MAKERERE UNIVERSITY

COLLEGE OF NATURAL SCIENCES

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DEPARTMENT OF ZOOLOGY, ENTOMOLOGY AND FISHERIES SCIENCES.

EFFECT OF CAGE FISH CULTURE ON THE DIVERSITY AND ABUNDANCE OF ZOOPLANKTON IN TENDE BAY LAKE VICTORIA.

BY

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AUGUST 2024

DECLARATION

I TUSIIME IVOR, declare that this work is original, entirely mine and that it has not been previously submitted to any institution of higher learning for any academic award.

Signature…………………………………… Date …20-AUG-2024…

TUSIIME IVOR.

CERTIFICATION

This is to affirm that I have approved this dissertation for submission

SIGNATURE…………………… DATE …20/8/24…

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SIGNATURE…………………… DATE …22/8/2024…

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km^2	Square kilometres
km^3	Cubic kilometres
m	Metres
%	Percent
m^2	Square metres
NO^{2-}	Nitrite
NH^{4+}	Ammonium
Kg	Kilograms
$\mu S\ cm–^{1}$	Microsiemens per centimeter
cm	Centimetres
UV	Ultraviolet
µm	Microns
ml	Millilitres
H'	Shannon Weaver diversity index
ANOVA	Analysis of variance
Sd	Standard deviation
DO	Dissolved oxygen
$mg\ L^{-1}$	Milligrams Per Litre
^{0}C	Degrees Celsius
Indiv	Individuals

ABSTRACT

Aquaculture is one of the fastest growing sectors in Uganda, producing up to 15000 tonnes of fish from small-scale farmers, emerging commercial fish farmers and stocked community water reservoirs and minor lakes. In order to cater for the increase in demand for animal protein, manifold fish rearing methods have been created and employed, one of which is cage fish farming. A fish cage is a meshed enclosure which is placed into a body of water to confine the fish in captivity until they grow to the required size. Fish cages can be put in freshwaters for fresh fish, or in marine waters for saltwater fish. Majority of Lake Victoria's Bays are subjected to aquaculture production, one of which is Tende Bay.

Two fish farms are situated in Tende bay, that is Pearl aquatics fish farm and Victoria treasures. However much the production of fish has solved the problem of low fish catch from the wild, the fish in cages impacts the water of Lake Victoria negatively.

There is deposition of materials from fish cages directly into the water, which distorts the physical parameters and chemical parameters of the water. It also brings about change in the aquatic biota thereby altering the ecology of the lake and subsequent loss of biodiversity.

The research is based on studying the community of zooplankton and the physico-chemical parameters of water, in order to find out the extent of cage culture practices on the water environment of Tende bay. Water samples for zooplankton were collected from selected three sites on Lake Victoria, that is site A, site B & site C.

The water parameters were measured in-situ and analyzed using one-way ANOVA and Mann-Whitney U test to test the differences. Zooplankton species abundance and diversity were done using Kruskall-Wallis test and Shannon-Wiener Diversity Index respectively.

The results of the three study sites compared, indicated minimal variation in the physico-chemical parameters ($p<0.05$), while oxygen indicated no significant difference ($p=0.1598$). The results for zooplankton species abundance indicated no significant differences between the study sites.

The fish cages thus had observed low impact on the lake water of Tende bay.

1 INTRODUCTION.

1.1 BACKGROUND

In Africa, the inland fisheries are crucial because they improve people's standards of living through offering job opportunities and nutritive values; Lake Victoria fisheries make up to approximately one percent of the world's total capture fisheries production while in Uganda the lake contributes half of the total fisheries production economically (Mpomwenda *et al.* 2022). Lake Victoria is part of the great lakes of Africa and has a surface area of 68800 km^2 and the largest lake in Africa in terms of surface area, globally it is the largest tropical lake and second biggest fresh water lake; has an average depth of 40 m and catchment area of 169858km^2 and is shared between the countries of Kenya, Uganda and Tanzania in percentages 6%, 45% and 49% respectively (Mawundu *et al.* 2023).

