growth rate, feeding ratio, and fish health. The main equipment used in the sampling included the scoop net, weighing machine, and ruler for assessing weight and length variables. Cage fish farmers who did not perform cage monitoring cited a lack of knowledge and equipment, or were not aware of monitoring necessity.

3.1.10 Cage fish management

Few farmers (n = 38; 32%) experienced about 20% of losses as a result of delays in selling fish after harvesting. However, the majority of the farmers (n = 80; 68%) indicated that they only sold fish by order hence no post-harvest losses were incurred. The post-harvest losses were managed by storing fish in ice and also by limiting the number of fish harvested. Many were aware of the fish post-harvest handling technologies including icing, and use of cold storage, although only (n = 52; 43%) were using these technologies. About 42% (n = 50) of the farmers reported fish escapees as a challenge to cage productivity. These were hugely attributed to predators like the otter and Nile perch which would occasionally tear the nets leading to fish escapes. Such escapees were reported to occur annually (65%) with 35% reporting monthly fish escapees. These attacks have, however, been managed by using anti-predator nets around the cages that have since reduced fish escapees.

Fish mortalities were reported by 79% (n = 95) of farmers and this often occurred daily (29%), weekly (16%), and monthly (35%) with others experiencing mortalities once during harvesting (19%). Farmers attributed this to fish handling during sampling and the closeness of cages that might transfer diseases and parasites to their cage farms. Most of the farmers use metal cages that are physically attached which could reduce water exchange in some cages. During periods of low oxygen, limited water exchange may exacerbate negative effects on growth rates, increasing variability among cages (Halwart, 2007). Cage location could also be a factor determining the survival of fish. A depth of 6-12 meters is the most suitable cage site with a high-water current for the removal of waste (Aura et al., 2020). However, the cage depths varied with an average depth of 5.6 meters in Busia County and 21.4 meters in Homa Bay County. Majority of the reported fish kills were in Homa Bay County (n = 31; 33%) probably due to the reported cage depth. Cages in Homa Bay County were installed at high depths which are unsuitable for cage siting due to strong currents that can damage the cage culture structure.

3.1.11 Extension services for cage fish farming

About 57% (n = 35) of cage farmers indicated that they occasionally receive extension services from organizations such as Non-Governmental Organizations (n = 14; 40%), Kenya Fisheries Service (n = 9; 26%), Kenya Marine and Fisheries Research Institute (n = 6; 17), County Fisheries Officers (n = 4; 11%) and National Environment and Management Authority (2; 6%). These agencies usually offer training and capacity building on best management practices for aquaculture. Kenya fisheries service (n = 26; 52%), NEMA (n = 16; 32%), and County governments (n = 8; 16%) were the main agencies consulted during cage installation and were also cited as being responsible for the issuance of various certifications for to cage investors.

3.1.12 Constraints to cage aquaculture

Climate change is a global production risk and a major danger to the aquaculture sector's sustainability due to its influence on production such as fish survival, growth, and reproduction (Hamdan et al., 2015). Generally, the reported climate change effects on cage aquaculture were increased winds (27%), waves (27%), water hyacinth (23%), temperatures (10%), algal bloom (9%), and floods (3%) (Figure 4). However, the impacts of these factors on cage production differed depending on aspects such as aquaculture practice systems, space, time, and production scale. Other constraints to cage culture included: lack of quality inputs, lack of extension services, lack of knowledge and skills in aquaculture, and theft. Farmers who cited theft of fish as a major challenge reported having undertaken security measures on their farms including the employment of security guards, locking cages, installing security lights, and conducting patrols around the cages. The additional cost on cage security has financial implications which have made some farmers to stop cage operations.

Risks to cage aquaculture included insecurity, illegal fishing gears used near the cages which cause stress to fish, strong winds in open waters that cause the drowning of cage workers and drifting of cages, high predation, human-wildlife conflicts, and floating island that seasonally destroy cages. Despite these challenges, farmers reported opportunities in cage aquaculture as clear open waters in some areas that provide suitable sites for installing cages, increased fish demand and ready fish markets, support from NGOs and local governments, availability of raw materials for cage construction, and readily available labor.

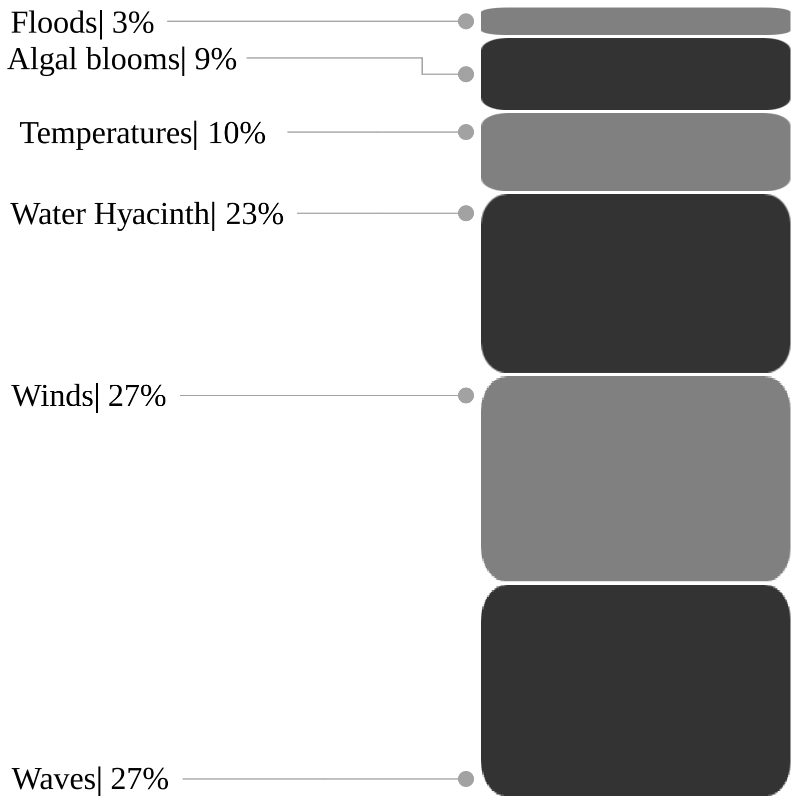


Figure 5. The main effects of climate change on cage aquaculture in Lake Victoria, Kenya

3.1.13 Perceptions of cage aquaculture

Cage fish farming has become a significant part of the fish value chain, as well as an important part of the local fisheries story. Unlike capture fisheries, most farmers believed that fish farming provided better returns and was more predictable in terms of the expected harvest. Cage farming is quickly becoming a valued alternative livelihood source for fishing communities and other value chain actors, with 74.1 % of farmers and local communities agreeing that it is a successful business. Inputs such as high-quality feeds and seeds, on the other hand, were generally not readily available in their areas of operation (Table 7).

Table 9. Cage fish farmers and local community perceptions on cage aquaculture in Lake Victoria in March 2022

	N	**Satisfaction Index**	**Satisfaction (%)**	**Rating**
Cage farmers				
Fish feed is readily available in this area	119	2.65	52.9	Neither
Sometimes I cannot afford food to feed my family or myself	118	2.89	57.8	Neither

Cage Aquaculture is a highly risky practice	118	3.48	69.7	Agree
I would encourage my friends and family to participate in cage aquaculture	118	4.42	88.5	Strongly Agree
High-quality fingerlings are readily available in my area	119	3.03	60.5	Neither
Aquaculture helps to conserve natural resources in the lake	118	4.16	83.2	Strongly Agree
Aquaculture is an economically viable and profitable activity	119	4.56	91.3	Strongly Agree
Community				
Good feeling about cage aquaculture in my area	47	4.53	90.6	Strongly Agree
Farmed fish are less delicious than wild-caught fish	47	3.23	64.7	Agree
Cage culture helps to conserve natural resources in the lake	47	3.77	75.3	Agree
The community readily gets fish from cages in this area	47	4.06	81.3	Strongly Agree
Cage fish is very affordable to the community in this area	47	4.00	80.0	Strongly Agree
Cage aquaculture has employed the community in this area	47	4.45	88.9	Strongly Agree

3.2 Physico-chemical parameters

Results of physical and chemical measurements across all the sampled cage sites in Busia, Siaya, Kisumu, Homa Bay, and Migori counties, respectively have been summarized by box plots depicting the spatial variations down the transects. The data points along the transects bear a composite of column water physical-chemical data at the onshore edge of the cage station (A), the midpoint of the cage field (B), the offshore edge of the cage station (C) and a far offshore reference point referred to as Control in all cases. This array of transect sampling points applies to all cases except for a few sites where the control station was not sampled due to safety constraints. However, in those sites which comprise mostly large cage farms, point C suffices to reveal a gradient for comparison to assess the spatial influence of the cage on the surrounding ecosystems.

There were marked spatial variability in water physico-chemical variables in all stations within Mulukoba cage farm site in Busia County, whereby a gradual trend is apparent from the examination of the visualization box plots charts for each parameter. Of most prominence in such trend is DO which increased dramatically down the transect to the control sampling station, while pH exhibited the reverse trend. Low DO levels in the cage culture sampling stations were attributed to increased consumption of DO by the cultured fish and the decomposition of the organic waste (Longgen et al., 2009) The patterns of spatial variabilities down the sampling transects of physical and chemical attributes as registered at Mulukoba was observed across most of the sites and stations in all the cages sites sampled in the riparian counties of Lake Victoria. Other water quality parameters measured are within normal ranges for fish growth (Boyd, 2008) and within the range of values previously reported in recent studies in Lake Victoria (Mwamburi et al., 2020; Simiyu et al., 2021; Deirmendjian et al., 2021).

There was no clear gradient trend in DO and pH due to the effects of cages (Figure 6 & 7). Lack of significant difference in DO along the gradient could be attributed considerable water exchange within the lake. However, lack of significant difference in pH along the gradients could be could be attributed to buffering effects due to high alkalinity in the lake (Musa et al., 2022).

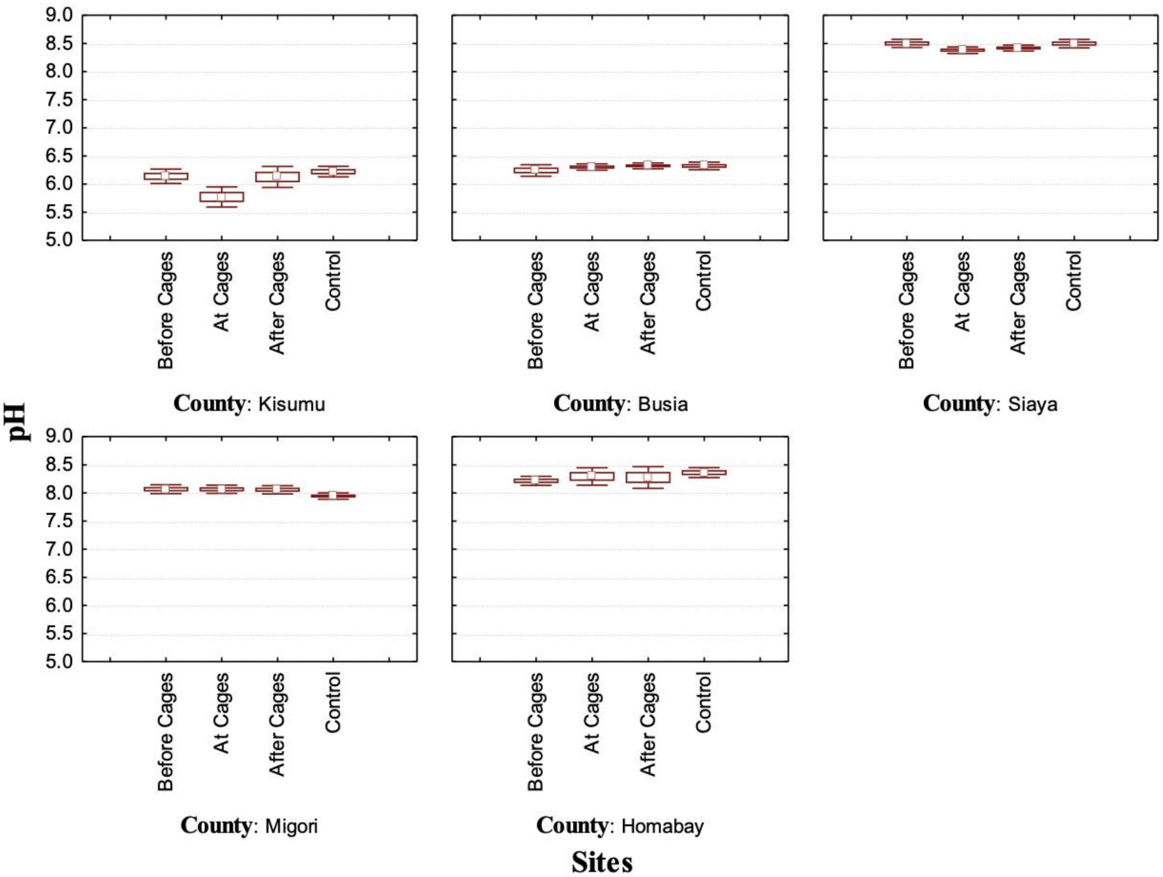


Figure 6: pH (mean ± SEM) at a cage culture sites in Lake Victoria, Kenya (SEM = Standard Error Margin)

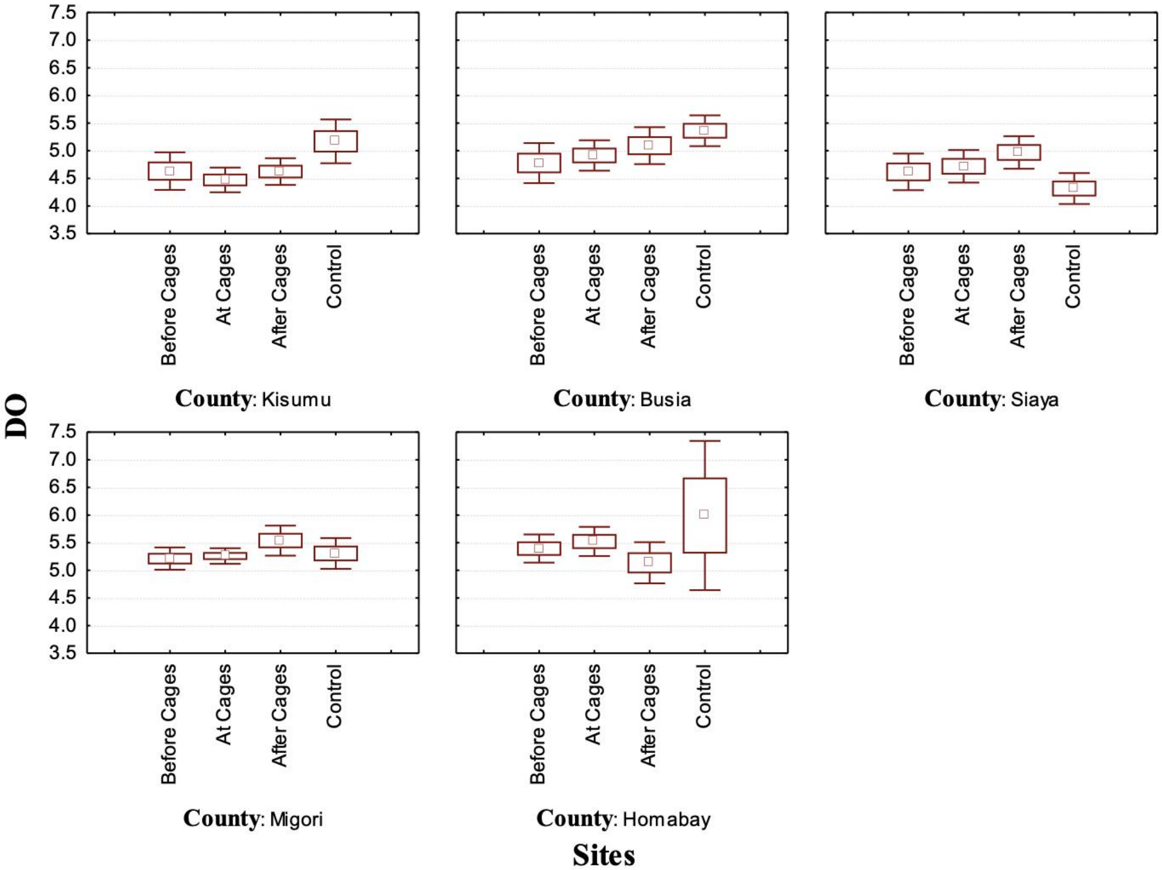


Figure 7: DO (mean ± SEM) at a cage culture sites in Lake Victoria, Kenya (SEM = Standard Error Margin)

Higher variabilities were registered in Homa Bay county cages where the water column depth was highest than the stations close to the open waters, hence prone to enhanced dilution and higher circulation (Table 8). Water temperatures at all cage station remained generally warm at above 25^{o}C (Table 1). Highest mean water column temperatures (28.06 ± 0.10 ^{o}C) were recorded at Oele Nyenye Got Agulu in Siaya County, while the lowest temperature (25.76 ± 0.05 ^{o}C) was recorded at Uyoga Kombe in Migori County. Generally, the cage sites of Siaya County had the warmest waters. Most of the sites recorded dissolved Oxygen (DO) levels above the critical DO for fish survival of 4 mgL^{-1} except Uyawi (3.99 ± 0.22 mgL^{-1}) and Uwaria (3.35 ± 0.29 mgL^{-1}). The highest DO levels of 8.97 ± 13.66 (mgL$^{-1)}$) were recorded at Obaria Beach site in Homa Bay County (Table 8).

Table 10. Summaries of water column physical attributes (Mean±SD) of the cage sites in all riparian counties of Lake Victoria Kenya in March 2022

Site	Temp (ºC)	DO (mg/L)	Cond (µS/cm)	TDS (mg)	Sal (ppm)	Ph	ORP (mV)	Secchi (m)
Busia								
Bumbe	27.7±0.09	5.33±0.15	71.31±0.89	43.96±0.54	0.03±0.00	6.27±0.16	163.66±12.69	0.98±0.04
Mulukoba	27.70±0.17	5.23±0.70	157.90±103.89	99.42±64.38	0.06±0.05	6.40±0.12	167.53±12.04	1.22±0.04
Rudacho	27.46±0.26	4.64±0.85	173.97±59.83	101.55±39.26	0.07±0.03	6.23±0.12	149.96±13.16	1.23±0.05
Homa Bay								
Alum Beach	27.15±0.28	5.29±0.49	143.10±0.81	89.21±0.31	0.06±0.00	7.92±0.09	145.75±0.79	0.80±6.51
Alum Beach	27.08±0.62	5.42±0.59	143.39±0.62	89.33±0.29	0.06±0.00	7.79±0.22	119.71±9.63	13.40±0.17
Global Tilapia	27.00±0.00	5.56±0.28	105.96±0.25	66.30±0.00	0.05±0.00	8.31±0.06	78.79±7.17	1.90±0.07
Humanist	27.71±0.18	6.45±0.32	106.90±0.26	56.31±0.05	0.10±0.15	8.42±0.06	88.78±7.04	2.25±0.14
Humanist	27.63±0.17	6.39±0.19	106.70±0.47	56.23±0.22	0.10±0.15	8.49±0.01	84.28±1.30	2.10±0.28
Jack Port	26.89±0.08	5.72±0.48	103.22±0.23	65.00±0.00	0.05±0.00	8.34±0.25	78.42±3.57	2.70±0.00
Kisaka Beach	27.00±0.56	6.46±1.02	146.52±2.12	91.72±0.56	0.06±0.01	8.53±0.28	66.46±19.99	1.40±0.09
Kitawi	26.98±0.47	4.53±2.12	100.20±4.93	60.52±8.07	0.05±0.00	8.59±0.16	96.83±16.96	2.60±0.10
Kitawi	26.79±0.21	5.18±1.54	97.09±5.92	60.61±7.67	0.05±0.00	8.19±0.77	285.98±153.60	2.30±0.49
Kiwa Island	27.09±0.48	6.06±0.60	104.84±0.80	65.63±0.11	0.10±0.14	8.61±0.15	59.36±8.21	2.10±0.57
Lake View	27.34±0.74	2.66±1.60	99.17±5.70	58.64±9.75	0.05±0.00	8.28±0.74	186.80±101.02	3.30±0
Litare Beach	27.01±0.63	6.07±0.57	105.81±0.67	66.30±0.09	0.08±0.11	8.28±0.05	95.31±4.38	2.80±0.14
Litare Beach	26.94±0.34	5.48±0.87	105.50±0.81	66.00±0.49	0.05±0.00	7.89±0.33	99.69±18.31	2.50±0.14
Lwanda Gembe	25.96±0.64	5.36±0.59	117.03±1.26	75.18±0.98	0.05±0.00	7.98±0.05	92.20±10.57	2.00±0.00
Mrongo	27.01±0.68	3.66±2.65	99.70±5.43	61.44±10.09	0.05±0.00	8.21±0.77	161.93±97.87	3.21±0.14
Mrongo	26.93±0.62	4.01±2.93	99.47±5.60	59.13±9.14	0.05±0.00	8.47±0.20	107.41±15.08	3.00±0.42
Ndhuru Beach	26.84±0.50	6.38±1.13	144.40±1.75	80.23±28.64	0.06±0.00	8.40±0.21	69.83±7.95	1.00±0.07
Nyandiwa	26.96±0.06	5.58±0.33	104.95±0.31	65.58±0.19	0.05±0.00	8.59±0.08	72.09±4.88	2.03±0.00
Obaria Beach	26.70±0.20	8.97±13.66	153.88±0.43	96.87±0.41	0.07±0.00	8.04±0.06	107.05±19.33	0.75±0.28
Obaria Beach	26.80±0.00	4.96±0.08	154.54±0.59	97.04±0.73	0.07±0.00	7.01±2.82	96.42±1.98	0.80±0.00
Rasira	27.40±0.48	6.17±0.48	105.74±1.93	65.73±0.66	0.07±0.10	8.64±0.21	66.93±6.63	2.20±0.00
Rasira	27.42±0.47	6.57±0.58	105.77±1.99	65.75±0.60	0.10±0.15	8.69±0.14	63.06±5.88	2.90±0.61
Victory Farm	26.67±0.05	5.87±0.34	102.20±6.94	65.00±0.00	0.10±0.14	8.09±0.91	69.59±5.37	2.60±0.00