Fisheries being one of the fastest sectors account contributes greatly to the national economy and income of 300,000 households in Uganda (Nunan 2006). To meet the global demand for fish as a source of human food, the number of fish farms is growing worldwide. According to Ameworwor *et al.* (2019), Cage culture is the rearing of aquatic organisms in holding facilities covered on all sides and bottom with netting material and suspended in a water body. Cage rearing of fish in natural water bodies requires a small volume to rear a large number of organisms compared to other systems like ponds (Ameworwor *et al.* 2019).

Cage fish culture on lake Victoria in both Kenya and Uganda are for rectifying the decrease in fish catches caused by using unauthorized fishing gears and methods (Nsinda 2021) coupled with high demand for protein required by the escalating population (Anusuya *et al.* 2017).

In case of poor feed management, fish rearing in Cages deteriorates water quality from release of uneaten feeds, and soluble wastes like phosphorus, nitrogen (Zadock *et al*. 2023;), causing eutrophication (Kashindye *et al*. 2015), which is one of the major causes of drop in fish abundance & productivity of lakes and other water bodies (Mustafa 2014, Mwebaza-Ndawula 2013).

In addition to disease transmission, cage fish culturing has also increased turbidity, conductivity and Biochemical Oxygen Demand; turbidity degrades habitat quality and alters substrata for egg laying(Ameworwor *et al.* 2019). The zooplankton community's structure is expected to rapidly reflect any significant changes in the environment quality brought on by cage fish operations

(Gazonato Neto *et al.* 2014), as some members of the community are frequently employed as bio-indicators of aquatic habitats (Erondu & Solomon 2017). In their larval and adult phases, almost all fish species rely on zooplankton as a food source, hence transform plant matter into animal tissue by feeding on phytoplankton. Thus, the percentage of zooplankton production can be utilized to determine the amount of fish stocks that are suitable for exploitation (AL-Keriawy 2021, Parakkandi *et al.* 2021).

1.2 PROBLEM STATEMENT.

There is observed increase in the amount of algae and a decrease in dissolved oxygen in Tende Bay compared to the previous years and reduced growth rate of the cultured fingerlings, the effect which is attributed to cage fish farming. Excessive pollution from uncontrolled cage farming causes water turbidity and dominance of cyanobacteria which produce cyanotoxins rendering the water unfit for human consumption alongside extinction of wild aquatic species zooplankton inclusive.

Fish rearing in Cages deteriorates water quality from release of uneaten feeds, and soluble wastes like phosphorus, nitrogen, causing eutrophication. Algae absorb released soluble nutrients, proliferate and upon their collapse decompose using lots of oxygen, which is the major determinant of aquatic life as it is used in respiration of the zooplankton . The limnetic and benthic zones of the lake are significantly impacted by cage aquaculture in terms of water chemistry because they bring about change in the range of physico-chemical parameters, hence altering the zooplankton species richness and abundance,

Eutrophication is one of the major causes of drop in fish abundance & productivity of lakes and other water bodies (Mustafa 2014). Additionally, solid wastes in the water column, particularly while feeding, may discourage zooplankton (Whoriskey & Cornel 1993) by increasing turbidity of the water thereby reducing the ability of zooplankton to see. Therefore, constant environmental assessments must be effected to prevent alteration of the quality and biological productivity of water.

1.3 GENERAL OBJECTIVE.

To assess the effect of cage fish culture on the diversity and abundance of zooplankton in Tende Bay, Lake Victoria.

1.4 SPECIFIC OBJECTIVES.

1. To determine the difference in selected physico-chemical water parameters between sites within the cage impact zone and those far from cages.
2. To determine the difference in abundance and diversity of zooplankton at the sampling sites within the cage impact zone and those far from cages.
3. To determine the relationship between the selected physico-chemical parameters and zooplankton abundance.

1.5 HYPOTHESES.

1. There is no significant difference in physico-chemical water parameters at the sampling sites within the cage impact zone and those far from cages.
2. The abundance and diversity of zooplankton at the sampling sites within the cage impact zone and those far from cages is not different.
3. There is no relationship between the selected physico-chemical parameters and zooplankton abundance

1.6 SIGNIFICANCE OF THE STUDY.

To guarantee the equitable and sustainable development and management of the shared aquatic natural resources, a deeper comprehension of the consequences of cage fish culture is required. Research must focus on improving our understanding of the interactions between abiotic variables and potential nutrient loading in the system in relation to the hydrography of the water body (Parakkandi *et al.* 2021). Comprehending these dynamics is crucial to preserving the ecological integrity of Lake Victoria and guaranteeing the aquaculture industry's sustained sustainability as a way to mitigate the food security issues facing the East African region (Zadock *et al.* 2023)

The goal of the project is to directly provide farmers with more scientific knowledge so that they can manage their fish cages more effectively, and water managers can better manage their water resources.

The research's findings will also help shape policies and plans for the development of large cage fish culture in Uganda by government organizations. It will also provide the basis for the logical design and scientific application of cage farming techniques that reduce environmental effects

2 LITERATURE REVIEW.

2.1 CAGE FISH CULTURING

In African inland aquatic habitats, cage fish farming holds promise for bridging the gap between fish supply and demand, as well as for enhancing additional livelihood benefits like job opportunities, poverty reduction, and food security (Musinguzi *et al.* 2019). Around 4400 fish cages are estimated to have covered 62,100 m^2 of Lake Victoria in 2020; the number is expected to rise over time (Aura *et al.* 2020). While cage culture is frequently viewed as a way to boost fish production and create jobs, unplanned growth of such practices, especially when neglecting the environmental effects of nutrient loading, may have detrimental effects on both the capture fisheries in such water bodies and the cage culture operations themselves (Anusuya *et al.* 2017).

There are few laws and management practices concentrating on sustainable aquaculture production within the framework of an ecosystem approach to fisheries management, despite the growing usage of fish cages in African lakes and reservoirs.

Because water quality affects aquatic creatures' physiological and behavioral processes as well as productivity, it is a crucial factor in determining the structure and functioning of ecosystems (Mwamburi *et al*. 2020). Studies on the impact of experimental fish cages on the water quality in the Tanzanian section of Lake Victoria have been published. However, there are often few research describing how cage aquaculture affects the ecosystem's functioning and water quality in African lakes.

Threats from eutrophication, however, are probably region-specific and season-specific and rely on watershed management, depth profiles, and maybe the extent of cage aquaculture in the lake (Okechi *et al*. 2022).

Fish kills and a decline in benthic biodiversity can result from the water column becoming over deoxygenated due to the breakdown of leftover food and waste plus turbidity due to excessive algae growth (Mawundu *et al.* 2023). The sediment beneath fish cages changes due to the buildup of waste food and fish faeces, and is distinguished by a high content of organic material (Safina *et al*. 2022), which lowers the pH (Anusuya *et al.* 2017) and elevates the conductivity (Parakkandi *et al*. 2021).

Fish cages have caused the concentrations of NO^{2-} and NH^{4+} in the water at caged sites to rise in comparison to the control sites. For every 1000 kg of fish produced, freshwater cage fish farms are estimated to produce between 240 kg and 318 kg of waste material, which is then discharged into the aquatic ecosystem (Baguma *et al.* 2023). The microorganisms accountable for the breakdown of organic materials are primarily located in the sediment layer at the surface and become less numerous as one descends due to the restricted supply of dissolved oxygen. This anoxic environment significantly reduces the rate at which organic matter is broken down by microbes (Zhen-Zhen *et al.* 2023).

Farming cages arranged closely together can obstruct the flow of bottom water (Parakkandi *et al.* 2021), resulting in conditions of hypoxia or even anoxia. Under these circumstances, inert phosphorus accumulates and the amount of phosphorus in the bottom sediment increases because active phosphorus cannot be completely oxidized and broken down (He *et al*. 2015). Increased phosphorus levels have reduced biodiversity in salmon farming areas in Chile and Norway, whereas increased organic matter and phosphorus levels have lowered species richness and abundance in sea bream farming in the Mediterranean region (Soto *et al.* 2019).

Cages generate waste that is highly concentrated in nitrogen and phosphorus and is discharged into the water column as a solute (Kashindye *et al.* 2015, Mawundu *et al.* 2023).
Nitrogen and phosphorus-driven eutrophication can lead to excessive plankton growth and oxygen-depleted conditions, which can have a negative impact on the health of aquatic animals (Parakkandi *et al*. 2021).
Plankton populations, biodiversity, and secondary output are all impacted over time, and the effects spread beyond the immediate vicinity of the cage farming area to a regional level (Zhen-Zhen *et al*. 2023).