Wakula Site	26.52±0.19	8.02±0.16	91.17±0.53	45.60±0.15	0.05±0.00	8.25±0.23	-	2.13±0.26
Kaugege	26.16±0.15	5.82±0.19	96.11±2.61	76.04±1.90	0.05±0.00	8.06±0.09	80.76±3.73	1.23±0.20
Luanda Rombo	26.37±0.07	5.12±0.20	98.38±3.18	68.29±0.57	0.05±0.00	8.19±0.04	60.95±5.10	1.83±0.55
Uyoga Kombe	25.76±0.05	4.88±0.24	106.94±1.09	72.34±0.79	0.05±0.00	8.00±0.05	71.77±4.03	1.62±0.02
Wayando Beach	26.47±0.10	5.12±0.12	98.40±0.37	68.03±0.32	0.05±0.00	8.19±0.09	49.13±9.12	1.83±0.05
Kisumu								
Achuodho	27.33±0.08	4.30±0.46	130.65±64.55	77.61±37.93	0.06±0.03	5.81±0.13	143.41±5.95	0.84±0.05
Dunga	26.28±0.40	4.73±0.49	88.76±0.60	56.57±0.48	0.05±0.02	5.96±0.31	149.39±10.45	0.85±0.05
Ogal	27.17±0.38	5.28±0.83	91.86±19.24	94.61±65.23	0.04±0.00	6.29±0.21	169.97±10.77	0.91±0.04
Othany	27.14±0.10	4.90±0.59	88.54±0.69	55.92±2.54	0.04±0.00	6.21±0.10	150.29±5.68	0.78±0.05
Migori								
Bam Got	26.60±0.19	4.74±0.13	89.94±0.40	44.88±0.29	0.05±0.00	7.65±0.19		1.25±0.09
Matoso Station	27.29±0.16	5.04±0.08	92.00±0.22	45.92±0.10	0.05±0.00	8.06±0.09		0.79±0.17
Oodi Beach	26.98±0.40	4.75±0.05	89.94±0.47	44.97±0.31	0.05±0.00	7.73±0.21		1.93±0.46
Sori Beach	27.93±0.17	5.06±0.28	94.31±0.59	47.24±0.43	0.06±0.01	8.20±0.16		0.58±0.12
Siaya								
Anyanga	27.26±0.56	5.65±0.60	104.30±1.01	65.13±0.38	0.05±0.00	8.49±0.14	-130.67±11.30	0.94±0.04
Lwanda K'Otieno	26.43±0.24	3.87±0.31	112.58±1.05	71.36±0.30	0.05±0.00	8.40±0.13	-141.26±7.86	0.82±0.07
Nyenye Got Agulu	28.06±0.10	6.37±0.58	109.06±1.07	66.92±0.47	0.05±0.00	8.95±0.02	-145.35±12.81	
Oele	27.97±0.17	3.64±0.26	106.80±0.88	65.79±0.44	0.05±0.00	8.35±0.23	-197.89±225.51	0.56±0.05
Usenge	27.47±0.10	4.86±0.71	106.57±0.76	66.22±0.64	0.05±0.00	8.70±0.18	-117.23±6.16	0.81±0.05
Uwaria	26.97±0.34	3.99±0.22	104.03±0.53	64.98±0.16	0.05±0.00	8.35±0.22	-136.74±15.42	0.78±0.10
Uyawi	26.74±0.22	3.35±0.29	103.15±0.38	64.85±0.61	0.05±0.00	8.42±0.24	-152.62±6.17	1.00±0.00

3.3 Nutrients

The nutrient species analysed included Ammonium (µgL$^{-1)}$),) Total Nitrogen (µgL$^{-1)}$), Soluble Reactive Phosphorous (µgL$^{-1)}$), Total phosphates (µgL$^{-1)}$), and silicates (mgL$^{-1)}$). This section also presents results on water alkalinity (mgL$^{-1)}$), Hardness (mgL$^{-1)}$), and Chlorophyll- a (µgL$^{-1)}$) concentrations. The gradual variation observed on the chemical parameters are presented in the following county specific plots.

There was no clear gradient trend in concentrations of nutrients due to the effects of cages (Figure 8 - 11). A number of factors could contribute to this such as flushing effects from the lake water and nutrients being rapidly sequestered into algae (Musa et al., 2022).

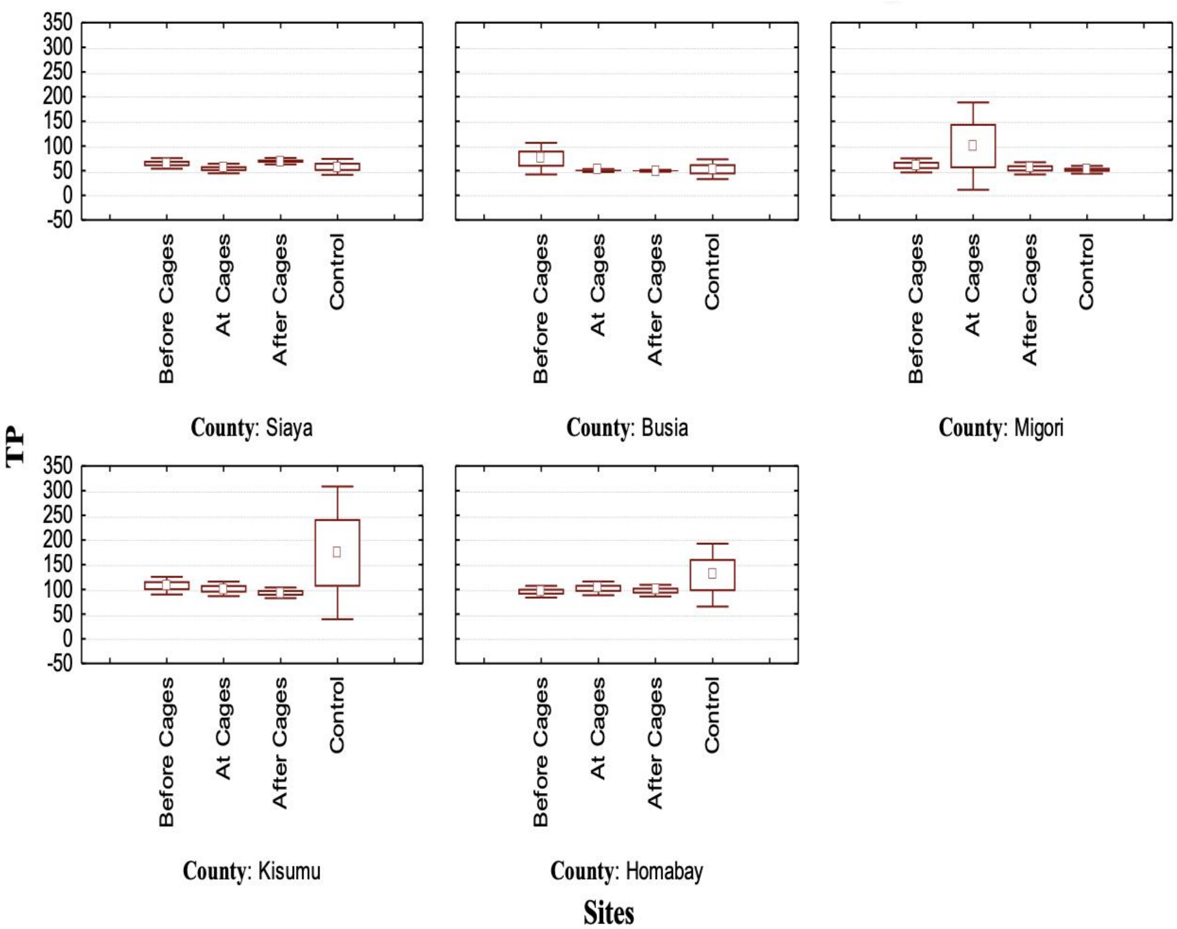


Figure 8: Total phosphorus (mean ± SEM) at a cage culture sites in Lake Victoria, Kenya (SEM = Standard Error Margin)

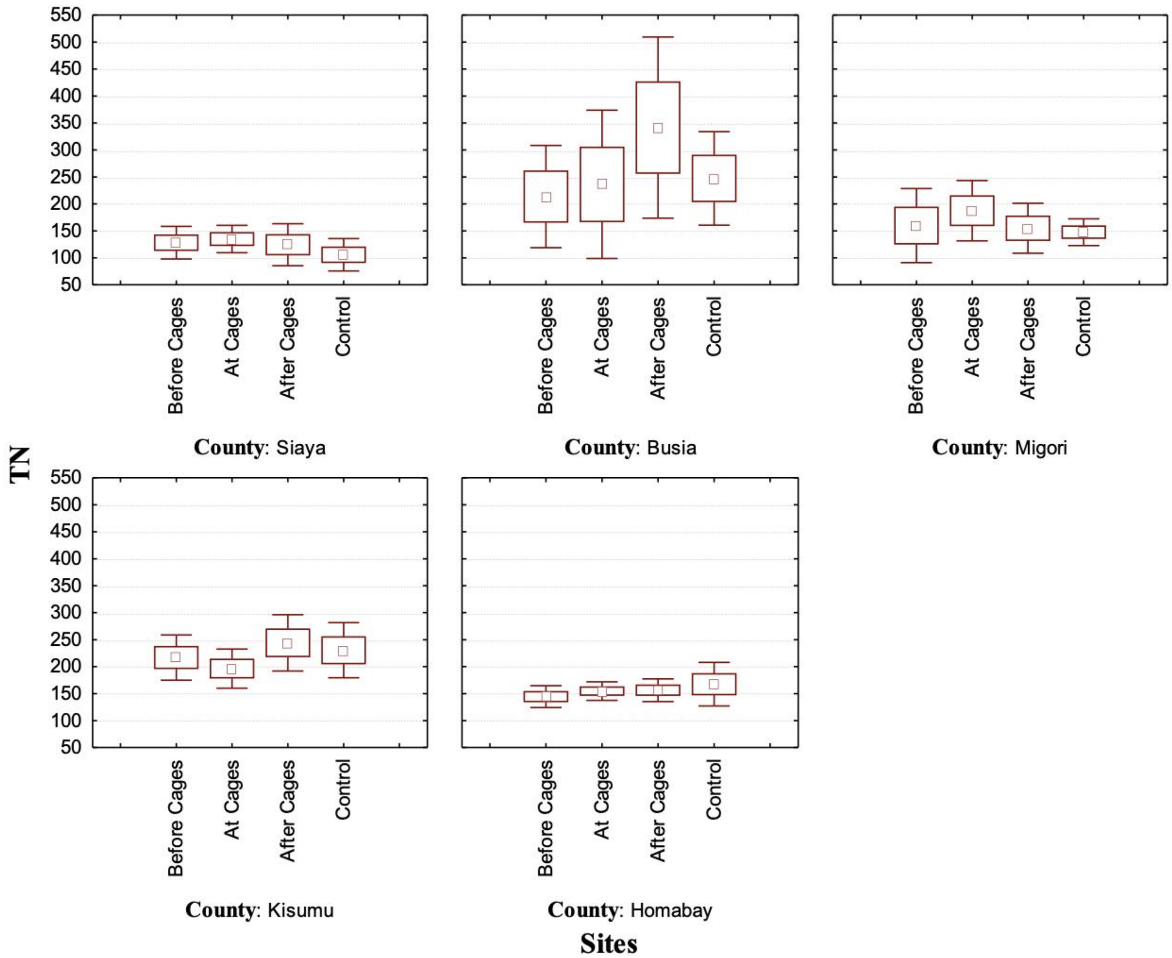


Figure 9: Total nitrogen (mean ± SEM) at a cage culture sites in Lake Victoria, Kenya (SEM = Standard Error Margin)

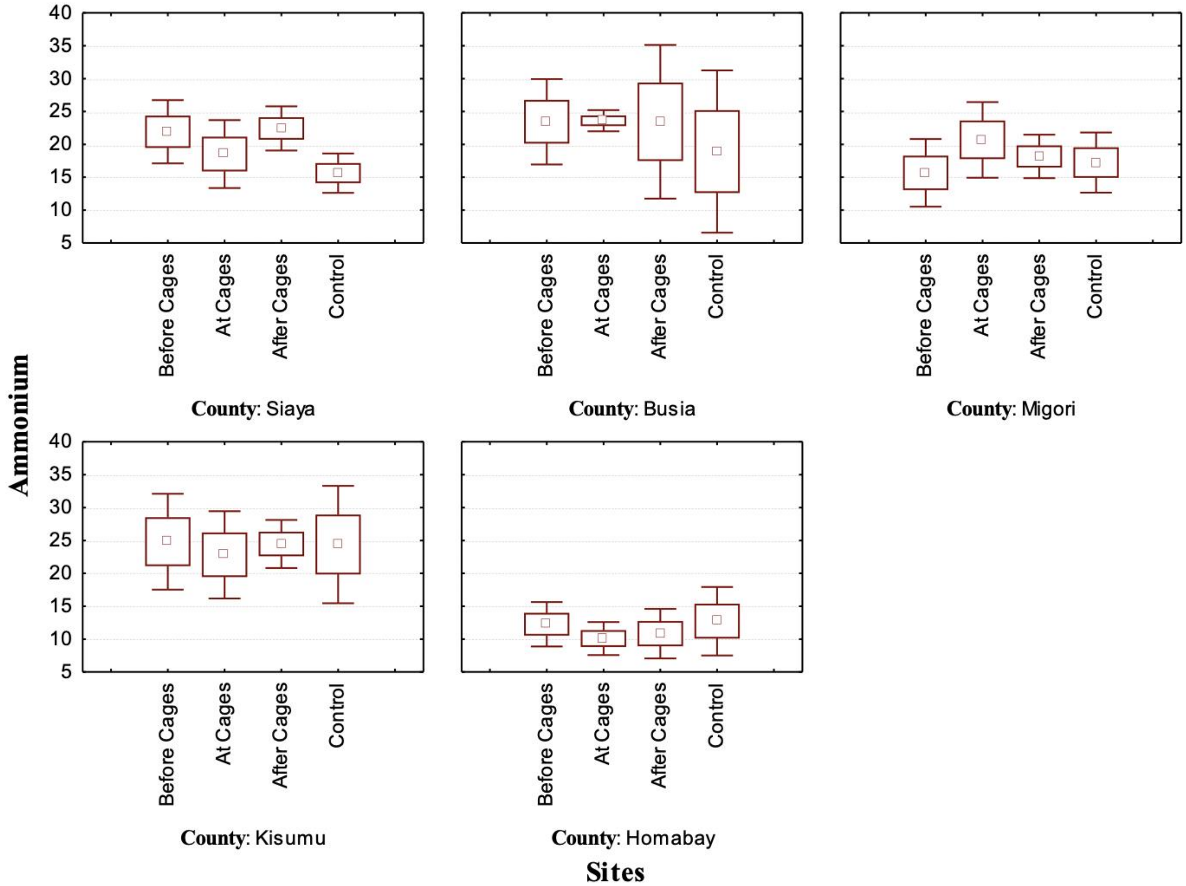


Figure 10: Total ammonia (mean ± SEM) at a cage culture sites in Lake Victoria, Kenya (SEM = Standard Error Margin)

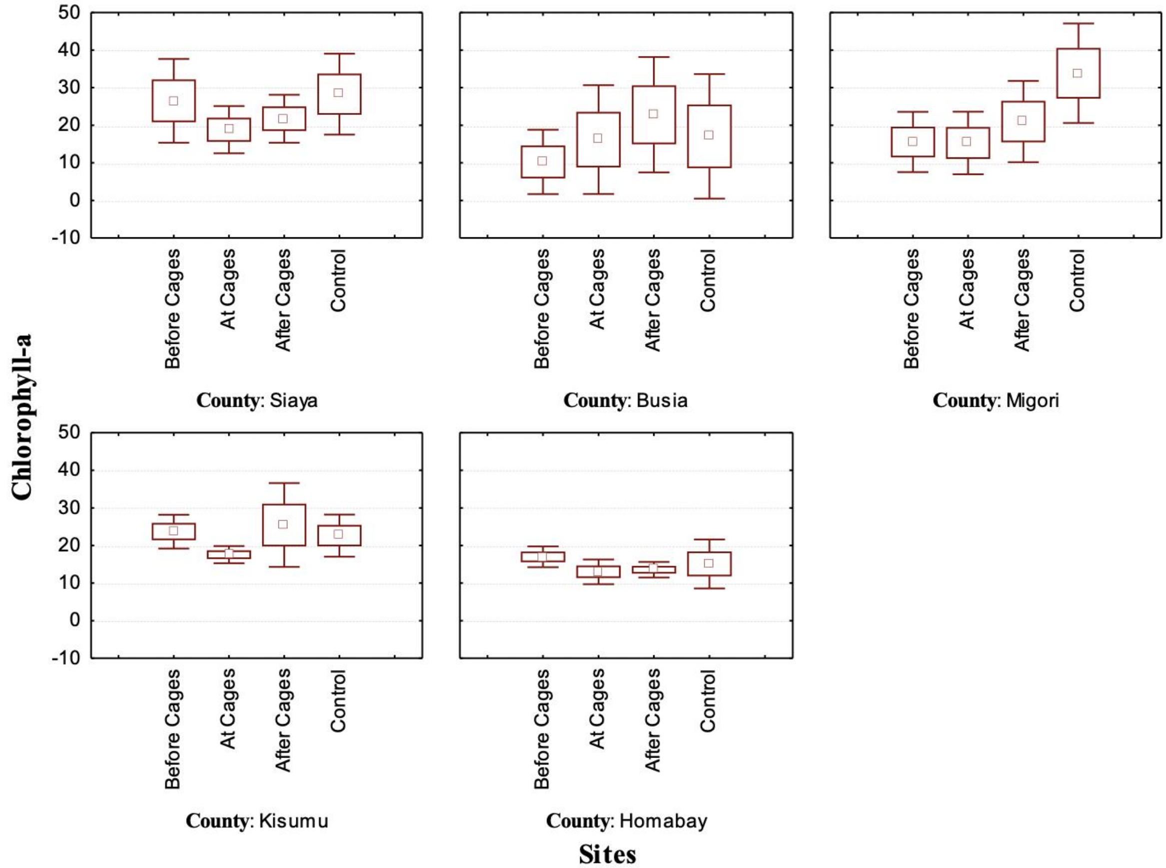


Figure 11: Chlorophyll a (mean ± SEM) at a cage culture sites in Lake Victoria, Kenya (SEM = Standard Error Margin)

By comparison, Othany cage station in Kisumu County recorded the highest Nitrite concentrations (30.67 ± 3.54 µg/L) while the lowest concentration of 12.33 ± 0.91 µg/L was recorded at Alum Beach in Homa Bay. Generally, cage stations in Kisumu County had the highest values of nitrites possibly as an effect of their location within Kisumu Bay, which has elevated nutrients from urban inflows (Guya et al., 2013). The highest nitrate concentrations were recorded at Rasira in Homa Bay county with a mean of 9.12 ± 0.00 µg/L compared to the lowest of 3.55 ± 1.28 µg/L recorded at Obaria Beach in Homa Bay County.

Ogal cage station in Kisumu County registered the highest mean concentration of Total Nitrogen (TN) of 166.38 ± 139.21 µg/L while the lowest of 80.21 ± 0.00 µg/L was recorded at Kitawi in Homa Bay County. The highest mean concentration of Total Phosphorous (TP) was observed in Kaugege cage station in Homa Bay County (206.14 ± 225.72 µg/L) whereas the least of 8.16 ± 5.97 µg/L was noted at Oodi cage station in Migori County. Oele cage station in Siaya county recorded the highest mean Chlorophyll-*a* of 41.28 ± 4.66 and the lowest of 8.16 ± 5.97 µg/L in Lakeview site in Homa Bay. Ammonium values were highest at Lwanda Kotieno (29.90 ± 7.81 µg/L) and lowest (3.65 ± 0.96 µg/L) at Global Tilapia farm.