According to research conducted in Kadimu bay Lake Victoria by Mawundu *et al.* (2023), a number of water quality parameters were measured, and the results showed that the aquaculture activities had less of an impact on the ionic composition of the water and, consequently, on the ecological functioning of the bay. These parameters included acidity, total dissolved solids, turbidity, electrical conductivity, total suspended solids, nitrates, nitrites, TN, ammonia, and ammonium ion concentrations. Water movements have been linked to similar findings for cage fish farming on the Tanzanian side of Lake Victoria.

Animal immune system enhancement is significantly aided by conductivity. Fish kept in aquaculture are more vulnerable to disease at low conductivity levels, and have better immunity at high conductivity levels, above 1000 μS cm^{-1} (Baguma *et al.* 2023).

To maintain aquaculture production and ecosystem function, the water quality parameters at the cage sites must be continuously monitored (Dos Santos *et al*. 2009). An advantage of regulating the sustainable exploitation of sites that use cages is that it lowers the possibility of disturbing the bays' physicochemical quality (Parakkandi *et al*. 2021).

Baguma *et al.* (2023) concludes that the bays' water quality is negatively impacted by cages. If these activities stopped, these locations would become excellent fish breeding grounds.
An examination of feed quality and how it affects Nile Tilapia growth would help to clarify the various tactics to take into account for successful aquaculture in such a setting (Kubiriza *et al.* 2024).

2.2 DIVERSITY AND DISTRIBUTION OF PLANKTON IN LAKE VICTORIA.

Phytoplankton are composed of a variety of eukaryotic, polyphyletic photosynthetic organisms which include unicellular microalgae (like Chlorella), diatoms (like Nitzschia and Amphora) and multicellular macroalgae (like giant kelp); Algae are classified broadly into Cyanophytes, Glaucophytes, Rhodophytes, Chlorophytes , Euglenophytes, Crytophytes and Heterokonts (Miruka *et al*. 2021).
Zooplankton are small aquatic organisms that float or drift in the water column throughout all or part of their life cycle; they are not very good at moving horizontally against currents with the exception of a few species that can migrate vertically (AL-Keriawy 2021). Zooplankton species include Rotifera (*Keratella cochlearis, K.valga,Euchlanis delatata, Philodina* etc), Cladocera *(Alona rectangular, Bosmina longistris, Chydorus sphaericus, Simocephalus vetulus, Moina* etc*)* and Copepods *(naupli, cyclopoids, calanoids* etc*).*
Phytoplankton make up the primary producer of energy in the aquatic environment and support all life in water.(Miruka *et al*. 2021).
Zooplankton growth and spatial dispersion are influenced by the mix and rate of growth of phytoplankton species (AL-Keriawy 2021). Growth of zooplankton is encouraged by increased phytoplankton output (Safina *et al.* 2022). They help transform plant matter into animal tissue by

feeding on phytoplankton, and as a result, they serve as the primary source of nutrition for higher animals like fish, especially their larvae (Erondu & Solomon 2017).

In terms of physical parameters, littoral stations differ from pelagic stations in having higher temperatures, higher pH, higher turbidities and lower secchi depths, which are generated by the higher algal abundances in littoral stations compared to the offshore; littoral stations generally have higher invariably total nitrogen, chlorophyll and organic matter concentrations than pelagic stations (Mwirigi 2023). Light limits the concentration of phytoplankton biomass because of self-shading, therefore littoral zones that are shallower and with mixing depths that are not deep shelter much more phytoplankton biomasses.

Phytoplankton are hypersensitive to their surrounding ecosystem where any change alters their composition, biomass and diversity; the major source of phosphorus and nitrogen that causes overgrowth of phytoplankton on the Lake Victoria basin are the human activities (Ssebiyonga *et al*. 2013). The major inorganic nutrients that control the abundance and diversity of phytoplankton are nitrogen, phosphorus and silica; Microcystis aeruginosa is the most abundant algal species in Lake Victoria.