Table 11. Summaries of water column nutrients (Mean±SD) measured at cage stations in the riparian counties of Lake Victoria, Kenya in March 2022

	Nitrites (µg/L)	Nitrates (µg/L)	Ammonium (µg/L)	TN (µg/L)	SRP (µg/L)	TP (µg/L)	Silicate (mg/L)	Alk (mg/L)	Hard (mg/L)	Chlorophyll a (µg/L)
Busia										
Bumbe	21.95±0.84	5.97±1.47	16.25±7.37	168.24±38.40	16.95±1.99	61.14±14.96	18.45±1.63	31.50±2.52	30.00±1.63	25.87±8.39
Mulukoba	21.73±0.89	5.85±0.40	17.34±6.48	242.06±38.77	17.00±3.60	49.36±8.84	18.59±0.51	32.50±1.00	30.50±1.00	19.23±14.27
Rudacho	22.94±1.33	5.95±1.89	27.66±9.45	213.63±111.98	13.72±1.75	50.07±6.53	19.14±1.03	32.00±1.63	28.50±1.91	20.25±13.61
Homa Bay										
Alum Beach	16.27±3.00	4.33±0.35	12.19±	312.32±	33.67±	116.14±	21.57±	46.00±	34.00±	3.51±
Alum Beach	12.33±0.91	4.70±0.00	6.25±1.33	261.00±16.74	27.84±12.96	143.29±26.27	19.32±8.32	47.00±4.24	33.00±1.41	20.55±0.80
Global Tilapia	15.67±11.36	3.04±0.63	3.65±0.96	173.89±18.30	14.78±4.20	69.00±29.93	14.11±3.13	48.00±2.00	32.00±6.93	16.98±8.44
Humanist	16.12±0.00	4.61±0.64	13.75±1.33	210.48±39.08	22.00±7.07	92.58±13.13	14.67±1.75	43.00±1.41	34.00±2.83	16.50±0.04
Humanist	30.21±1.29	4.45±0.00	10.31±0.00	347.05±0.00	20.33±0.00	81.86±0.00	12.99±0.00	48.00±0.00	34.00±0.00	12.21±0.00
Jack Port	15.36±1.50	6.28±0.35	5.00±2.21	150.48±12.28	27.00±7.07	100.43±8.08	14.09±3.19	44.00±0.00	38.00±2.83	11.79±1.05
Kisaka Beach	16.12±0.00	4.60±1.48	7.81±1.77	182.05±3.35	32.00±2.36	108.29±3.03	13.94±0.10	46.00±0.00	31.00±1.41	21.20±12.22
Kitawi	13.55±0.93	4.21±0.00	7.19±0.00	80.21±0.00	27.00±0.00	87.57±0.00	14.30±0.00	38.00±0.00	32.00±0.00	6.32±0.00
Kitawi	12.84±1.83	5.35±1.16	10.11±2.89	125.47±3.98	33.67±7.26	69.48±19.02	13.53±0.31	36.00±2.00	32.67±1.15	7.05±4.50
Kiwa Island	16.17±4.32	5.46±1.26	5.31±2.87	164.42±0.91	32.56±9.18	114.72±15.05	14.55±0.80	45.33±3.06	36.67±1.15	20.08±4.62
Lake View	20.44±0.64	4.39±0.43	8.91±2.81	110.60±14.26	29.92±7.12	81.86±27.82	15.65±1.40	39.00±3.83	31.00±3.83	8.16±5.97
Litare Beach	16.73±0.00	4.60±1.48	10.94±0.88	191.53±3.34	34.50±8.24	100.43±22.22	17.36±8.63	46.00±2.83	38.00±0.00	12.46±5.68
Litare Beach	16.58±1.93	5.64±0.00	13.56±0.00	193.89±0.00	40.33±0.00	116.14±16.68	11.40±0.00	46.00±0.00	36.00±0.00	13.60±0.00
Lwanda Gembe	18.55±5.39	3.69±1.48	9.38±2.21	161.53±7.81	19.50±8.24	110.43±0.00	16.41±1.33	46.00±2.83	35.00±1.41	16.49±5.43
Mrongo	17.08±0.00	6.21±1.00	18.65±4.43	131.79±26.06	29.78±0.96	74.24±5.05	14.84±1.05	38.00±0.00	33.33±12.31	14.09±1.23
Mrongo	22.33±0.86	6.52±0.00	19.69±0.00	159.16±0.00	33.67±0.00	127.57±27.91	14.16±0.00	34.00±0.00	30.00±0.00	10.70±0.00
Ndhuru Beach	14.76±8.88	5.23±1.14	10.00±10.17	133.11±0.00	17.84±	114.00±1.18	14.38±0.52	45.00±1.41	29.00±1.41	29.80±30.16
Nyandiwa	23.75±2.72	6.04±0.95	9.48±0.00	138.63±37.34	27.56±1.93	109.00±17.56	14.74±1.39	46.00±2.00	34.00±2.00	14.05±3.09
Obaria Beach	21.12±4.71	3.55±1.28	9.38±1.32	136.27±32.38	25.34±2.35	80.43±10.10	12.78±1.34	45.00±4.24	33.00±0.00	23.71±1.41

Obaria Beach	30.52±0.00	4.15±0.00	10.31±0.00	149.68±0.00	20.33±0.00	101.86±0.00	11.54±0.00	48.00±0.00	34.00±4.24	17.19±12.08
Rasira	15.22±3.64	6.44±2.12	4.38±0.45	177.32±5.58	27.83±3.54	100.43±34.34	17.14±6.89	41.00±1.15	30.00±0.00	14.79±0.00
Rasira	15.06±0.00	9.12±0.00	3.44±0.00	182.84±0.00	27.00±0.00	91.86±0.00	21.86±0.00	42.00±2.00	28.00±2.83	18.82±2.83
Victory Farm	16.37±0.93	4.23±2.61	7.19±1.65	145.47±5.07	25.89±7.88	101.86±33.59	15.71±1.43	51.33±3.42	33.33±0.00	15.14±0.00
Wakula Site	14.66±1.26	5.25±1.38	21.56±9.44	132.84±29.72	40.44±18.73	113.29±58.88	14.78±0.17	36.00±5.74	30.67±1.15	8.48±2.17
Kisumu										
Achuodho	32.33±1.13	8.15±1.77	21.88±7.92	207.71±38.19	20.75±8.86	106.50±5.13	58.35±1.34	50.50±0.34	38.00±2.31	20.99±4.02
Dunga	33.77±1.17	9.49±1.73	28.70±7.44	286.92±8.85	39.50±2.15	81.15±5.53	10.53±1.38	48.50±1.00	37.00±2.83	23.65±3.34
Ogal	31.10±4.23	7.96±1.22	26.16±3.29	209.33±12.22	61.86±79.43	166.38±139.21	58.00±1.59	51.83±1.15	35.50±2.58	24.13±6.10
Othany	30.67±3.54	6.98±1.18	17.66±5.98	193.76±48.08	33.67±13.74	127.21±25.85	47.66±2.36	49.50±1.91	38.50±1.14	18.43±4.18
Migori										
Bam Got	28.09±4.66	6.47±1.19	21.10±2.52	217.97±30.93	17.00±5.77	109.00±113.36	15.50±0.38	33.00±1.15	29.00±5.26	23.88±7.17
Kaugege	33.50±2.32	7.65±1.49	28.07±12.61	149.16±52.34	38.25±6.44	206.14±225.72	22.88±0.68	39.50±1.71	35.50±3.83	16.90±20.42
Luanda Rombo	14.96±1.43	6.02±0.26	9.06±5.73	122.84±24.61	28.67±12.02	85.67±22.69	18.08±0.91	36.67±9.38	32.00±2.52	9.28±8.73
Matoso Station	21.80±1.09	5.62±1.08	19.77±6.59	162.51±27.37	18.04±3.99	61.32±5.06	17.10±0.18	35.25±0.00	30.00±2.00	23.55±3.34
Oodi Beach	21.96±0.76	7.28±0.28	17.03±1.80	144.16±24.21	26.58±4.98	41.86±6.90	15.36±1.11	40.00±2.00	31.00±0.82	9.51±1.26
Sori Beach	23.62±1.00	5.18±1.51	12.03±2.70	124.82±10.89	14.50±7.52	60.43±5.22	10.59±0.60	34.00±0.00	30.00±9.02	26.58±8.99
Uyoga Kombe	15.77±4.38	5.31±1.16	15.94±4.72	112.31±9.25	35.33±7.27	120.43±26.46	21.81±1.47	38.00±1.50	33.33±3.65	14.04±18.69
Wayando Beach	17.34±6.22	3.37±0.22	10.63±0.45	93.64±7.81	23.67±14.14	104.72±38.39	18.59±0.72	40.00±1.15	35.00±2.31	12.51±5.40
Siaya										
Anyanga	13.00±0.99	7.10±1.89	13.52±3.13	158.17±15.05	10.33±1.36	52.57±11.98	9.56±0.46	32.75±2.00	26.75±1.41	22.05±11.50
Lwanda K'Otieno	15.26±1.53	5.36±0.48	29.90±7.81	164.25±42.78	14.22±0.96	61.38±20.02	20.70±3.77	34.67±1.00	33.33±5.97	16.74±7.25
Nyenye Got Agulu	14.66±0.97	4.96±1.34	21.77±4.16	96.00±20.64	25.33±14.53	74.71±8.92	19.19±0.30	34.00±1.00	28.00±1.15	22.32±1.67
Oele	15.06±1.29	5.26±1.47	20.16±2.90	86.92±32.75	17.4±21.60	67.22±17.67	10.71±1.35	33.50±3.06	27.00±3.46	41.28±4.66
Usenge	15.74±0.80	6.65±1.26	16.72±3.83	102.71±17.83	17.83±10.67	67.93±5.99	16.81±0.56	34.50±9.30	29.00±9.02	22.35±16.84
Uwaria	24.49±3.35	5.22±0.51	18.13±2.52	139.03±47.34	8.25±3.70	56.14±20.30	8.31±0.32	30.50±1.91	29.50±2.58	27.04±5.37
Uyawi	13.04±0.17	6.12±0.57	16.77±1.58	108.63±9.61	22.02±11.53	51.38±10.82	17.50±1.15	32.00±0.00	35.33±1.00	12.81±5.30

3.4 Phytoplankton Community

3.4.1 Busia County

There was a mix of different phytoplankton taxa in the sampled sites (Figure 12). Diatoms were the most dominant group, contributing an average 60% to the total phytoplankton biovolume in most cages. There were fewer diatoms in (e.g. Mulukoba C 17% and Mulokoba A had 20 %, and Rudacho B 2% and Bumbe C 25 % respectively.) than in the open waters (Mulokoba B and Control both had more than 70 %). Except for a few other diatom species, *Aulacoseira* and *Cyclotella* taxa were clearly the most dominant in most of the stations whereas *Nitzschia* and *Synedra* were the more abundant.

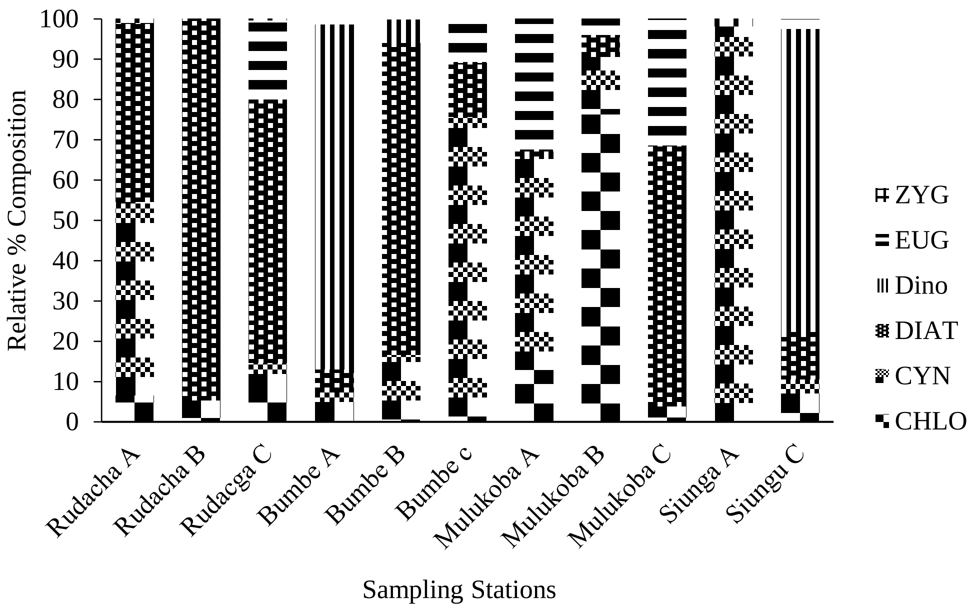


Figure 12. Percentage phytoplankton composition ($mm^3\ l^{-1}$) assigned to phytoplankton classes or families as recorded at different sites of the cages in Busia County Lake Victoria, Kenya.

Within the Cyanobacteria, *Microcystis* spp. and *Anabaena* spp. were the most abundant at Bumbe C with 72% and Siungu Control and Bumbe A had over 45% respectively. This may be attributed by inorganic matter from inshore areas inshore. Results of this study showed temporal changes of phytoplankton community structure which is influenced by anthropogenic inputs of nutrient from catchment areas to the Lake. Cyanophytes were dominant by over 60 %, because of a direct result of supply of nutrients from agricultural lands that surround the lake. Despite the low algal cell density in the region, there were wide spread incidences of surface blooms compared to other zones of the cages towards the open. This may not be reflected in the algal cell density due to the fact that the water sampler is immersed to about 0.5 m below the water surface. Changes in these water quality variables bring about changes in phytoplankton communities and consequently affect the quantity and quality of food items available for invertebrates as well as fish and wildlife, thus, affecting fish production. Phytoplankton studies, therefore, help to explain the distribution and abundance of fishes in a particular cage or niche.

3.4.2 Siaya County

Composition of the phytoplankton community the lake is largely dominated by Cyanophytes contributing between 15 and 25% in both Anyanga A and B and Usenge (Figure 13). Diatoms form an equally important component of the algal flora contributing between 30 - 45%. The phytoplankton abundance was higher at control (2748 indiv. l^{-1}) and lowest at A and B (1501 indiv. l^{-1}). Shannon Weiner index was higher at A and B (0.725) than at the Control (0.7073). Chlorophytes were also encountered in the cages site both in Anyanga and Usenge and they were represented by *Coelomoron spp, Kirchnella spp*, Pediastum spp and *Ankistrodesmus falcatus*. Similarly, eight species of Zygnematophyceae (*Cosmarium* spp and *Closterium Navicula*) were encountered towards the open. Diatom populations were represented by *Nitzschia palea*, *Synedra cunningtonii, Surillella* spp and *Fragillaria spp* and were most abundant taxa in the littoral zones and this was attributed by macrophytes at the shoreline.

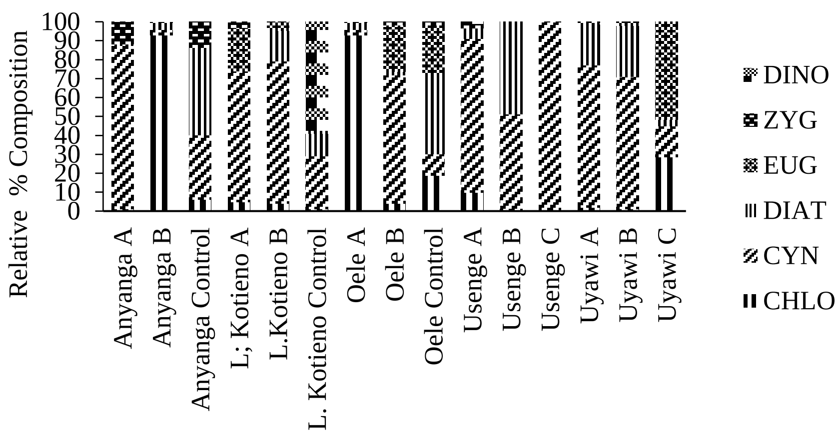


Figure 13. Percentage phytoplankton composition ($mm^3\ l^{-1}$) assigned to phytoplankton classes or families as recorded at different sites of the cages in Siaya County Lake Victoria, Kenya

Phytoplankton mainly comprised Diatoms (40%), Cyanophytes (20), Euglenophytes, Zygnematophyceae, Chlorophytes in the present study. Diatoms were represented by *Nitzschia palea*, *Synedra cunningtonii*, *Fragillaria* spp. Cyanobacteria were dominated by *Planktolyngbya taringii*, *Anabaena flos-Aquae* and *Anabaena limnetica*. Both at Oele, Luanda Kotieno and Uwaria. This may be attributed by light limitation of phytoplankton growth which occurs when there is mixing of water in the cage site towards the open. The depth becomes greater than the photic depth hence phytoplankton are forced to spend more time in the photic zone or can occur under high light attenuation conditions in the upper water column, hence is caused by mineral or biogenic turbidity.

There were 31 different species of phytoplankton identified at Nyenye Got and Uyawi of which 12 species were chlorophytes; *Botryococcus spp* and *Tetraedron sp*, were the most common genera. Six 6 species of Zygnematophyceae were encountered, *Crucigenia spp*. Diatoms were constituted mainly by *Cymbella* sp, *Nitzschia sp*, *Synedra sp*, and *Ampora spp.* Euglenophytes was represented by genera with 4 species and dominated by *Phacus* spp, *Euglena* spp and *Trachelemonous.* The abundance and Shannon Weiner index at both A and B was 5132 indiv.l^{-1} and 1.944 respectively. Phytoplankton abundance at the control site (C) was (4436 indiv.l^{-1}) and Shannon diversity of (2.401). P form an important energy link in the food web that result in fish production hence they are a significant component diet of several juvenile fishes especially at the cage site and at towards the littoral zone.

Results of this survey showed spatial changes of phytoplankton community structure which is influenced by anthropogenic inputs of nutrient from catchment areas and within the cages. Diatoms were dominant (30%) followed by cyanophytes with 28% in most of the station sampled. Diatoms dominated the lake phytoplankton especially at Uyawi, Nyenye Got Oele and Uwaria and Luanda Kotieno. There appeared to be some pockets of other algal groups such as Chrolophytes and Cyanobacteria which also contributed significantly to the phytoplankton community with variations in time and space. For example, Anyanga Control site was dominated with over 54% rchlorophytes and Cyanobacteria. This can also be explained by the washing effect of the diatoms from the upper catchment but also input of nutrients especially soluble reactive silicates (SRSi) for their growth. Thus, they are also indicators of cultural eutrophication in the lake ecosystem which are known to prevail in nutrient-rich as observed by Wetzel (1991). Thus, the nature and health of aquatic communities is an expression of the limnological status of the water body. High light intensity areas can attain high photosynthetic activity to increase primary production.

3.4.3 Kisumu County

Relative abundance at Dunga (150), Ochuodho (460), Ogal (720) and Nyakwara (790) and in Control Dunga (5790), Ochuodho (3220), Ogal (4450) and Nyakwari (1080) individuals' l^{-1}. (Figure 14). There were 44 species identified belonging to groups; Diatoms, Cyanophytes, Euglenophytes and Chlorophytes during the survey.

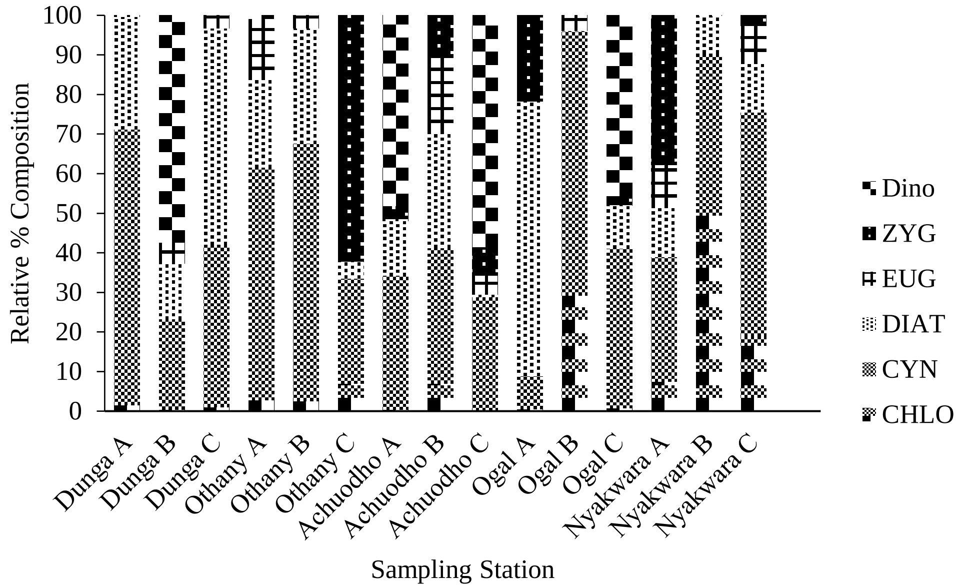


Figure 14. Percentage phytoplankton composition ($mm^3\ l^{-1}$) assigned to phytoplankton classes or families as recorded at different sites of the cages in Kisumu County Lake Victoria, Kenya

There were 14 different species of diatom were encountered, *Nitzschia sub-acicurarils, cymbella cistula, Fragillaria* spp, *Synedra cunningtonii*, *Nitzschia recta* and *Surillela* spp were the most common genera. Similarly, there were 10 species of chlorophytes encountered of which, *Rhopalodia vermicularis, Crucigenia heteracatha Pleurotaenium maximum, Ankistrodesmus falcatus, Coelomoron reguraris,* and *Schroederiella Africana*. Euglenophytes were represented by 8 genera and were represented by *Euglena acus, Phacus sp, Euglena acus, Strombomonous* spp,*Trachelemous* spp. Cyanobacteria were represented by 10 *Planktolyngbya taringii, Chroococcus turgidus Planktolyngbya limnetica.* The high abundance of diatoms Chlorophytes and Cyanophytes are dominating is an indication of cultural eutrophication.