The fast growth and colonization of most parts of Lake Victoria by heterocystous cyanobacteria is mainly brought about by nitrogen limitation (Sitoki *et al.* 2012). Excessive nutrification brings about an upwelling effect in the lake water thereby altering the productivity of phytoplankton; the narrow range of temperature variation in the tropics does not affect the biomass and composition of phytoplankton but rather the nutrient levels and light (Ameworwor *et al.* 2019). In the rainy season, the concentration of phytoplankton in lake Victoria is higher, dominated by the diatoms because of much introduction of nitrogen, phosphorus and silicon; the offshore regions of Lake Victoria have the synthesis of phytoplankton limited by sunlight because the mixing column of the water goes deeper below the depth of the euphotic zone (Haande *et al.* 2011).

All aquatic ecosystems, even marine ones, contain zooplankton, along with other organisms that live in freshwater or saltwater, as well as in static and dynamic situations. The cladoceran, copepods, ostracods, and rotifers are the main zooplankton taxa present in the majority of tropical freshwater lakes (Erondu & Solomon 2017).

According to Mwebaza-Ndawula *et al.* (2013), zooplankton eat the phytoplankton and proliferate, however in cases of low number of zooplankton, and far many more phytoplankton, is attributed to nutritionally inadequate and toxin containing forms of cyanobacteria. Predation pressure has a greater effect on zooplankton population density than water quality, particularly when predatory fish species are present to feed on copepoda and cladocera (AL-Keriawy 2021). Further, on Lake Victoria's near-shore regions, rotifer prominence in eutrophic circumstances was correlated with the superiority of rotifer species richness in all study transects. Food availability and nutrient enrichment increased the abundance of rotifera and cladocera.

2.3 IMPACT OF PHYSICO-CHEMICAL PARAMETERS ON THE DISTRIBUTION AND ABUNDANCE OF ZOOPLANKTON.

The time of the day and season influence the behaviour of zooplankton, due to variations in the physical-chemical parameters of the water. Numerous environmental parameters, including water, light, temperatures, chemical agents (particularly dissolved oxygen, pH, and hazardous contaminants), and the availability of food, are strongly linked to their presence. (Mamcarz 1995, AL-Keriawy 2021)

Temperature has a significant impact on aquatic habitats because it affects oxygen solubility and metabolic rates (Zadock *et al.* 2023). Dissolved oxygen is critical to the genesis and maintenance of life and indicates the extent of pollution (Anusuya *et al*. 2017).

One of the main elements influencing the zooplankton movement patterns over the 24-hour cycle is light as a noticeable response to light is predicted in the light-sensitive Cladocera and Copepoda that migrate vertically in response to relative variations in light intensity (Andrzej & Skrzypczak 2015).

According to AL-Keriawy (2021), Copepoda and Rotifera thrive and develops more favorably during warmer temperature. Cladocera are vulnerable to extreme sensitivity to pollution and filter feeding, however the cladocera species with the highest resistance to pollution is Simocephalus exspinosus, Bosmina longirostris are typically found in water that has high levels of plant nutrients. Rotifers, especially those in the genus Brachionus, react to increased eutrophication more quickly than other zooplankton species. *Brachionous calyciflorus and Keratella valga* prefer organically contaminated water while *Keratella cochelaris* is distinguished by its exceptional capacity to tolerate a broad range of pH values and elevated amounts of suspended matter. Many zooplankton adults and eggs adopt a state of hibernation as turbidity increases while Rotifers thrive in high turbidity as their competitors for food like crustacean young ones die before they reproduce. However, there are genomes in the Brachionidae family, which primarily inhabits oligotrophic to mesotrophic conditions with minimal turbidity and few acidic water bodies

In terms of photosensitivity, *Brachionus calyciflorus* & *Asplanchna priodonta* are not photosensitive, unlike *Kerateila quadrata*. Cladocerans are negatively phototactic with the exception of *Bosmina longirostris* (Mamcarz 1995). A few Daphnia species exhibit positive phototaxis in response to visible light and negative phototaxis in reaction to UV-emitting light sources, Certain species of Copepoda do not exhibit UV light sensitivity and the reason behind their migration patterns is yet unknown for example *Eudiaptomus spp*. and *Cyclops spp*. exhibit various migration patterns hence undeniable that they spend the majority of their nighttime hours in the surface layers and the *Copepoda nauplius* forms have not been observed migrating, which could be due to their decreased sensitivity to light cues (Andrzej & Skrzypczak 2015).