Because studies on the effects of cage farming on the population structure of phytoplankton show change in their structure. Parameters such as using food for feeding and farming the fish in the cages, taking antibiotics increases the immunity of fish in the cages, hence the presence of nutrient substances in food and soluble water and ultimately influencing the water quality especially changing the amount of phosphorous and nitrogen hence affecting the structure of plankton. Thus, the population of phytoplankton is a good means of the detection of environmental conditions that respond to changes in the structure. Water rotation diet directly affects the structure of phytoplankton and can be effective in accessing the nutrients in the water column and reduction in the diversity along with an increase in certain populations of phytoplankton. In general, this survey gives a good diversity of the algal flora and relatively not clear waters since most species like *Microcystis* spp and *merismopedia* indicating that the water quality in that environment is poor. Phytoplankton forms an important area of aquatic ecology for conservation and advising managers on the enhancement ecosystem health.

Despite high algal cell densities, cyanophytes were the most abundant in almost all sampling sites with over (> 40 to 46%) in the present survey of which could be an indication of less pollution in the lake ecosystem as a result to nearby wetland especially Ogal, Ochuodo and Dunga. Euglenophytes and Diatoms were less indicating the presence of enriched environment. Hence there is need proper integrated management of the watershed and catchment areas with the aim of reducing inputs of nutrient especially phosphorous and silicates which drives the proliferation of phytoplankton hence impacting our ecosystem health of the lake.

3.4.4 Homa Bay County

Litare A, B and C are dominated *by cyanobacteria* (81%), Euglenophyes (19%) Among the abundant species, Trachelemous was 55% of total euglenophytes. This implies that they are being grazed by Zooplankton. In Control the dominant species was cyanobacteria. Abundance in A and B was 11.14 indiv.l^{-1} and Shannon Weiner index was 1.1536. Equally Rasira is dominated by *Cosmarium regnesi* (70%). There were more abundant of diatoms in Station B, *Nitzschia sub-acicuraris* (38%) and Control, *Synedra cunningtoni*i (64.1%). Abundance in A and B was 24.2 indiv.l^{-1} and Shannon Weiner index was 1.422 and in Control and 2.99 indiv.l^{-1} and Shannon Weiner index was 1.729 at Rasira.

Phytoplankton in Global Tilapia is dominated by Euglenophytes at both A and B in which T*rachelemonous spp* being the most abundant with over (30%) but all groups of species were represented. Diatoms were the most abundant. Abundance at Alum was 2.99 indiv.l^{-1} and Shannon Weiner index was 1.729. Diatoms dominated by *Nitzschia sub-acicuraris* (25.5%) in both cage A and B). Euglenopytes (86%) and Control was dominated by Zygnemetaphacaae and was represented by *Cosmarium* spp and Microcystis *Spp* (43%). Unlike Victory farm abundance was 15.5 indiv.l^{-1} and Shannon Weiner index was 1.280 and in C abundance was 13.86 indiv.l^{-1}. The Shannon Weiner index was 0.1417.

At Luanda Gembe and Nduru algal community indicates that *Cylindrospermosis* spp was the most abundant species with percentage composition (38%) followed by *Cyclotella Kutzinghiana* (32%). In Station B and C it is composed of Anabaena *spp*. *Coelomolon* spp, *Monoraphidium spp*, Synedra spp were the most common genera. However, Cyanophytes were equally abundant in Nduru with over46% in both Nduru A, B and Control.

There was a moderate mix of different phytoplankton taxa in the sampled sites both in Nyandiwa, Homa Bay, and Jackport. Chrolophytes and diatoms were the most dominant group, contributing an average of 74% in both of Abundance was 2887 in A and B, C had 35.68 indiv.l^{-1} at Nyandiwa respectively. Shannon Weiner index was 1.060 in A and B and varied at site CC (0.7442). In Homa Bay County, cyanophytes were *dominant* at the cages, littoral zone, and towards the open. At Nyandiwa and towards the littoral zones and Control are attributed to dominance of diatoms which are relatively photosynthetic

Results of this study showed changes of phytoplankton community structure which is influenced by anthropogenic inputs of nutrient from cage areas in Ubaria, Kasaka and Kiwa. Diatoms were dominant by over 65 % and were represented by *Aulacoseira Spp, Nitzschia recta*. Abundance was 1734 in A and B, Control had 2792 indiv.l^{-1} respectively. Shannon Weiner index was 1.661 in A and B. and in Control (1.061). This is correlated with the high physio-chemical parameters recorded in the present study and can be explained by high washing effect of the diatoms from the upper catchment but also input of nutrients especially Soluble reactive silicates (SRSi) for their growth.

There were differences in phytoplankton taxa. Chrolophytes were the most dominant group, contributing an average 28 % at Mwongo, Kaugege (20%), Kitawi (15%), Uyoga (12%) and Luanda Gembe (10%) followed by diatoms of the total phytoplankton biovolume. Abundance at Kaugege was 788 in A and B and 1178 indiv.l^{-1} at Control site while Shannon Weiner index was 1.746 in A and (1.803) at control site. It was noted that the phytoplankton was higher in cage sites than the control. The abundance at Wanyando A and B was 780.6 and B 2344 indiv.l^{-1}respectively. Likewise, Shannon Weiner index was 1.751 at A and 1.964 at B.). This could be attributed to trophic state index of around the cages indicated that at the cage area diatoms and Cyanophytes dominated toward the open Lake.

Some phytoplankton species have photo physiological adaptation to low light availability by adjusting their capacity to capture and adjust their position in low turbulent water columns through production of gas vesicles. Therefore, they have an advantage over other species. (Walsby et al 2001; Brookes et al., 2010). The study observed that along transect, the occurrence of *Microcystis* and *Anaebeana* spp are attributed to the morphological differences between the littoral zone, cage sites and the control site. This is associated with physical processes which influences nutrient cycling. Thus, they may not be reflected in the algal cell density due to the fact that the water samples were collected from the surface at about 0.5 m. In addition, the waters were quite turbid making light attenuation to be very high, thus primary production is limited to the uppermost water layer.

The high eutrophication in the lake is attributed to frequent formation of algal blooms in the lake. Degradation is manifested through reduced fish stocks; decline in biodiversity; dense algal blooms, increased sedimentation, nutrient loading, and anoxia in the water column (Sitoki et al., 2012; Miruka, 2022). More so, the lake ecosystem indicated poor quality and may be attributed to intrinsic sources of nutrients, especially phosphorus and TP demonstrated clearly the intrinsic existence of varying amounts of various fractions of particulate hence lead to a stressful status with oxygen concentration changing from lethal to stressful levels hence it affects fish in the cages.

According to the study, phytoplankton community structure in Homa Bay County is dominated by Cyanophyceae constituting 45% in abundance and were represented by species like *Microystis* spp, *Anabaena* spp, *Planktolyngya* spp and *Aphanocapsa* spp, appearing in almost all the stations. The other less abundant but common algal groups were, Chlorophyceae, Bacillariophyce and Dinophceae. The least taxa in terms of abundant constituted Euglenophyceae and Zygnematophyceae appeared to be dominant with species like Species biodiversity in the lake was moderate and are known to prevail in nutrient rich lakes (Wetzel and Liken, 1991), with presence of Cyanophyceae and high nutrients load depicted the bay to be eutrophic.

3.4.5 Migori County

High abundance at Matosa was (419 individuals l-) and Muhuru A and B was 7075 indiv.l^{-1} and C (806) (Figure 15). There were variations at Sori A and B (1364.5) indiv.l^{-1} and Control (352). Shannon Weiner index in A and B was 1.708 and Control (1.362) and this may be attributed to inorganic matters from near shore to the cages. There were 43 different species of phytoplankton identified during the survey of which 7 species of chlorophytes were encountered. *Coelomolo*n spp, *Monoraphidium* sp, *Pediastrum* spp were the most common genera. There were 10 species of Zygnematophyceae encountered, *Crucigenia* spp were the most frequently encountered genera. Five species of diatoms constituted mainly *Aulacoseira nyansenssis*, *Aulacoseira schroidera*. Euglenophytes and dinoflagellates were represented by 7 genera. Cyanophytes was represented by 13 genera of which the most genera were *Merismopedia* spp and *Microcystis s*pp.

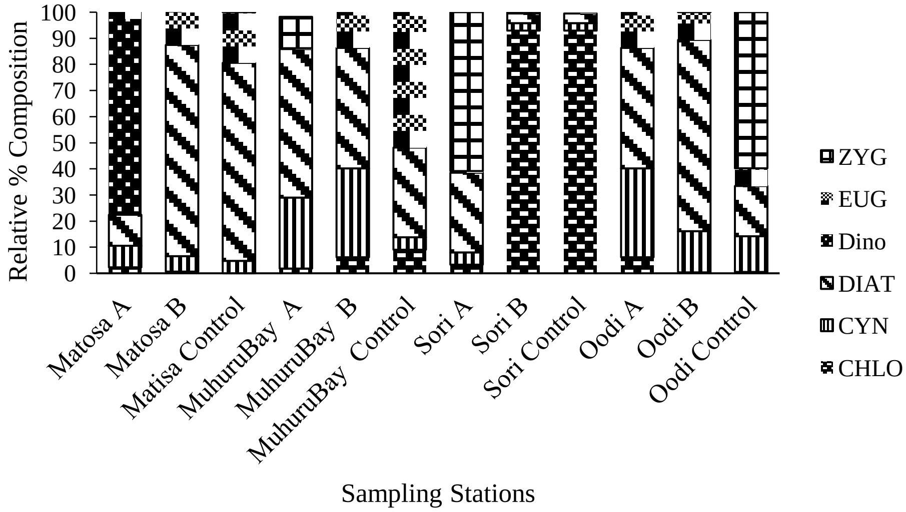


Figure 15. Percentage phytoplankton composition ($mm^3\ l^{-1}$) assigned to phytoplankton classes or families as recorded at different sites of the cages in Migori County Lake Victoria, Kenya

The high concentration of cyanobacteria cells at the sori is related to the aggregation of sediment particles to buoyant cyanobacteria e.g. Microcystis and Anabaena taxa. (Verspagen et al., 2006). The phytoplankton abundance in A and B was 7075 indiv.1 -^{1} and c (806). Shannon Weiner index in A and B was 0.9779 and Contol (1.27). High algal cell densities especially Diatoms, Euglenophytes, Zygnematophyceae, Chlorophytes, and Dinoflagellates with Cyanophytes being abundant in the cage site with over (> 43 %) is an indication of a polluted ecosystem.

It is evident that turbidity favors the dominance of Cyanobacteria which are able to fix nitrogen from the atmosphere hence is an indication of less nutrient enrichment (Miruka, 2022; Sitoki 2012 and Lungayia, 2001). Some algal species, for example, *Anabaena flos –aqua and Microsystis aeruginosa* are unpalatable and even toxic to fish hence makes them stunted. Cyanobacteria can pose serious public health concerns hence producing potent nerve and liver toxins that cause serious human suffering. Towards the littoral and open diatoms *like Amphora* spp were abundant. This may be an indication that there is enough food for juvenile fish hence at the cages. Abundance of these species indicates that the area is eutrophic

The high abundance of diatom families is an indication of cultural eutrophication which is a clear indication of the trophic status of the lake. This is correlated with the high physio-chemical parameters recorded in the stations sampled. Turbidity favors the dominance of cyanobacteria which are able to fix nitrogen from the atmosphere. The high nutrient enrichment seems to enhance growth and is responsible for the increased algal density and more especially diatoms which are proportionately high in most of the stations. The greens and diatoms species are known to prevail in nutrient-rich (Wetzel, 1991) and high light intensity areas and can attain high photosynthetic efficiencies. For instance, the present study has shown that water is rich in silica which contains a high population of diatoms hence there is available food for other aquatic organisms and can support a fishery.

3.5 Zooplankton community

3.5.1 Busia County

3.5.1.1 Zooplankton abundance

The mean total zooplankton abundance ranged from 123.7 ± 9.9 (Bumbe, B) to 265.4 ± 15.6 indiv. L^{-1} (Mulukoba control). There were variations in zooplankton abundance between and and off the cages. The values at the cage sites were relatively higher at Rudacho B than other sites (Figure 16).

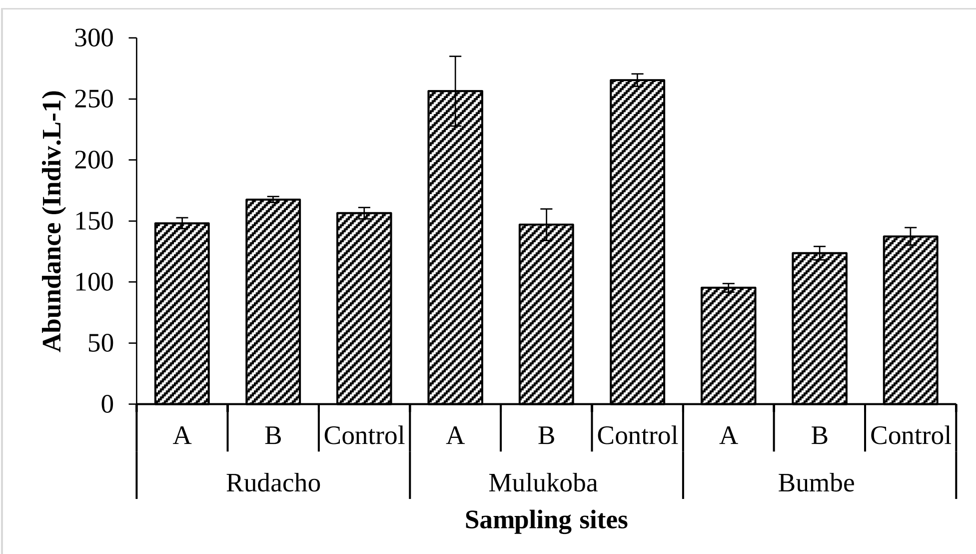


Figure 16. Spatial variations (mean ± SE) in zooplankton abundance in the water column from the sampled cage culture sites in Lake Victoria, Kenya ~ Busia County. (transect point A = near first cage ~ approx. 100m from shoreline; point B = midpoint in the cages; point C = near the last cage inshore; Control = approx. 50m away from the cages offshore)

3.5.1.2 Composition

The zooplankton community in Busia County was composed of three broad taxonomic groups: Copepoda, Cladocera and Rotifera. Spatial variations were observed in zooplankton abundance along each of the study locations. Copepoda dominated the zooplankton community in all the sampling sites with abundance estimates ranging from 127.5 ± 6.0 ind. L-1 to 247.0 ± 12.0 ind. L-1 at Rudacho A and Mulukoba control point respectively. Cladocera followed with values ranging from 4.9 ± 0.9 (Bumbe control point) ind. L^{-1} to 15.9 ± 1.8 ind. L^{-1} (Bumbe, B) compared to rotifers which are slightly lower in abundance ranging from 4.1 ± 1.5 (Rudacho, B) and 10.5 ± 2.4 ind. L-1 (Rudacho, A). The three groups showed relatively consistent abundance patterns across the study sites. Copepods abundance differed significantly with rotifers and cladocera (Figure 17).

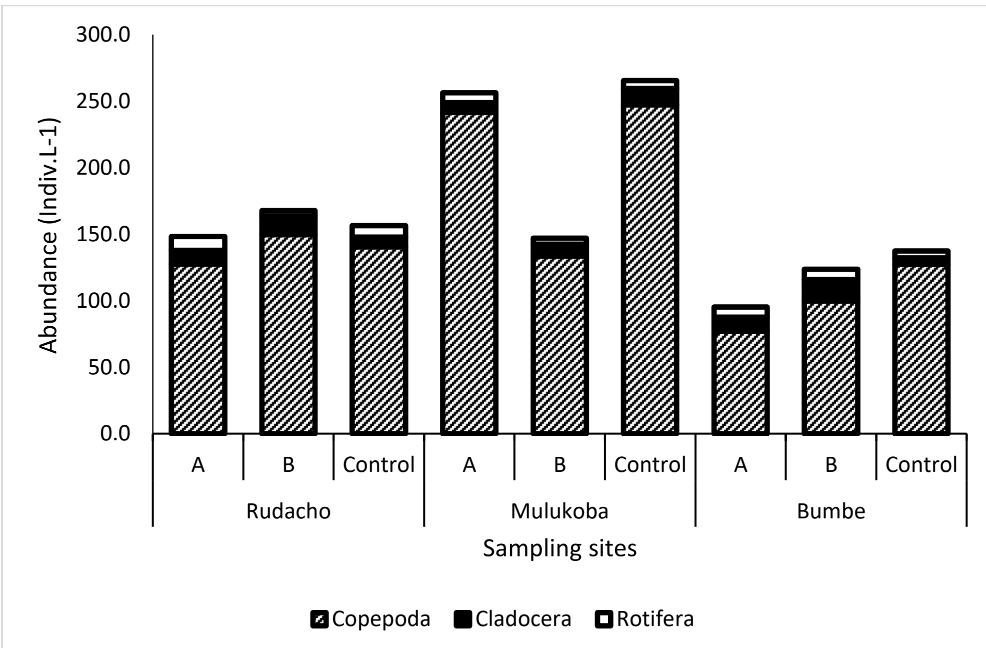


Figure 17. Spatial variations in zooplankton abundance in the water column from the sampled cage culture sites in Lake Victoria, Kenya ~ Busia County. (transect point A = near first cage ~ approx. 100m from shoreline; point B = midpoint in the cages; point C = near the last cage inshore; Control = approx. 50m away from the cages offshore)

3.5.1.3 Zooplankton composition and distribution pattern

Zooplankton community was represented by three main taxa/group, i.e Copepoda, Cladocera and Rotifera (Figure 18). Copepods were the most dominant group, contributing an average 88.6% to the total zooplankton in most sites. Copepods were relatively high in proportion at the reference sites (control). There were fewer Cladocera at the control point (4.5%) and Bumbe control point (3.6%).

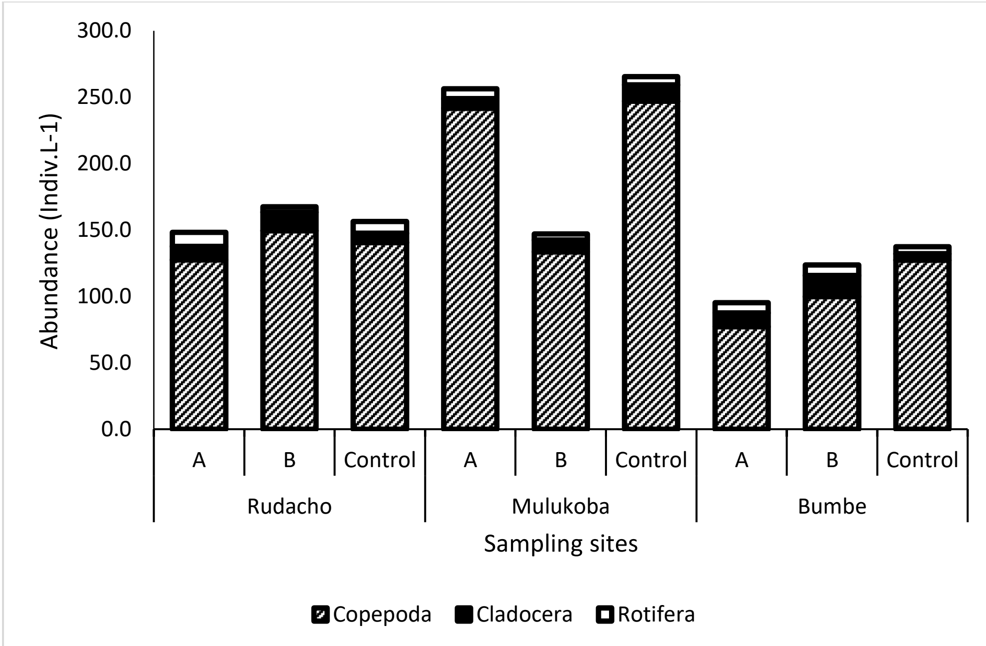


Figure 18. Percentage composition (indiv. l^{-1}) of main zooplankton taxa recorded from the sampled cage culture sites in Lake Victoria, Kenya ~ Busia County. (transect point A = near first cage ~ approx. 100m from shoreline; point B = midpoint in the cages; point C = near the last cage inshore; Control = approx. 50m away from the cages offshore)

3.5.1.4 Species richness and composition

Cladocera were represented by 7 species belonging to families *Sididae, Moinidae and Daphnidae* and constituted 6.7 % of the total zooplankton abundance. *Diaphanosoma excisum* was the most dominant species, followed by *Moina micrura*. Other cladoceran species recorded include, *Daphnia lumhorltzi*, *D.barbata*, *Ceriodaphnia cornuta*, *Chydorus* spp and *Bosmina longirostris.* Rotifers were represented by 10 species, mainly by family brachionidae with 4 species *Brachionus angularis, B. calyciflorus, B. falcatus* and *B. patulus.* Otherequally dominant rotifer was *Keratella tropica* and *Filinia sp, Asplanchna sp, Polyathra sp, Euchlanis sp, Hexarthra sp and Trichocerca sp*

3.5.1.5 Diversity index (H'), evenness index (E), and dominance index (C) of zooplankton

Diversity, evenness, and dominance index value of zooplankton could be used to evaluate aquatic ecosystem stability. The diversity index for zooplankton community in the sampled cage culture sites from Busia County ranged from 1.13 to 1.60, evenness index ranged from 0.16 to 0.29, and dominance index ranged from 0.328 to 0.4356 (Table 12). Diversity index showed that zooplankton diversity in Lake Victoria waters was relatively high. Evenness index showed that zooplankton distribution was not evenly distributed. This condition was supported by dominance index value which showed domination of zooplankton genus/group. Dominant species in a community shows strength of the species than other species. Shannon diversity index, species richness and equitability (evenness) of zooplankton species within the cage area and off the cage site reflected spatial variation depending on whether cages exist near or not.