According to Safina *et al*. (2022), the number of rotifers at the cage site increased dramatically over sixfold in the production cycle composed of *B. angularis* and *B. calyciflorus* as other rotifer species vanished, while the number of Copepoda and Cladocera declined. All Cladocerans vanished except *Moina micrura* which tripled. Of the Copepods, nauplii persisted while Calanoids and Cyclopoida vanished. In the period of fallowing, all the three species compositions returned to preproduction numbers. Compared to Rotifers, Copepoda and Cladocera are more susceptible to decreased water quality.

3 MATERIALS AND METHODS.

3.1 STUDY AREA.

The study area was Lake Victoria which has an average depth of 40 m and a maximum depth of 81m, covers an area of 68800 km^2 at an altitude of 1134m above sea level with a volume of 2760 km^3. The specific area of study on the lake was Tende Bay situated near Kagolomolo village at an elevation of 1134 meters at latitudes and longitudes 0^o03’03.8” N & 32^o33’29.6” E respectively and average depth 12.5m. The site had twenty-one cages each measuring 6m×6m×6m where fish were cultured 90 pieces/m^2 the cages belonging to Pearl Aquatics limited. The specific areas for sampling were three, the first one within the cage area (site A), the second one 50m from the cage area (site B) and the third one 100m (site C) away from the cages. The three sites were opted for in order to allow proper replication. Each area has two sampling points. Each sampling point has three different depths (0.5m, 3m and 10m) in order to have a proper estimate of the zooplankton community structure. Therefore a total of 72 samples were collected