Table 12. Zooplankton diversity indices for the sampled sites in Lake Victoria, Kenya ~ Busia County

Parameter	Rudacho A	Rudacho B	Rudacho Control	Mulukoba A	Mulukoba B	Mulukoba Control	Bumbe A	Bumbe B	Bumbe Control
Taxa_S	21	14	18	20	15	17	20	17	17
Individuals	148.40	167.50	156.20	256.10	146.90	265.60	95.30	123.80	137.40
Dominance_D	0.38	0.42	0.40	0.43	0.39	0.41	0.37	0.33	0.44
Simpson_1-D	0.62	0.58	0.60	0.57	0.61	0.59	0.63	0.67	0.56
Shannon_H	1.42	1.22	1.32	1.13	1.26	1.17	1.55	1.60	1.19
Evenness_e^H/S	0.20	0.24	0.21	0.16	0.23	0.19	0.23	0.29	0.19

3.5.2 Siaya County

3.5.2.1 Zooplankton abundance

Seven locations with cages were studied in Siaya County. Mean total zooplankton abundance ranged from 207.7 ± 9.2 (Anyanga, Control) to 494.2 ± 32.9 indiv. L^{-1} (L/Kotieno, A). There were variations in zooplankton abundance between and off the cages.

At Nyenye, zooplankton was more abundant at the cage site (356.4 ± 20.4 ind. L^{-1}) with the lowest value (283.4 ± 21.0 ind. L^{-1}) at the reference point of same area (Nyenye C). Zooplankton abundance at the control sites in Siaya County ranged between 207.7 ± 9.2 indiv. L^{-1} to 494.2 ± 32.9 indiv. L^{-1} at Anyanga control point and Lwanda Kotieno control point reference site respectively (Figure 19).

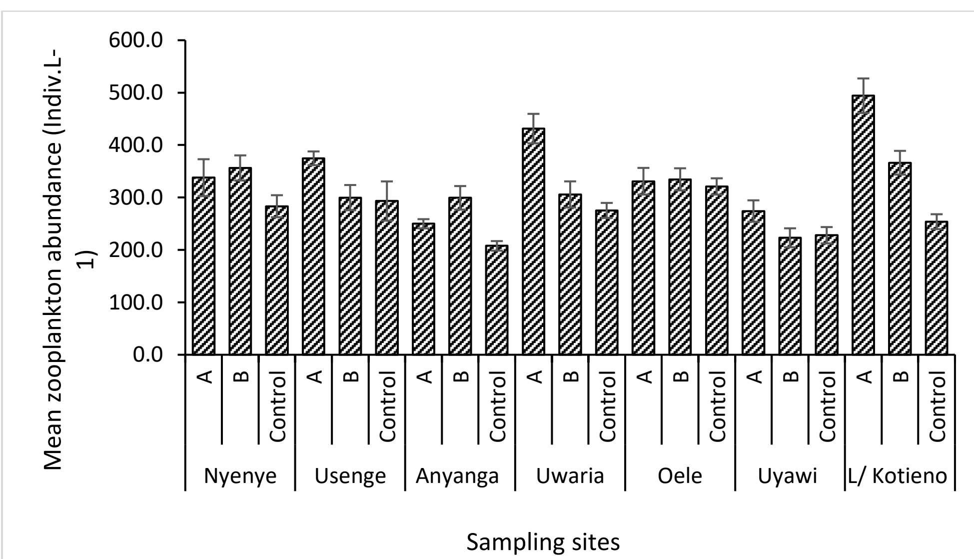


Figure 19. Spatial variations (mean ± SE) in zooplankton abundance in the water column from the sampled cage culture sites in Lake Victoria, Kenya ~ Siaya County. (transect point A = near first cage ~ approx. 100m from shoreline; point B = midpoint in the cages; point C = near the last cage inshore; Control = approx. 50m away from the cages offshore)

3.5.2.2 Composition

The zooplankton community in Siaya County is composed of three broad taxonomic groups: Copepoda, Cladocera and Rotifera (Figure 23). Copepoda dominated the zooplankton community in all the sampling sites with abundance estimates ranging from 185.4 ± 6.0 ind. L^{-1} at Anyanga control site to 444.0 ± 25.4 ind. L^{-1} at Lwanda Kotieno A. Cladocera followed with values ranging from 3.1 ± 1.3 ind. L^{-1} (Nyenye C control point) ind. L^{-1} to 34.8 ± 4.8 ind. L^{-1} (Lwanda Kotieno A). Rotifers were lower in abundance ranging from 3.1 ± 1.3 (Ayanga B) and 29.0 ± 4.1 ind. L-1 (Uwaria A). The three groups showed relatively consistent abundance patterns across the study sites. Copepod and rotifer densities differed significantly (Figure 20).

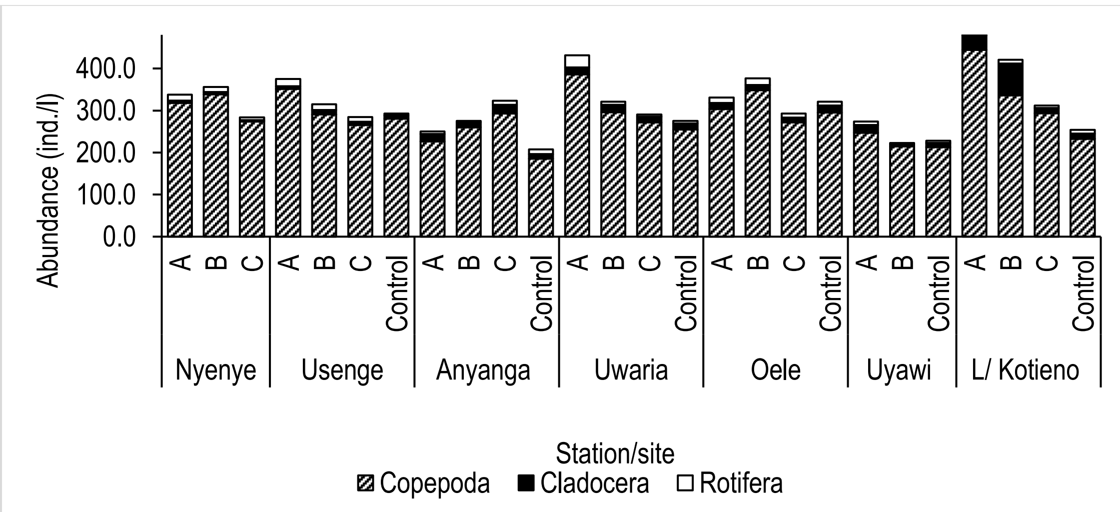


Figure 20. Spatial variations in abundance of different zooplankton taxa from the sampled cage culture sites in Lake Victoria, Kenya ~ Siaya County. (transect point A = near first cage ~ approx. 100m from shoreline; point B = midpoint in the cages; point C = near the last cage inshore; Control = approx. 50m away from the cages offshore)

3.5.2.3 Zooplankton composition and distribution pattern

Zooplankton community was represented by three main taxai.e Copepoda, Cladocera and Rotifera. Copepods were the most dominant group, contributing an average 92.2% to the total zooplankton, cladocerans, 4.6% and finally rotifers 3.2% respectively. Occurrence of relatively high abundance of cladocera at Lwanda Kotieno B accounting for 17.9 % of the total zooplankton is worth noting (Figure 21).

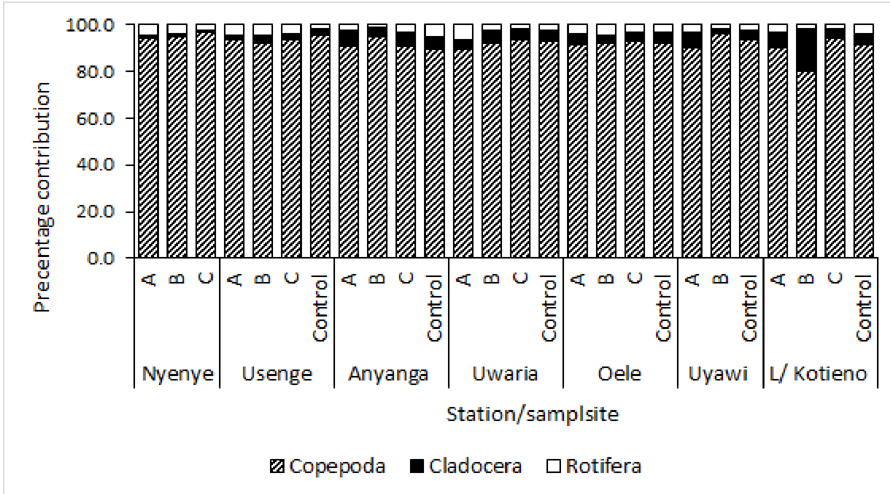


Figure 21. Percentage composition (indiv. l^{-1}) of main zooplankton taxa recorded from the sampled cage culture sites in Lake Victoria, Kenya ~ Siaya County. (transect point A = near first cage ~ approx. 100m from shoreline; point B = midpoint in the cages; point C = near the last cage inshore; Control = approx. 50m away from the cages offshore)

3.5.2.4 Species richness and composition

Cladocera were represented by 7 species belonging to families Sididae, Moinidae and Daphnidae and constituted 4.6 % of the total zooplankton abundance. *Diaphanosoma excisum* was the most dominant species, followed by *Moina micrura*. Other cladoceran species recorded that were widespread but occured in low abundance include, *Daphnia lumhorltzi*, *D.barbata*, *Ceriodaphnia cornuta*, *Chydorus spp* and *Bosmina longirostris*. Rotifers were represented by 12 species, mainly by family brachionidae with 4 species *Brachionus angularis*, *B. calyciflorus*, *B. falcatus* and *B. patulus. Other* rotifers were *Keratella tropica*, *K. cochleris* and *Filinia sp*, *Asplanchna sp*, *Polyathra sp*, *Euchlanis sp*, *Hexarthra sp and Trichocerca sp*

3.5.2.5 Diversity index (H'), evenness index (E), and dominance index (C) of zooplankton

The diversity index for zooplankton community in Siaya County ranged from 0.8972 to 1.456, evenness index ranged from 0.16 to 0.29, and dominance index ranged from 0.3477 to 0. 5537.

3.5.2.6 Community Analysis Package (CAP)

Community analysis package using complete Euclidian linkage based on zooplankton abundance divided the sampling areas into two arms separating Lwanda Kotieno B with all other stations at the first level. At the lower arm of the figure, sampling sites Lwanda Kotieno A is further separated from at all other sites/stations (Figure 22).

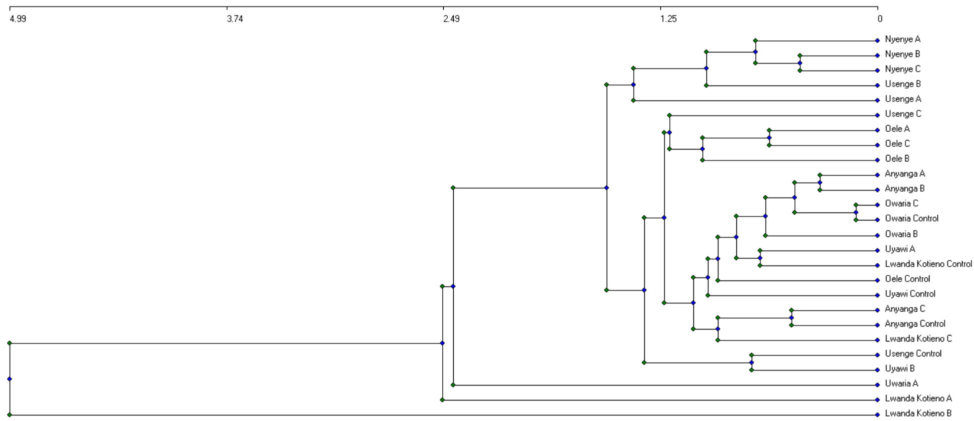


Figure 22. Dendrogram showing zooplankton community linkage at different sampling sites from Lake Victoria, Kenya ~ Siaya County.

3.5.3 Kisumu County

3.5.3.1 Zooplankton abundance

Four locations with cages were studied in Kisumu County (Dunga, Ogal and Achuodho, Othany). Mean total zooplankton abundance was generally lower at Ogal and Achuodho compared Dunga and Othany. The zooplankton community was composed of three broad taxonomic groups: Copepoda, Cladocera and Rotifera (Figure 23). Mean total zooplankton abundance for sample point A ranged from 260.5 ± 2.9 (Ogal A) to 476.0 ± 18.3 indiv. L^{-1} (Dunga A). Zooplankton abundance at the control sites ranged between 290.6 ± 16.8 (Ogal) indiv. L^{-1} to 362.5 ± 15.7 indiv. L^{-1} (Othany). Copepoda dominated the zooplankton community in all the sampling sites. Spatial variations were observed in zooplankton abundance along each of study locations.

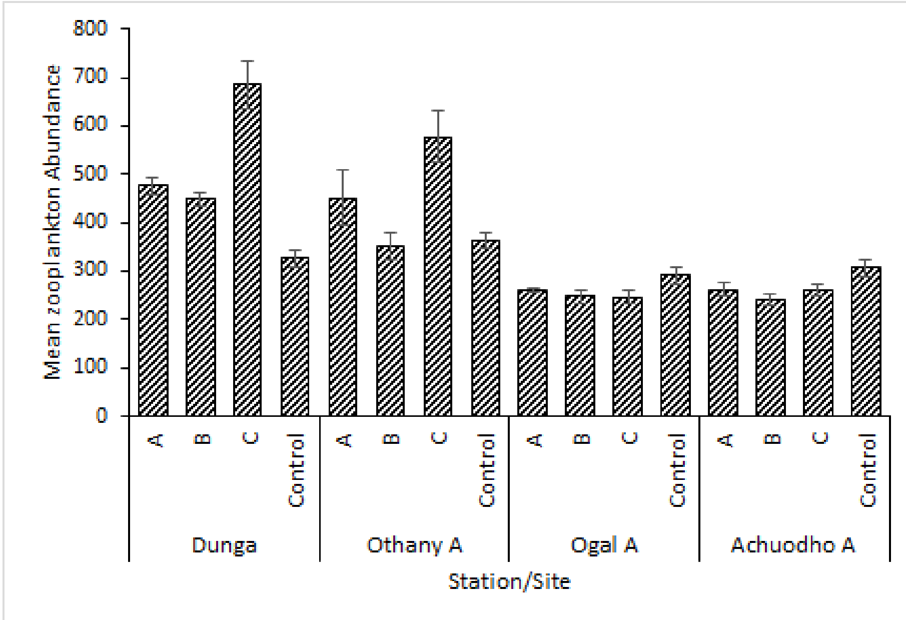


Figure 23. Spatial Variations (mean ± SE) in zooplankton abundance in the water column from the sampled cage culture sites in Lake Victoria, Kenya ~ Kisumu County. (transect point A = near first cage ~ approx. 100m from shoreline; point B = midpoint in the cages; point C = near the last cage inshore; Control = approx. 50m away from the cages offshore)

3.5.3.2 Composition and distribution

Zooplankton community was represented by three main taxa/group, i.e Copepoda, Cladocera and Rotifera and presence of some few ostracods in all the sampled sites (Figure 24). Copepods were the most dominant group, contributing an average 75.4% to the total zooplankton in most sites. There was slightly lower copepod contribution at Dunga and Achuodho with contribution being 74.5% and 76.1% respectively. At the control was points copepods were above 76 % while there were fewer Cladocera at the control site compared to all other sites.

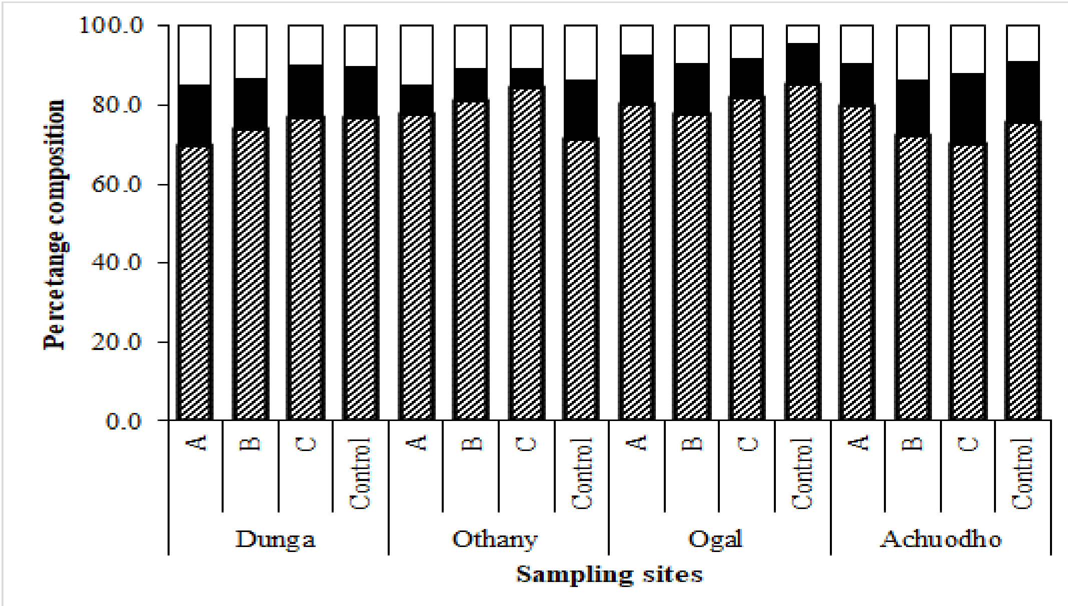


Figure 24. Percentage composition (indiv. l^{-1}) of main zooplankton taxa recorded from the sampled cage culture sites in Lake Victoria, Kenya ~ Kisumu County. (transect point A = near first cage ~ approx. 100m from shoreline; point B = midpoint in the cages; point C = near the last cage inshore; Control = approx. 50m away from the cages offshore)

Cladocerans had a mean composition of 11.2% and ranged from 3.7 - 15.1% while rotifers made 10.8%. However, there were variations at the sampling points. Zooplankton species occurred in different densities with *Diaphanosoma exscisum* being the most widespread and abundant cladoceran zooplankter.

3.5.4 Homa Bay County

3.5.4.1 Zooplankton

Five locations with cages were studied in Homa Bay County (Lwanda Rombo, Wayando, Uyoga, Kaugege and Nyandiwa. Mean total zooplankton abundance ranged from 86 ± 7.2 to 248.2 ± 20.5 indiv. L^{-1}. Zooplankton_abundance value was comparatively high at Kaugege A (230.2 ± 21 indiv. L^{-1}) with the other sample points at Kaugege recording relatively low abundance values. There were variations in zooplankton abundance between and off the cages. The abundance values recorded at Nyandiwa cage site were unusually very low or negligible probably due to the sampling equipment used (Figure 25).

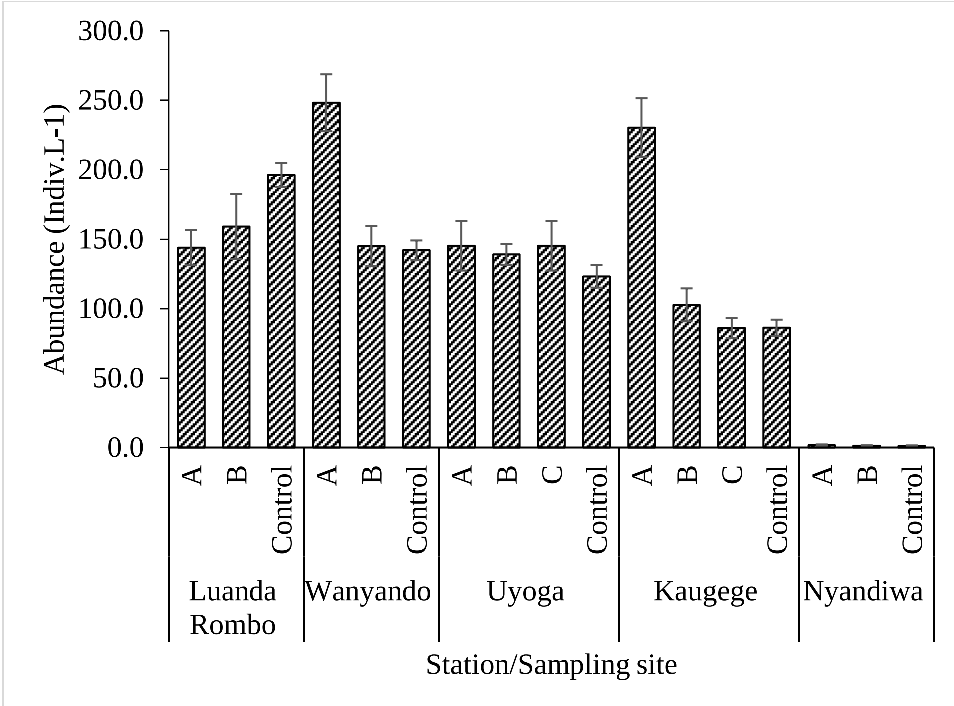


Figure 25. Spatial Variations (mean ± SE) in zooplankton abundance in the water column from the sampled cage culture sites in Lake Victoria, Kenya ~ Homa Bay County. (transect point A = near first cage ~ approx. 100m from shoreline; point B = midpoint in the cages; point C = near the last cage inshore; Control = approx. 50m away from the cages offshore)

Copepoda dominated the zooplankton community in all the sampling sites with abundance estimates ranging from 0.6 ind. L^{-1} to 208.9 ind. L^{-1} with an average of 104.4 ± 15.3, Cladocera raged from 0.1-61.0 Ind. L-1 with average of 13.9 ± 4.0 ind. $L^{-1.}$ and rotifers ranged from 5.1± 1.3 $L^{-1.}$ (Figure 26).

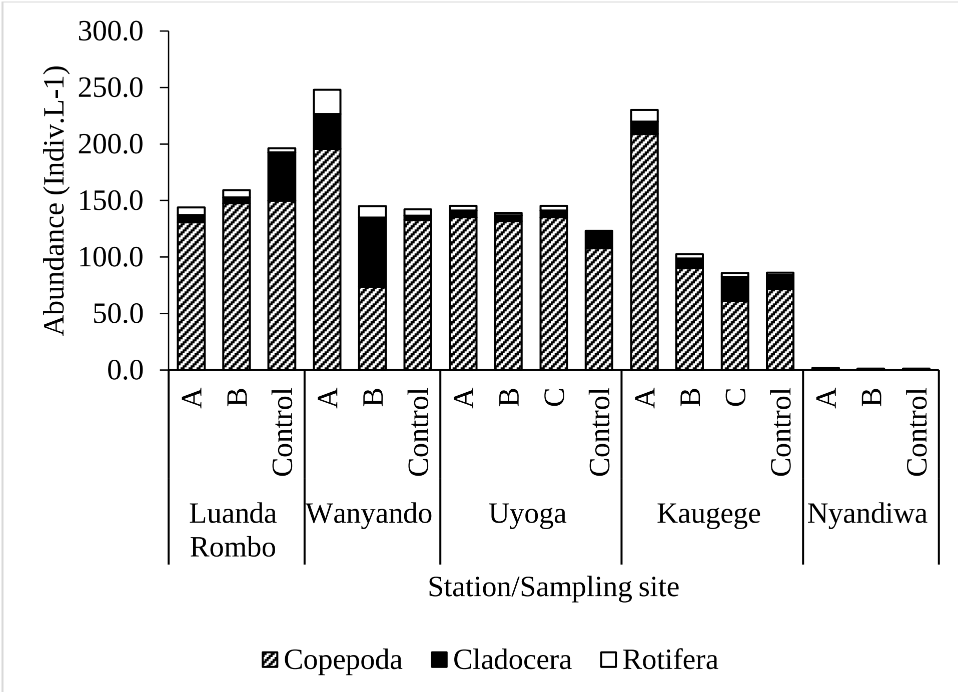


Figure 26. Spatial variations in abundance of different zooplankton taxa from the sampled cage culture sites in Lake Victoria, Kenya ~ Homa Bay County. (transect point A = near first cage ~ approx. 100m from shoreline; point B = midpoint in the cages; point C = near the last cage inshore; Control = approx. 50m away from the cages offshore)

3.5.4.2 Composition

The zooplankton community in Homa Bay County is composed of three broad taxonomic groups: Copepoda, Cladocera and Rotifera. Copepods dominated the zooplankton community averagely constituting 79.3 % of the total zooplankton. Cladocerans composed averagely 11.6% while rotifers an average of 9.1% (Figure 27).

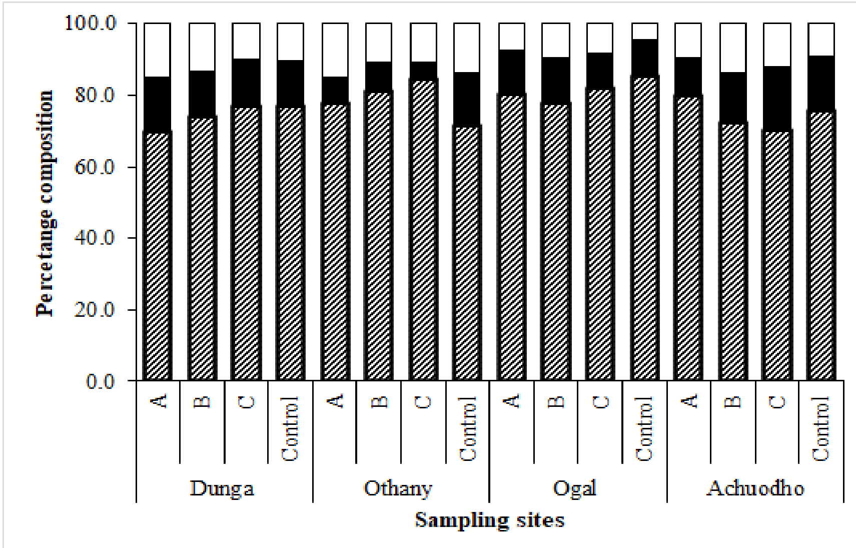


Figure 27. Percentage composition (indiv. l^{-1}) of main zooplankton taxa recorded from the sampled cage culture sites in Lake Victoria, Kenya ~ Homa Bay County. (transect point A = near first cage ~ approx. 100m from shoreline; point B = midpoint in the cages; point C = near the last cage inshore; Control = approx. 50m away from the cages offshore)

Zooplankton community dominance was Copepoda > Cladocera > Rotifers. Copepods abundance ranged from 135.1 ind. L^{-1} to 328.7 ind. L^{-1}. Cladocera ranged from 2.5 to 36.6 Ind. L-1 while rotifers values ranged from 3.6 to 9.4 indiv. $L^{-1.}$

There were no consistent patterns in zooplankton abundance among the study areas with some areas recording higher values at cage areas while others recorded lower values. This is in contradiction to our earlier findings where consistent lower zooplankton abundance were observed at the site with cages on all sampling sites and was presumed to be an impact from the fish cages. Generally, there were relatively high abundance at cage areas comparative to reference sites. These results suggest the impact of fish farming on the structure of this community. High zooplankton abundances near cage-culture and low abundances upstream were observed in a Turkish reservoir by Demir et al., 2001. Fish farming in the lakes produces waste with a high concentration of N and P released in solute form into the water column (Neofitou and Klaoudatos, 2008). However, previous studies dealing with the analysis of plankton response to fish farming showed no significant difference between cages and control sites (Dias et al., 2011).

Cage fish farming is expected to expand in many water bodies in Kenya to increase the supply of fish. Therefore, water quality impacts associated with fish cage culture should be avoided or reduced by careful cage siting and adherence to best management practices. Though the results of this study indicate no significant difference in terms of zooplankton abundance, nonetheless, long-term studies on the impacts of fish cages on these various water quality variables are for future management options for fish farming in the lake and water bodies. The zooplankton community was composed of three broad taxonomic groups: Copepoda, Cladocera, and Rotifera. Rotifers registered higher species numbers across sampling study sites. Stations with cages generally registered lower mean species numbers compared to other sites.

Copepods constituted the bulk of total zooplankton abundance at all the sampling sites with total density estimates varying among different sites/station due to difference in various physico-chemical and biological attributes. The three groups (Copepoda, cladocera and roifera) showed no consistent abundance patterns across the study sites (A, B, C and Control point) during the study. Zooplankton species numbers were consistently lower at sites with cages compared to those at reference site and those before. 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, 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 on all sampling dates was presumed to be an impact from the fish cages.

The relatively higher number of rotifer species richness in all the study areas concurs with Mwebaza (Ndawula et al., 2004) who associated rotifer prominence with eutrophic conditions in most near-shore areas of Lake Victoria. There was varying difference in total mean densities of zooplankton across the study sites in all the five counties sampled, suggesting some impacts on abundance so far from the fish cages even when the number of cages especially in areas with high cage densities like Siaya county.

Even though not clearly observed in some of the areas sampled under our study, the effects of cage fish farming can be detected if the culturing system was more intensive. Some effects on zooplankton assemblages were shown by (Demir et al., 2001) for trout cage farming in a Turkish Reservoir. In Brazil, (Dias, 2008) showed these effects in a tilapia cage farm in Rosana Reservoir (Paranapanema River), where a higher abundance of rotifers and cladocerans were observed next to the cages, due to the nutrient enrichment and food availability.

3.6 Microbiological quality of water

The mean total coliforms for the sampled stations ranged from 90 – 1600 cfu/10ml of water sampled (Figure 28).

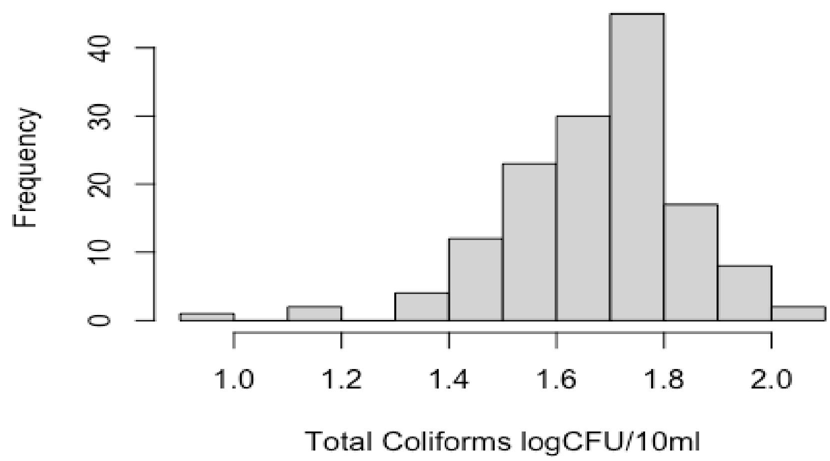


Figure 28. Total coliform histogram from the sampled cage culture sites in Lake Victoria, Kenya. (log cfu = logarithmic colony forming unit)

The mean fecal coliforms for the sampled stations cage ranged from 30 – 540 cfu/10ml of water sampled (Figure 29).

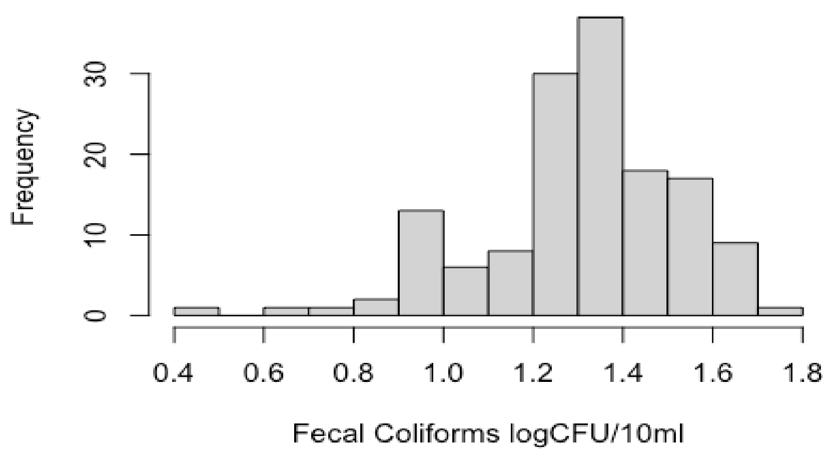


Figure 29. Fecal coliform histogram from the sampled cage culture sites in Lake Victoria, Kenya. (log cfu = logarithmic colony forming unit)

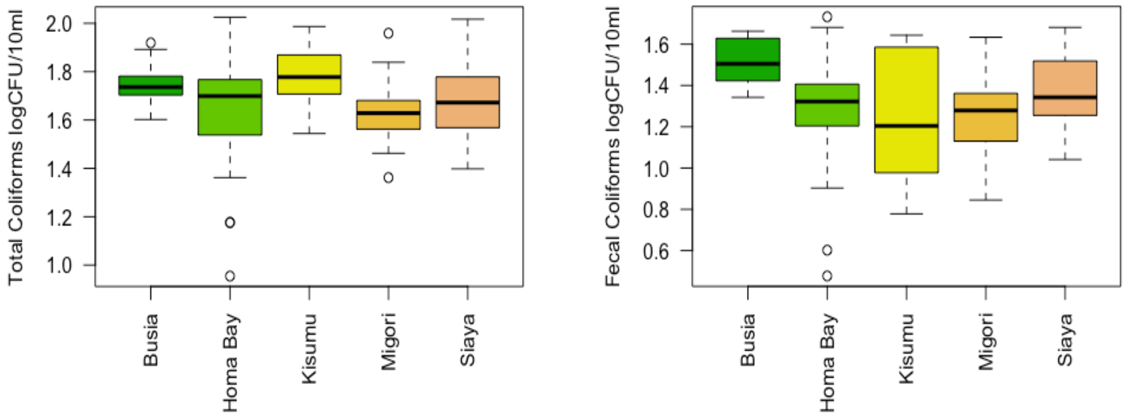


Figure 30. Mean log total and fecal coliforms counts from the sampled cage culture sites in the five counties annexing Lake Victoria, Kenya. (log cfu = logarithmic colony forming unit)

Variation in the concentrations of both total and fecal coliforms from the sampled cage culture sites in the five counties was not significant ($p < 0.05$). The only exception is Busia County ($p = 0.11$) and this could be attributed to the few numbers of cage culture sites ($n = 3$) recorded. There is a strong positive correlation in *R-values* indicating that an increase in total coliforms concentration could attribute to an increase in fecal coliform concentration.

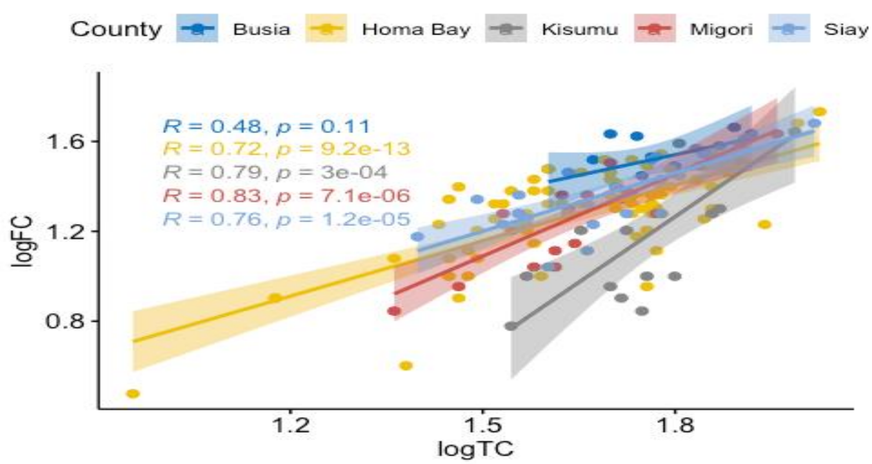


Figure 31. Pearson correlation between mean total and fecal coliforms from the sampled cage culture sites in the five counties annexing Lake Victoria, Kenya. (logTC = logarithmic total coliforms; logFC = logarithmic fecal coliforms; p = 0.05; R = correlation coefficient)

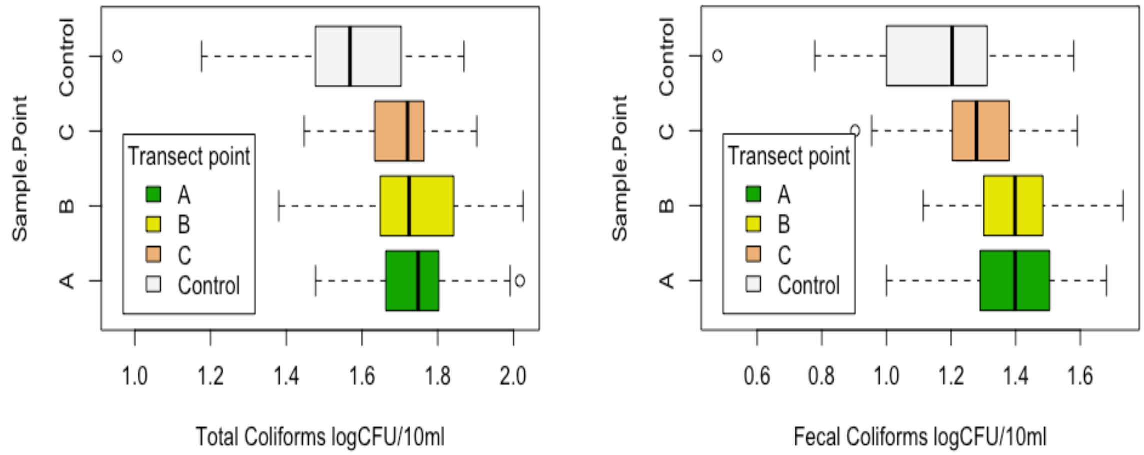


Figure 32. Mean log total and fecal coliforms counts from the sampled transect points in the sampled cage culture sites in Lake Victoria, Kenya. (transect point A = near first cage ~ approx. 100m from shoreline; point B = midpoint in the cages; point C = near the last cage inshore; Control = approx. 50m away from the cages offshore)

Variation in the concentrations of both total and fecal coliforms from the four sampled points per each cage culture site in the five countieswas not significant ($p < 0.05$). The only exception is sample point C (end of farthest cage inshore, $p = 0.22$), which could be attributed to the missing values for sample point C from several cage culture sites in Homa Bay ($n = 15/20$) and Siaya ($n = 3/7$) counties. There is a strong positive correlation in *R-values.*

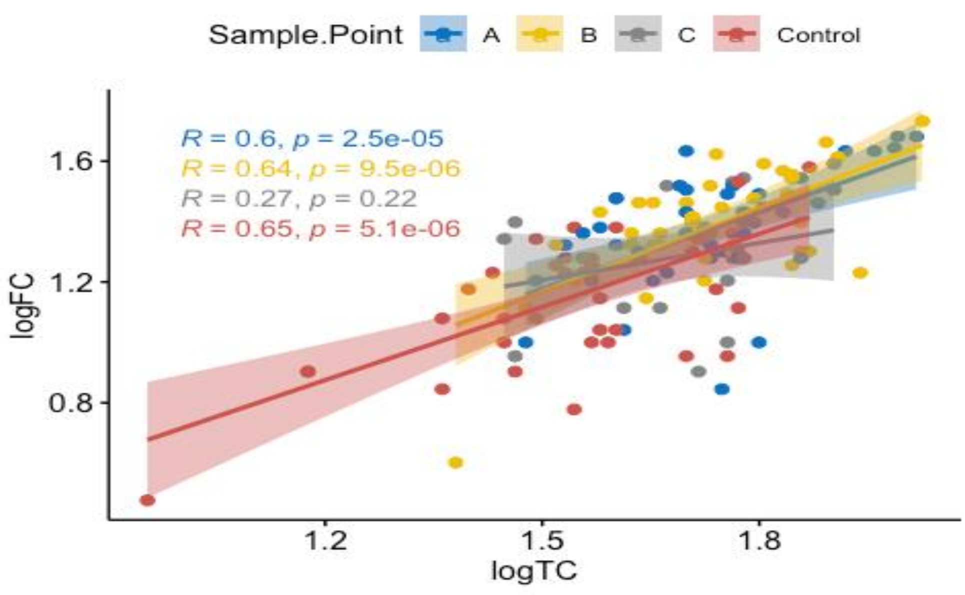


Figure 33. Pearson correlation between mean total and fecal coliforms from the sampled points in the cage culture sites for the five counties annexing Lake Victoria, Kenya. (logTC = logarithmic total coliforms; logFC = logarithmic fecal coliforms; $p = 0.05$; R value = correlation coefficient)

The mean total coliform counts reported in all the counties from the water sampled from cage culture sites in this study ranged from 90 – 1600 cfu/10ml with a mean value (480 cfu/10ml). Majority of the cage culture sites had values above the recommended limit of <100cfu/10 ml of total coliforms for aquaculture (Osei et al., 2019). Kisumu cage culture sites recorded the highest median total coliforms counts (560 cfu/10ml) which could be attributed to the high pollution and effluent discharge from people and industries within Kisumu City and the sheltered Winam Gulf thus limiting the ability of the water mixing up to flush the effluent.