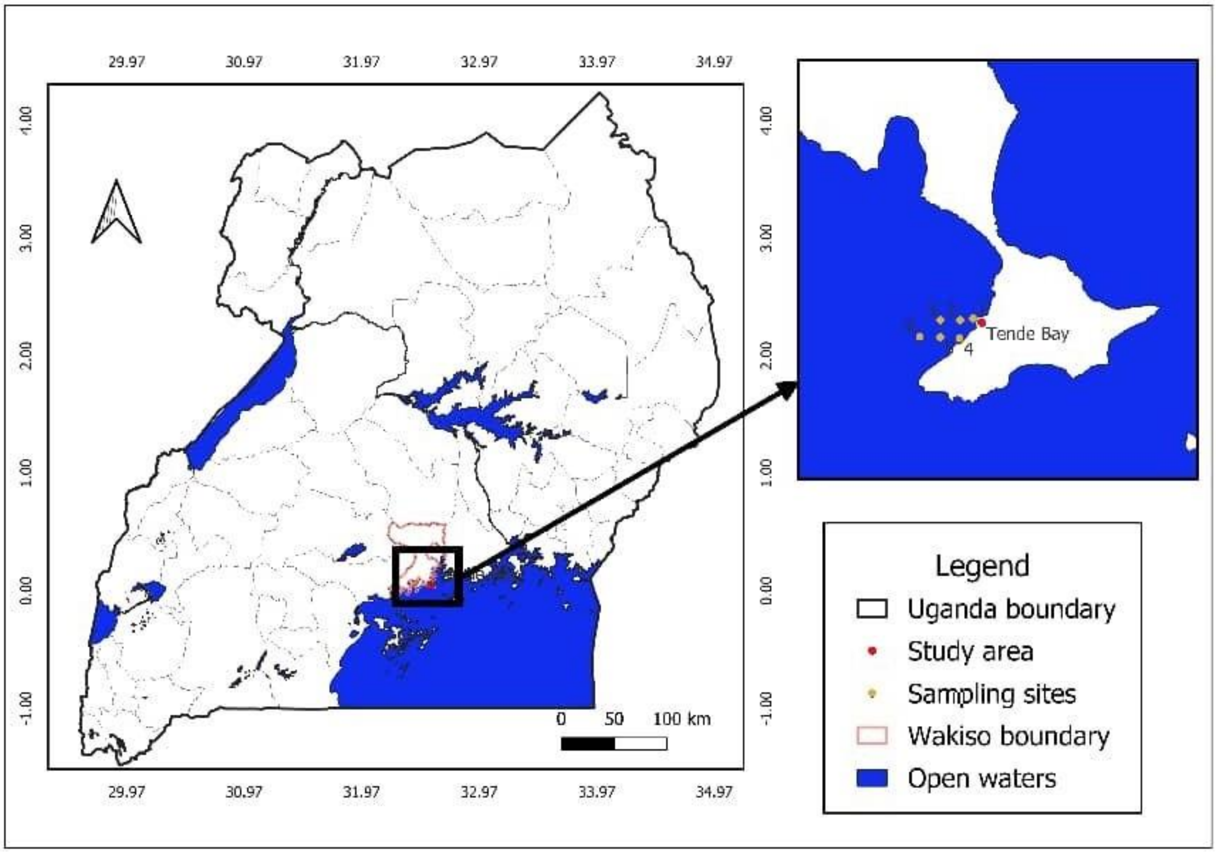

Figure 1: A map of Uganda showing Tende Bay the study area.

3.2 DATA COLLECTION METHODS

3.2.1 Collecting water samples for analysis of zooplankton.

Water samples for analysis of zooplankton were collected using a five-litre Van Don sampler and filtered over a plankton net (100 µm mesh size) and concentrated into 25ml universal plastic bottles using 96% ethanol from a wash bottle via a funnel. The concentrated samples were labelled and taken to the laboratory for analysis.

In the laboratory, the two zooplankton samples obtained from 0.5m of site A were each filtered to free zooplankton of ethanol and rinsed in tap water over a 50 µm nitex mesh and each diluted to 5 ml, both totaling to 10 ml volume. They were each examined under a compound light microscope (model MBL2000) at x100 magnification for counting (total counts) and taxonomic identification respectively to the level of genus by use of a 1ml Sedgewick-Rafter counting chamber. This was done for the rest of site A samples of 3m and 10m, and also the sites B and C. The samples were collected on four sampling dates, that is 20th February and 2nd march for the dry season; then 25march and 13th April for wet season, in order to properly determine the physico-chemical parameters and zooplankton abundance in the different seasonal conditions. The samples collected each round were analyzed separately.

The identification keys by Dussart and Defaye (1995) were used for copepods, Korovchinsky (1992) and Smirnov (1996) for Cladocera, Koste and Shiel (1987) and Segers 1995 for rotifers.

3.2.2 Measuring physico-chemical parameters.

The water quality parameters (temperature, dissolved oxygen, pH and conductivity) were measured *in situ* at the different depths of 0.5m, 3m and 10m.

Water transparency was measured with a 25cm diameter black and white secchi disk.

Dissolved oxygen, pH, and temperature were measured using a portable multiparameter water quality probe model IP67,

Conductivity was measured using a conductivity meter model HQ40d.

3.2.3 Determining of zooplankton community parameters

The community parameters, that is total numerical abundance and Shannon Weaver diversity index (H') were calculated for all the three sampling sites. Shannon Weaver diversity index was preferred because it quantifies the species richness and evenness within a given population. It is a measure that combines both the number of species present and their relative abundance, providing a comprehensive view of diversity.

Numerical abundance of the different genera was estimated by counting the individual zooplankton genera from each of the three classes.

Total numerical abundance was expressed as the total number of zooplankton per milliliter, using the formula:

$$\text{Total numerical abundance (number/ml)} = \frac{\text{total number of zooplankton in 10 ml}}{10}$$

Diversity at each sampling site was calculated by means of Shannon-Wiener Diversity Index (H') which takes into account both species richness and evenness.

Using the formula: $H' = -\Sigma p_i \ln (p_i)$,

Where H' represents the Diversity Index and p_i the proportion of a particular species in a sample belonging to the i^{th} species.

3.3 DATA ANALYSIS.

Data were analyzed using R Core Team (2021).

To determine the selected physico-chemical water parameters at the sampling sites within the cage impact zone and those far from cages, One-way ANOVA to indicate the difference in the physico-chemical parameters between the sites A, B & C.