The mean fecal coliform counts reported in all the counties from the water sampled from cage culture sites in this study ranged from 30 – 540 cfu/10ml with a mean value (200 cfu/10ml). All of the cage culture sites had values above the recommended limit of < 1cfu/10 ml of fecal coliforms for aquaculture (Osei et al., 2019). This indicates that the microbiological quality of the water at the study area, as shown by counts of fecal coliforms, were unusually high. The high counts of fecal coliforms may be due to fecal effluent deposition in the lake by the people and livestock in the area and also the discharge of sewage from the human settlements along the lake.

The results indicate that cage aquaculture has an effect on water quality as the cultivation of fish in net cages which requires the use of large quantity of alimentary inputs results in a discharge of large amounts of alimentary residues to the environment which can influence the microbiological quality of water (Gorlach-Lira et al., 2013). Additionally, it could be attributed to population pressure in the riparian counties resulting to increased anthropogenic activities. The people living along the lake depend on the lake's water for domestic purposes such as water abstraction, animal watering, swimming, cleaning of vehicles and other purposes. Also, the high temperature of the water observed and the neutral and alkaline pH are favorable for the growth of bacteria (Gorlach-Lira et al., 2013). Such conditions were observed in this study where the water temperature ranged from 25 - 30ºC and the majority of samples showed a pH of over 7.00 during the period of study.

3.7 Macroinvertebrates

Benthic macro-invertebrates (macrofauna) are restricted in sediments (sessile), but they can also move from terrestrial or emergent and floating aquatic vegetation to the aquatic environments. Other groups undergo complete or incomplete metamorphosis and can be found at different life stages (larvae, nymphs, instars, or adults). The freshwater macro-invertebrates recorded in this study consisted of a total of 2628 individuals representing 9 orders, 15 families, and 18 genera (Table 13 & 14). In general, Mollusca and Oligochaeta dominated in abundance. Prosobranchiata, Haplotaxida, Unionoida, Venenoida, Diptera, and Trichoptera were the dominant groups. The rare groups included Decapoda, Hirudinida and Plumonata. Cages in Ogal, Achutho, Luanda Gembe, Litare (control), and Bumbe beaches recorded the highest number of taxa. A relatively lower number of taxa were found in control sites as compared to cage sites, except for Litare, Victory farms, Global Tilapia Husbandryia and Humanist sites (Figure 34). However, analysis done for comparison using the Mann-Whitney non-parametric test revealed no significant difference (Mann-Whitney test, $p = 0.507$) between the number of macro-invertebrates recorded in the control and cage sites (pooled data).

Species dominance was observed in cages at Bumbe, Othany, Dunga, Ogal, Rudacho, Mukuloba and Luanda Gembe beaches. There was a clear rare occurrence of the sensitive taxa in the sampled areas. The Shannon-Weiner diversity index (H') ranged from 0.287 (Kaugege Control) to 2.652 (Usenge control). A higher evenness value, indicating higher diversity was found in control sites except for Victory farms, and cages in Kiwa and Kaugege beaches. The species *Melanoides tuberculata, Gillia altilis, Tubifex tubifex,* and *Anadonta cygnea* were the dominant species in the lake sediments. Hirudinea were only represented by leech, *Hirudo medicinalis*, but previous reports also indicated presence of Oligochaetes (*Branchuira sowerbyi* and *Alma emini)* in the lake sediment.

Table 13. Recorded occurrences of macro-invertebrate species in control and caged areas of Lake Victoria (Kenya) in March 2022

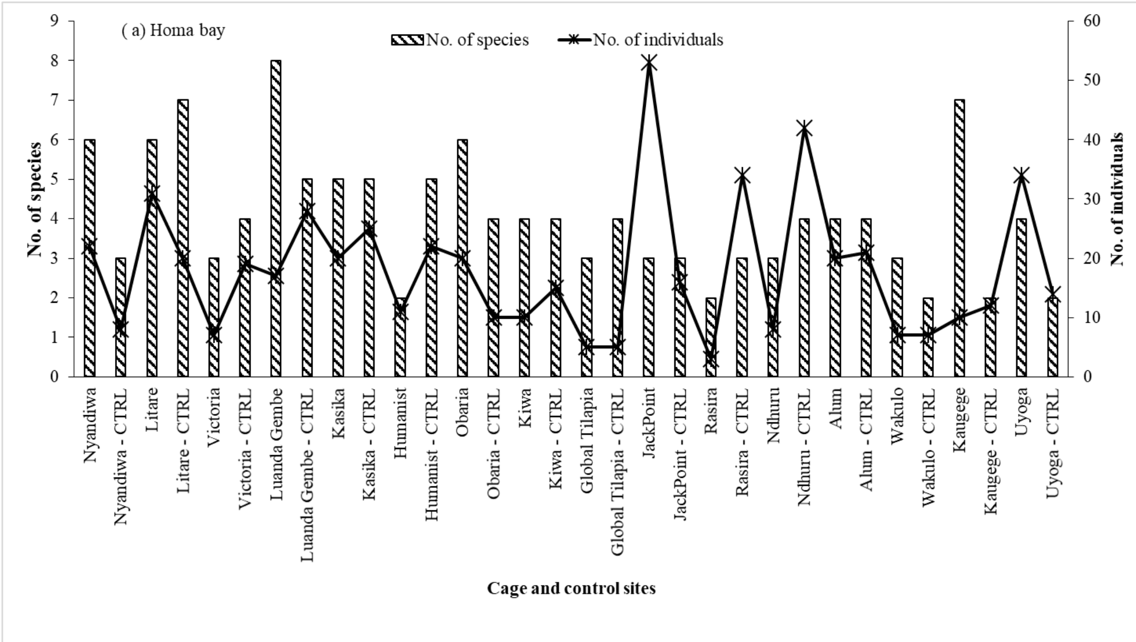
Order	**Family**	**Species**	**Caged and control sampling sites (Frequency of occurrence, %)**	**Individuals (% composition)**
Prosobranchiata	Bithynidae	*Trionia sp*	55 (1.7 %)	2 (0.1)
	Thairidae	*Melanoides tuberculate*	1, 3, 4,5,6,7,8,9,10,13,14,16,17,22,24,25,26,28,31,32,33,35,36,37,38,39,40,41,42,43,44,45,46,47,48,49,50,51,52,53,54,55 (75 %)	575 (21.9)
	Hydrobiidae	*Gillia altilis*	1, 3, 4,7,8,10,11,12,16,17,18,19,22,23,24,25,26,29,30,31,33,35,36,37,38,39,40,41,42,44,45,46,47,48,49, 50,51,52,53,55,56 (73 %)	830 (31.6)
Haploxida	Tubificidae	*Tubifex tubifex*	1, 3, 4,6,7,8,9,10,11,12,13,15,17,22,23,24,25,26,29,34,35,36,37,38,39,40,41,42,43,50,51,53,54,55,56 (62.5 %)	218 (8.3)
	Lumbricidea	*Lumbriculus variegatus*	1, 2, 3, 4,14,15,16,18,19,20,29,41,46,47,48,53,56 (30.4%)	26 (1.0)
	Naididae	*Naids sp*	55 (1.7 %)	2 (0.1)
Unionoida	Unionidae	*Anadonta cygnea*	1, 2, 3, 4,7,8,9,10,12,13,18,20,25,26,27,28,29,30,31,33,34,35,40,41.42,,43,44,45,46,47,48,49,50,51,52,53,54,55,56 (69.6%)	425 (16.2)
		Unio pictorum	1,7,8,12,13,14,15,38,39,41,48,50,52,53,56 (26.8 %)	40 (1.5)
Veneroida	Sphaeridae	*Sphaerium sp.*	2, 4, 5,6,7,9,10,12,14,18,23,37,38,39,40,53,55 (30.4 %)	254 (9.7)
Diptera	Chronomidae	*Chiromomus tentans*	3, 5,6,15,16,18,19,20,21,32,35 (19.6 %)	99 (3.8)
		Ablebesmyia sp.	4,7,24,27,36,44,53,54,55,56 (17.9 %)	79 (3.0)
	Tipulidae	*Tipulus sp*	35 (1.7 %)	1 (0.0)
Ephemeroplera	Caenidae	*Caenis rivulorum*	27 (1.7 %)	2 (0.1)
	Ephemeridae	*Hexagenia bilineata*	33 (1.7 %)	18 (0.7)

Trichoptera	Polycentropodidae	*Polycentropus sp*	7,9,13,21,27,35,36,41,45,49,53,55 (21.4 %)	30 (1.1)
	Leptoceridae	*Leptocerus sp*	27,53,55,56 (7.1 %)	21 (0.8)
		Setodes sp	53 (1.7 %)	3 (0.1)
Decapoda	Palaeomonidae	*Paleomonetes paludosus*	33 (1.7 %)	1 (0.0)
Hirudinida	Hirudinididae	*Hirudo medicinalis*	33 (1.7 %)	1 (0.0)
Plumonata	Physidae	*Physa agripa*	43 (1.7 %)	1 (0.0)
Total				2628

Table 14. Recorded macro-invertebrates' taxa, species richness, evenness, diversity and number of sensitive groups in caged areas of Lake Victoria, Kenya in March 2022

Lake zones	Sites	Taxa	Species richness	Shannon-Weiner Diversity	D- Simpsons Diversity	E, Evenness	1-D Simpson's index of diversity	Sensitive taxa
Open lake	Nyandiwa	5	22	1..313	0.331	0.425	0.669	
	Control	3	8	1.040	0.375	0.500	0.625	
	Litare	6	31	1.601	0.255	0.466	0.745	
	Control	7	20	1.429	0.295	0.477	0.705	
	Victoria	3	7	0.956	0.429	0.491	0.571	
	Control	4	19	0.854	0.568	0.290	0.432	
	Kasika	5	20	1.277	0.340	0.426	0.660	1
	Control	5	25	1.390	0.290	0.432	0.710	
	Humanist	2	11	0.305	0.835	0.127	0.165	
	Control	4	22	0.925	0.554	0.299	0.446	
	Obaria	5	20	1.261	0.365	0.421	0.635	1
	Control	4	10	1.221	0.340	0.530	0.660	
	Kiwa	4	10	1.089	0.420	0.473	0.580	
	Control	4	15	0.988	0.484	0.365	0.516	
	Global Tilapia	3	5	1.055	0.360	0.656	0.640	
	Conrol	4	5	1.332	0.280	0.828	0.720	
	JackPoint	3	53	0.376	0.825	0.095	0.175	
	Control	3	16	0.463	0.773	0.167	0.227	
	Rasira	2	3	0.637	0.556	0.580	0.444	1
	Control	3	4	1.040	0.375	0.750	0.625	
	Ndhuru	3	8	0.900	0.469	0.433	0.531	
	Control	4	42	1.049	0.412	0.281	0.588	
	Alum	4	20	1.305	0.285	0.436	0.715	
	Conrol	4	21	0.567	0.741	0.186	0.259	
	Mukuloba	4	170	0.988	0.484	0.192	0.516	
	Control	5	40	1.264	0.331	0.343	0.669	
	Rudacho	5	200	1.098	0.442	0.207	0.558	

	Control	5	64	1.492	0.245	0.359	0.755	
	Usenge	6	47	2.494	0.354	0.648	0.646	
	Control	5	53	2.652	0.319	0.668	0.681	1
	Dele	4	37	1.033	0.427	0.286	0.573	
	Control	4	21	1.145	0.374	0.376	0.626	
	Anyanga	4	44	1.200	0.325	0.317	0.675	
	Control	4	21	1.047	0.420	0.344	0.580	1
	Luanda Kotieno	4	172	1.170	0.328	0.227	0.672	
	Control	4	9	0.849	0.506	0.386	0.494	
	Uyawi						1.000	
	Control	4	8	1.321	0.281	0.135	0.719	1
	Nyenye Got	4	52	1.229	0.329	0.311	0.671	
	Uwaria	4	18	0.974	0.488	0.337	0.512	
	Luanda Rombo	3	20	0.996	0.430	0.332	0.570	
	Bumbe	9	233	1.248	0.492	0.229	0.508	25
Winan Gulf	Luanda Gembe	7	17	1.895	0.156	0.156	0.844	1
	Control	4	28	1.189	0.367	0.367	0.633	
	Kaugege	5	10	1.471	0.260	0.260	0.740	3
	Control	2	12	0.287	0.847	0.847	0.153	
	Uyoga	4	34	0.982	0.424	0.424	0.576	
	Control	2	14	0.652	0.541	0.541	0.459	
	Wakulo	3	7	0.956	0.429	0.429	0.571	
	Control	2	7	0.683	0.510	0.510	0.490	
	Othany	6	253	1.064	0.437	0.437	0.563	18
	Control	2	23	0.646	0.546	0.546	0.454	
	Achutho	7	68	1.031	0.513	0.513	0.487	2
	Control	5	35	1.571	0.215	0.215	0.785	9
	Dunga	4	209	1.111	0.376	0.376	0.624	
	Ogal	10	213	1.380	0.327	0.327	0.673	6
	Wayanda	4	47	1.347	0.341	0.341	0.653	1


(a) Homa bay
No. of species
No. of individuals
Cage and control sites
Nyandiwa
Nyandiwa - CTRL
Litare
Litare - CTRL
Victoria
Victoria - CTRL
Luanda Gembe
Luanda Gembe - CTRL
Kasika
Kasika - CTRL
Humanist
Humanist - CTRL
Obaria
Obaria - CTRL
Kiwa
Kiwa - CTRL
Global Tilapia
Global Tilapia - CTRL
JackPoint
JackPoint - CTRL
Rasira
Rasira - CTRL
Ndhuru
Ndhuru - CTRL
Alum
Alum - CTRL
Wakulo
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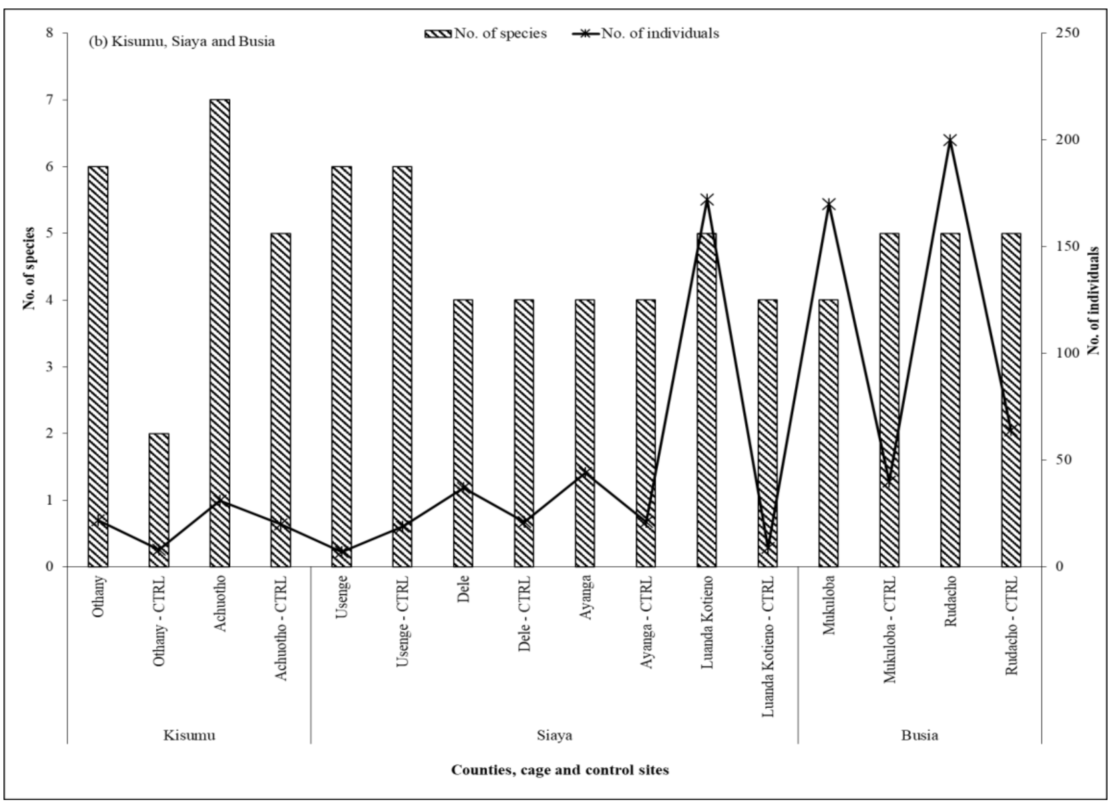
Kaugege
Kaugege - CTRL
Uyoga
Uyoga - CTRL


(b) Kisumu, Siaya and Busia
No. of species
No. of individuals
Othany
Othany - CTRL
Achuotho
Achuotho - CTRL
Usenge
Usenge - CTRL
Dele
Dele - CTRL
Ayanga
Ayanga - CTRL
Luanda Kotieno
Luanda Kotieno - CTRL
Mukuloba
Mukuloba - CTRL
Rudacho
Rudacho - CTRL
Kisumu
Siaya
Busia
Counties, cage and control sites

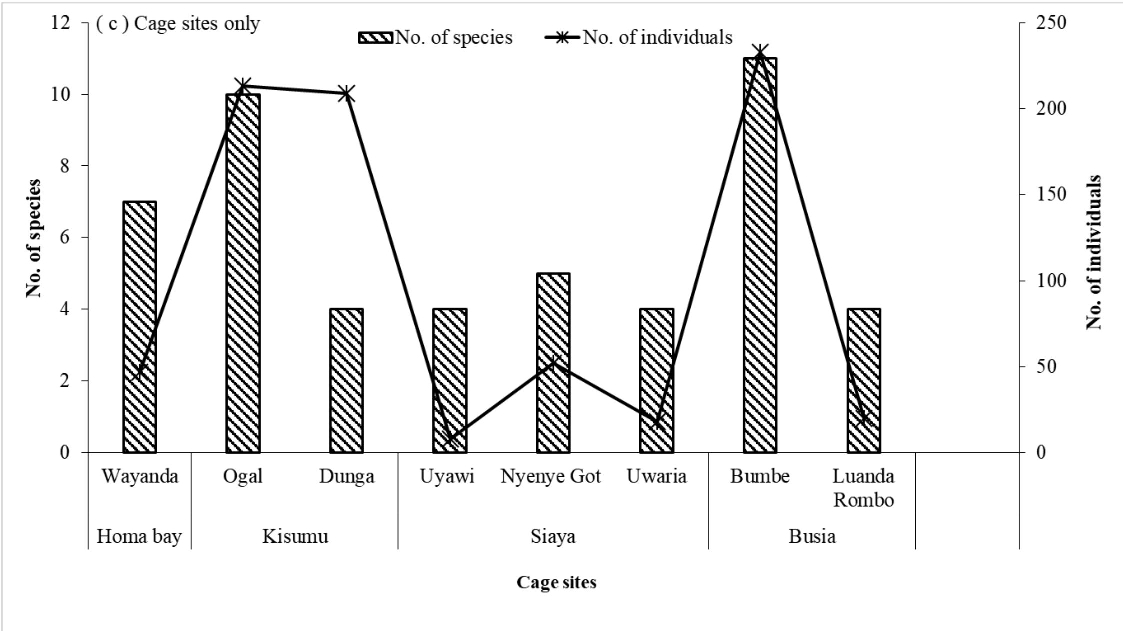


Figure 34. (a - c). The number of macro-invertebrate species and individuals recorded in caged and control sites within Homa Bay (a), Kisumu, Siaya and Busia (b & c) counties in March 2022 (CTRL = Control sites)

Macroinvertebrates species abundances varied spatially among the cage and control sites. There were no control sites for cages at Wayanda, Ogal, Dunga, Uyawi, Nyenye Got, Uwria Bumbe and Lunda Rombo beaches (Figure 35) to allow for a comparative evaluation of macro-invertebrate species. However, between these sites, a relatively lower species abundance was evident for cages at Wayanda and Nyenye Got beaches.

The results are comparable with previous initial findings on benthic macroinvertebrates in Lake Victoria which found dominance of non-insect groups. According to previous studies on macroinvertebrate community in the Nyanza gulf (Muli, 2005), molluscs were found to dominate in the gulf and off Yala river mouth while Tubificidae were more dominant in the open lake. The species diversity in the sediments was higher (0.287 - 2.652) in the current study than previously reported (0.7 to 1.1 in Nyanza gulf area and 0.07 to 0.2 in open lake stations) (Muli, 2005). However, the observed differences could be as a result of the few sampling stations in the previous study.

Muli (2001) reported the dominance of insecta group of macroinvertebrates (80% Insecta, Mollusca 8% Crustacea 2%, Annelida 7%; Arachnida 2%) associated with water hyacinth mats in the Nyanza gulf. The high number of these tolerant species (Tubificidae and Oligochaetes) in the gulf may indicate increasing organic pollution in sediment, especially due to subsequent previous invasions and accumulation of water hyacinth plant remains in the major bays of the Winam gulf and eutrophication. In this study, there were large numbers of gastropods and bivalves, especially the family *Thairidae*, *Hydrobiidae* and *Sphaeridae* respectively. Besides some of the gastropod species acting as intermediate hosts of disease vectors, are part of the group of organisms of economic benefit (as animal feed; soil additives ornamental) since the empty molluscs and bivalve shells is a natural resource usually exploited by the fisher communities along the sandy lake shores, and can provide additional source of livelihoods apart from the fishing activities.

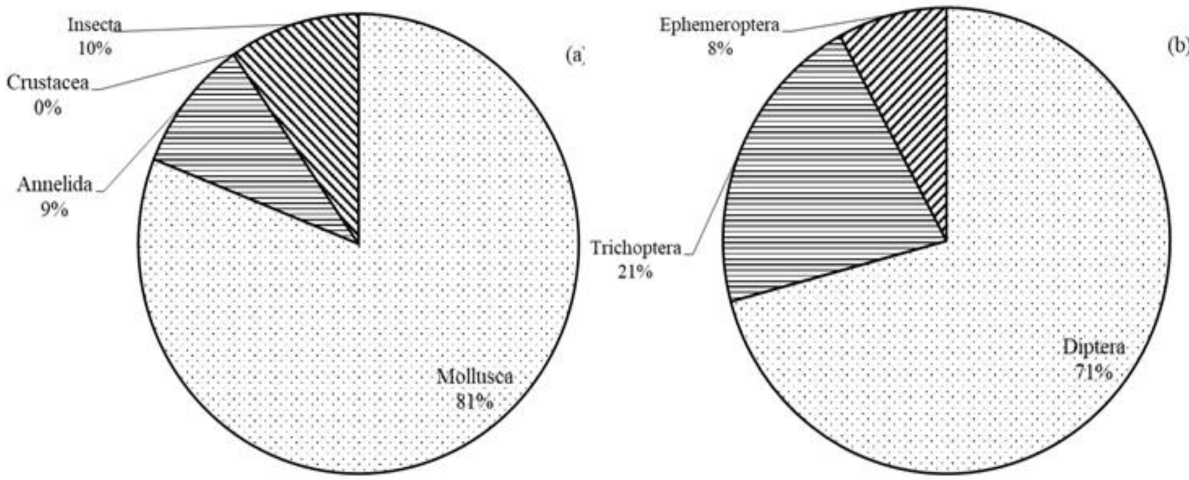


Figure 35. (a-b). The spatial taxonomic composition of the main macroinvertebrate (a) and insecta (b) groups in Lake Victoria, Kenya in March 2022

3.8 Biological aspects - Fisheries

3.8.1 Length-weight relationship

A total of 825 specimens of *O.niloticus* across the five counties were sampled (Table 15). Bumbe in Busia county had the highest count of samples (n = 91) while the lowest sample size collected was from Kisaka in Homa Bay County (n = 8). A one-sample t-test per county revealed that the b values of the specimens from Kisumu county (T−1.43 p = 0.25), Busia (T-0.74, p = 0.51) and Migori (T -1.25, p = 0.43) were not significantly different from the hypothesized isometric value of 3, while Siaya (T-5.27, p = 0.01) and Homa Bay (T-2.33, 0.04) were significantly less than 3. Most of the Length-weight relationships (LWR) for majority of the stations were strongly positive and significant save for Lwanda Nyamasaria ($r^2 = 0.14$, p = < 0.001) and Othany ($r^2 = 0.32$, p = < 0.001).

The LWR of a fish is a reliable indicator of the well-being of a fish population, therefore it is a crucial parameter in depicting the growth pattern and growth performance of fish in various culture systems (Bolger and Connolly, 1989; Da Costa and Araujo,2003). When the value of *'b'* i.e. the slope of the regression line is equal to 3, it is indicative of isometric growth i.e. the fish increases uniformly in length and weight as it grows. Allometric growth ($b \neq 3$) is of two types; negative allometric growth and positive allometric growth. Negative allometric growth is where by $b < 3$ indicating that the fish increases faster in length than weight as it grows while positive allometric growth i.e. $b > 3$ indicates that the fish increases in weight faster than length as it grows (Riedel et al., 2007).

The b values of the specimens from Kisumu, Busia, and Migori counties were not significantly different from the hypothesized isometric value of 3, indicative of allometric growth while Siaya (T-5.27, p = 0.01) and Homa Bay (T-2.33, 0.04) were significantly less than 3 indicative of negative allometric growth. This variation in b values of the same species may be due to differences in environmental parameters such as salinity, temperature, nutrition, state of gonad development, and physiological state of the fish at the time of sampling (Armin et al., 2005).

In terms of establishments, there are some whose b value is less than 3 such as Ayanga (Siaya) 1.45, Ludacho (Busia) 1.69, Lwanda Nyamasaria (Homa Bay) 1.31 and Othany (Kisumu) 1.91. This may also be due to a combination of factors such as poor nutrition, water quality in these establishments (Mommsen, 1998), sample size, and length range (Ecoutin and Albaret, 2003).

Table 15. Length-weight relationships of *O. niloticus* for the sites samples during the survey across five (5) counties. Significant difference ($p < 0.001$) was noted across sites.

	Stations		**TL (cm)**		**L-W parameters**		
County		**N**	**Min**	**Max**	**A**	**b**	**r^2**
Busia	Bumbe	91	8.7	23.7	-1.91	3.18	0.98
Busia	Ludacho	60	9.6	111	-0.11	1.69	0.55
Homa Bay	Alum	48	8.7	18.1	-0.88	2.29	0.79
Homa Bay	Global	29	22.9	33	-0.28	2.01	0.39
Homa Bay	Humanist	32	12.2	28	-1.02	2.48	0.92
Homa Bay	Jack Port	18	12.4	31.5	-1.34	2.69	0.96
Homa Bay	Kamba	17	16.3	27.5	-1.9	3.12	0.96
Homa Bay	Kaugege	10	24.4	29	-0.98	2.72	0.53
Homa Bay	Kisaka	8	18.8	25.1	-1.65	2.96	0.81
Homa Bay	Kitawi	27	15	31.3	-1.68	2.95	0.94
Homa Bay	Litare	26	11.9	23.6	-1.9	3.17	0.95
Homa Bay	Lwanda N	15	26.1	30.2	0.69	1.31	0.14
Homa Bay	Mrongo	40	13.8	26.8	-1.91	3.15	0.93
Homa Bay	Nyandiwa V	27	19.3	25	-0.98	2.48	0.57
Homa Bay	Obaria	25	5	16.3	-1.89	3.11	0.97
Kisumu	Achuodho	29	13.3	25	-1.29	2.69	0.96
Kisumu	Dunga	38	21.9	28.9	-1.46	2.84	0.91
Kisumu	Ogal	68	17.2	30.1	-1.8	3.1	0.97
Kisumu	Othany	34	19.4	25.5	-0.23	1.91	0.32
Migori	Oodi	88	20	41.5	-1.4	2.82	0.9
Migori	Sori	23	13	21	-1.63	2.98	0.9
Siaya	Ayanga	9	22.5	27.4	0.51	1.45	0.67
Siaya	Lwanda K	10	26	30	-0.44	2.12	0.64
Siaya	Usenge	11	22.4	30.4	-0.71	2.27	0.7
Siaya	Uwaria	27	11.5	27.2	-0.59	2.19	0.69
Siaya	Uyawi	15	11.5	26.5	-1.36	2.76	0.89

	Total	825

N = sample size; a = is a scaling constant for weight at length of fish; b = is a shape parameter indicating body form of fish/allometry, b = 3 Isometric growth, b < 3 negative allometric growth, b >3 positive allometric growth; r^2 = coefficient of determination, it ranges from 0-1 when r^2 <0.5 the correlation between length and weight is weak, r^2 >0.5 the correlation is strong; P value is a statistical measure of significance when p < 0.05 indicates that the correlation of length and weight is significant >0.05 is not significant.

3.8.2 Relative condition factor

The mean relative condition factor (Kn) for specimens sampled in each station was approximately 1.00 ± 0.01 apart for Uwaria which had a mean value of 0.93 ± 0.04 (Table 16). However, the mean Kn for the specimens did not vary between the stations (DF 26, p = 0.41). The condition factor pwas used to determine the feeding activity of a species to determine whether it is making good use of its feeding source (Lizama and Ambrósia, 2002; Weatherlley, 1972; Gomiero et al., 2008). The mean relative condition factor of 1.00 ± 0.01 indicated that the cultured fish were in a good physiological state and well-fed at the time the survey was being conducted. However, Uwaria had a mean of 0.93 ± 0.04 indicating that the fish were not in good health condition. This difference may have been due to the kind of food consumed, level of muscular development, and amount of fat reserve (Barnham and Baxter, 2003).

Table 16: Mean relative condition factor (Kn) for *O. niloticus* samples from the stations sampled during the survey across five (5) counties. (n = sample size; Min = Minimum Kn; Max = Maximum Kn. Condition factor (Kn) is a value indicating the well-being of a fish. When Kn <1 fish is unhealthy and not well fed, when Kn >1 fish is healthy and well fed)

Stations			**Condition Factor (Kn)**		
County		**n**	**Mean ±SE**	**Min**	**Max**
Busia	Bumbe	91	1.01 ±0.02	0.75	1.97
Busia	Ludacho	60	1.14 ±0.07	0.05	2.29
Homa Bay	Alum	48	1.03 ±0.04	0.68	2.34
Homa Bay	Global	29	1.02 ±0.04	0.58	1.42
Homa Bay	Humanist	32	1.01 ±0.03	0.68	1.65
Homa Bay	Jack Port	18	1.01 ±0.04	0.7	1.37
Homa Bay	Kamba	17	1.00 ±0.02	0.74	1.16
Homa Bay	Kaugege	10	1.01 ±0.05	0.78	1.37
Homa Bay	Kisaka	8	1.01 ±0.05	0.84	1.26
Homa Bay	Kitawi	27	1.01 ±0.03	0.8	1.74
Homa Bay	Litare	26	1.01 ±0.03	0.74	1.24
Homa Bay	Lwanda N	15	1.02 ±0.06	0.66	1.38
Homa Bay	Mrongo	40	1.01 ±0.03	0.81	2.11
Homa Bay	Nyandiwa V	27	1.01 ±0.03	0.68	1.43

Homa Bay	Obaria	25	1.01 ±0.03	0.76	1.54
Kisumu	Achuodho	29	1.00 ±0.02	0.87	1.2
Kisumu	Dunga	38	1.00 ±0.01	0.89	1.21
Kisumu	Ogal	68	1.00 ±0.01	0.82	1.12
Kisumu	Othany	34	1.02 ±0.03	0.68	1.71
Migori	Oodi	88	1.01 ±0.02	0.54	1.66
Migori	Sori	23	1.01 ±0.03	0.84	1.61
Siaya	Ayanga	9	1.00 ±0.02	0.92	1.08
Siaya	Lwanda K	10	1.00 ±0.02	0.89	1.13
Siaya	Usenge	11	1.01 ±0.04	0.73	1.21
Siaya	Uwaria	27	0.93 ±0.04	0.53	1.39
Siaya	Uyawi	15	1.04 ±0.08	0.63	2.06

3.8.3 Specific growth rate

Victolapia cages in Nyandiwa had the highest mean specific growth rate (SGR) (1.77 ± 0.01) while Othany had the lowest (0.50 ± 0.01) (Table 17). One-way ANOVA performed on the samples revealed that the mean SGR for the stations was significantly different from each other (DF 17, $p < 0.01$). Post hoc pairwise comparison test indicated that the samples from Victolapia (1.77 ± 0.01) significantly differed from all the other stations ($p < 0.05$). The SGR values for the specimens in this study were compared with other studies. The study by Kembenya and Ondiba, (2021) obtained a value of 1.98 for the monosex population reared in cages while Omweno et al. (2020) obtained a higher value (2.78) for the monosex population, though they were reared in wooden ponds as compared to cages in this study. Similarly, Githukia et al. (2015) obtained an SGR value of 1.83 in earthen ponds. There are significant differences in mean SGR for the counties (DF 3, p = < 0.01) with Migori having the highest mean value (1.42 ± 0.02) and being significantly different from Siaya, Homa Bay and Kisumu. Homa Bay and Kisumu were not significantly different from each other however Kisumu had the lowest mean SGR (0.96 ± 0.02) (Figure 36). The SGR of *O. niloticus* is usually affected by the type of feed (Opiyo et al., 2014) and Physico-chemical parameters of water quality (Makori et al., 2017), either one or a combination of these may have brought about the differences encountered in this study.

Table 17. Mean specific growth rate (SGR) for *O. niloticus* samples from the stations sampled during the survey across five (5) counties. (n = sample size; Min = Minimum Kn; Max = Maximum Kn. Specific growth rate (SGR) shows growth performance i.e., percentage weight gained per day. The higher the SGR the higher the weight gained per day.)

	Stations		Specific growth rate (SGR)		
County		**n**	**Mean ±SE**	**Min**	**Max**
Homa Bay	Alum	48	0.79 ±0.02	0.68	2.34
Homa Bay	Globol	29	1.16 ±0.01	0.89	1.21
Homa Bay	Humanist	32	0.66 ±0.02	0.58	1.42
Homa Bay	Jack Port	18	0.71 ±0.04	0.68	1.65
Homa Bay	Litare B	26	1.08 ±0.02	0.7	1.37
Homa Bay	Nyandiwa V	27	1.77 ±0.01	0.78	1.37

Homa Bay	Obaria	25	0.67 ±0.07	0.84	1.26
Kisumu	Achuodho	29	1.17 ±0.01	0.87	1.2
Kisumu	Dunga	38	1.31 ±0.01	0.75	1.97
Kisumu	Ogal	68	0.92 ±0.01	0.8	1.74
Kisumu	Othany	34	0.50 ±0.01	0.05	2.29
Migori	Oodi	88	1.54 ±0.01	0.74	1.24
Migori	Sori Bea	23	0.97 ±0.02	0.89	1.13
Siaya	Anyanga	9	0.71 ±0.01	0.92	1.08
Siaya	Lwanda K	10	1.22 ±0.01	0.74	1.16
Siaya	Usenge	11	1.46 ±0.01	0.66	1.38
Siaya	Uwaria	12	1.12 ±0.04	0.81	2.11
Siaya	Uyawi	15	1.17 ±0.02	0.63	2.06

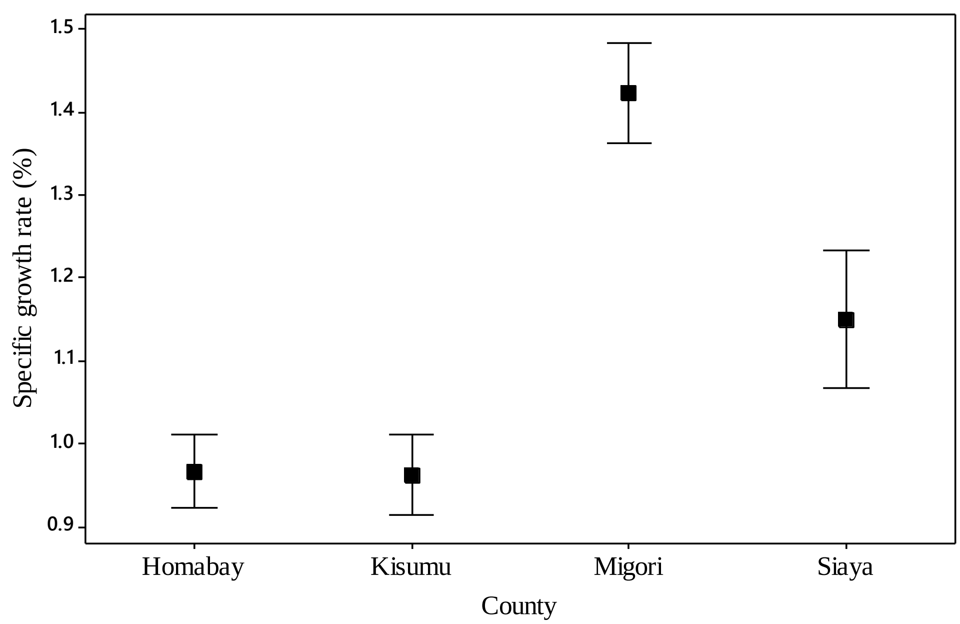


Figure 36. County mean specific growth rate (SGR) for *O. niloticus* sampled from the stations during the survey across five (5) counties.

4. Conclusions

The survey recorded a total of 5242 cages across 170 establishments in the five riparian counties with Siaya County having the highest number of cages attributed to the special support from the Ministry of Devolution in 2018. Majority of the cages are owned by Kenyans while the remaining are owned by Indians, Chinese and Europeans Cage investment is mainly by individuals while the remaining are invested by community groups, BMUs, companies, families and cooperatives. The floating cage system is the preferred technology by majority of cage investors who prefer metal frames due its sturdiness during operations such as changing fouled nets, grading, and harvesting.

Most cages and net materials are locally others out-sourced from China and the Philippines. Majority of the employees were men mainly due to the labor-intensive nature of cage production system. Women were mainly employed as casual laborers during harvesting while men were employed as feeders, security personnel, and managers. Very few marginalized and vulnerable groups were considered as employees. The cost of production and the gross margin for the various cage sizes indicate that cage aquaculture is an economically viable business. However, the profitability of the cages varied depending on the scale of operations with the 10 m diameter cage having the highest return on investment. Clearly, cage culture is a capital-intensive venture. It was established that famers had no access to quality affordable seed and feed, and extension services thereby limiting cage productivity. Lack of quality feeds locally was the main reason for importing feeds. The carrying capacity was estimated to be more than 500 percent of the current cage culture production, which is estimated to be 21,000 metric tonnes. The water quality parameters were generally within the optimal levels recommended for aquaculture. However, there was no clear gradient on the concentration of the parameters in cage locations probably due to the dilution effect of the lake water which may in the long run lead to deterioration. Fish exhibited normal growth with uniform length and weight gain. Opportunities for cage investment were noted to include the availability of materials for cage structure, adequate labour, rising demand for fish and political goodwill.

5. Recommendations

Some suggestions for developing sustainable aquaculture in Lake Victoria are provided below.

Recommendations	**Lead Institutions**
i. Monitor the certified hatcheries and feed manufacturers to ensure production standards are adhered to, explore and prioritize fish feed manufacture using locally available ingredients and capacity build the farmers through trainings.	KMFRI/KeFS/ County Governments
ii. Based on present aquaculture production and the estimated carrying capacity of the most suitable cage production sites in Lake Victoria, the lake is currently underutilized, necessitating	SDFA & BE

	additional investment in cage culture alongside best management practices.	
iii.	Geographical information systems (GIS) can be utilized to organize and show spatial data for zoning the lake in order to allow for effective environmental management planning.	KMFRI
iv.	Cage investors should adhere to the guidelines of good cage farming practices that include proper siting for better productivity.	KeFS/ County Governments
v.	Due to the high capital and operational costs of cages, the small cage investors are highly recommended to form groups or Savings and Credit Cooperative Organizations (SACCO's) to enable them to have the financial capacity to purchase and operate them.	County Governments
vi.	Appropriate policies and regulations are required for improved lake and resource management, as well as to guide cage culture business, improve security, and facilitate resource usage dispute resolution procedures.	SDFA & BE/ KeFS

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Appendices

Appendix 1. Sampled cages in Lake Victoria

1	Nyandiwa	2	Nyandiwa Control	17	Global Tilapia	18	Global Tilapia Control
3	Litare	4	Litare Control	19	Jack Point	20	Jack Point Control
5	Victoria	6	Victoria Control	21	Rasira	22	Rasira Control
7	Luanda Gembe	8	Luanda Gembe Control	23	Ndhuru	24	Ndhuru Control
9	Kisaka	10	Kisaka Control	25	Alum	26	Alum Control
11	Humanist	12	Humanist Control	27	Kaugege	28	Kaugege Control
13	Obaria	14	Obaria Control	29	Uyoga	30	Uyoga Control
15	Kiwa	16	Kiwa Control	31	Wakulo	32	Wakulo Control
33	Othany	34	Othany Control	41	Usenge	42	Usenge Control
35	Achuotho	36	Achuotho Control	43	Dele	44	Dele Control
37	Mulukoba	38	Malukoba Control	46	Anyanga	47	Anyanga Control
39	Rudacho	40	Rudacho Control	48	Luanda Kotieno	49	Luanda Kotieno Control
50	Nyenye Got Agulu	45	Uyawi Control				
51	Uwaria	54	Dunga				
52	Luanda Rombo	55	Ogal				
53	Bumbe	56	Wayanda				

Appendix 2. Socio-economics survey tool

CAGE AQUACULTURE STUDY IN LAKE VICTORIA KENYA AND SELECTED SMALL WATER BODIES IN RIPARIAN COUNTIES

Introduction

Good morning/afternoon/evening! We are a research team from Kenya Marine and Fisheries Research Institute (KMFRI) and collaborating with the Aquaculture Business Development Programme (ABDP), Kenya Fisheries Service (KeFS) and county governments. We are conducting a survey to learn about sustainable community-based cage aquaculture in the Kenyan portion of Lake Victoria and large dams in the riparian to provide policy recommendations for environmental and socio-economical sustainability of aquaculture production in the country. You have been selected to participate in an interview. This interview will take less than one hour to complete. Your participation in this study is entirely voluntary, and all responses will be anonymous. If you agree to participate, you can choose to stop at any time or to skip any questions you do not want to answer. Your answers will be completely confidential; we will not share information that identifies you with anyone. Your participation and input is very important for our study objectives.

Do you agree to participate in the survey?

- ◯ Yes
- ◯ No

Enumerators name

Date of Interview

yyyy-mm-dd hh:mm

GPS Coordinates

latitude (x.y °)

longitude (x.y °)

altitude (m)

accuracy (m)

Part I: Sociodemographic