To determine the abundance and diversity of zooplankton at the sampling sites within the cage impact zone and those far from cages, Diversity of zooplankton was calculated by means of Shannon-Wiever Diversity Index using R-studio with package vegan. Mann-Whitney U test to test differences in Shannon-Wiever Diversity Index. Abundance was determined as shown below:

$$\text{Total numerical abundance (number/ml)} = \frac{\text{total number of zooplankton in 10 ml}}{10}$$

Differences in zooplankton numerical abundance between sites A, B & C tested using Kruskal-Wallis and Mann-Whitney U tests

To determine the relationship between the selected physico-chemical parameters and zooplankton abundance, Generalized Linear Mixed Models was used

4 RESULTS.

4.1 RESULTS FOR WATER QUALITY PARAMETERS.

Dissolved oxygen, pH, temperature, conductivity and secchi depth were measured and the results are provided.

The water quality parameters in the six sampling points were measured *in situ* at different depths of 0.5m, 3m and 10m, the average calculated and used to find the mean and standard deviation of the five physico-chemical parameters in site A, site B and site C.

Table 1: Physico-chemical parameters for the study sites (mean±sd)

SITE	CONDUCTIVITY (μScm^{-1})	SECCHI DEPTH (cm)	TEMPERATURE (^0C)	PH	DO (mg L^{-1})
A	94.83 ± 7.97	91.91 ± 4.72	27.51 ± 0.81	6.78 ±0.53	7.15 ± 1.26
B	96.69 ± 9.87	97.16 ± 5.81	27.24 ± 0.61	7.72 ± 0.77	7.04 ± 0.95
C	90.46 ± 10.1	98.62 ± 11.37	27.18 ± 0.61	7.70 ± 0.74	7.27 ± 1.11

4.1.1 Electrical Conductivity

Electrical Conductivity ranged from 90.46 μScm^{-1} at site C to 94.83 μScm^{-1} at site A as shown in *figure 3* below.

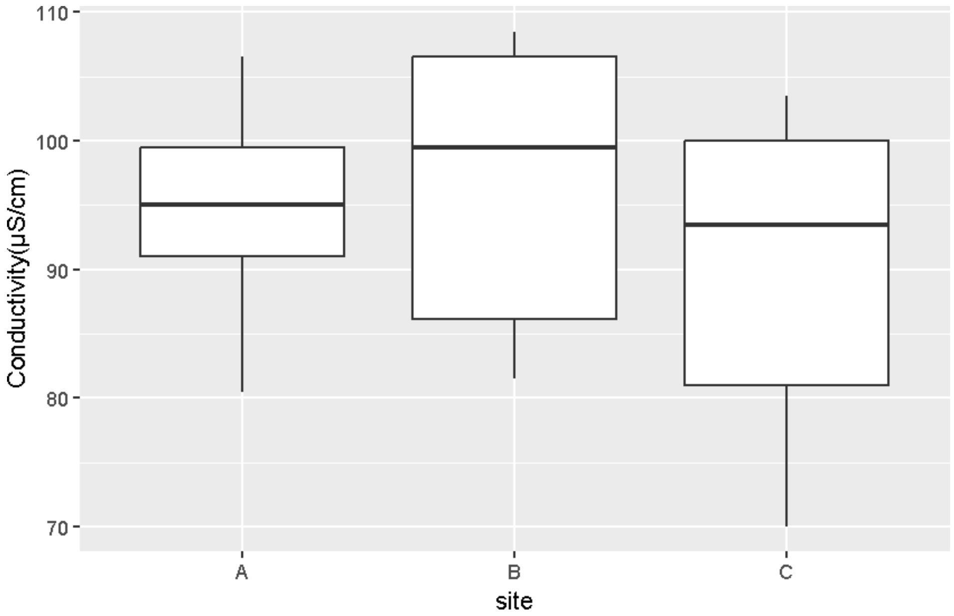

Figure 2: Mean variation in electrical conductivity of the study sites

There was a significant difference in conductivity between the sites ($F_{(2,87)} = 4.107$; $p<0.02$) According to the Posthoc, site C had significantly lower electrical conductivity compared to site A and site B, site A had the highest.

4.1.2 Secchi depth

Secchi depth ranged from 91.91cm at site A to 98.62cm at site C as shown in *figure 4* below.

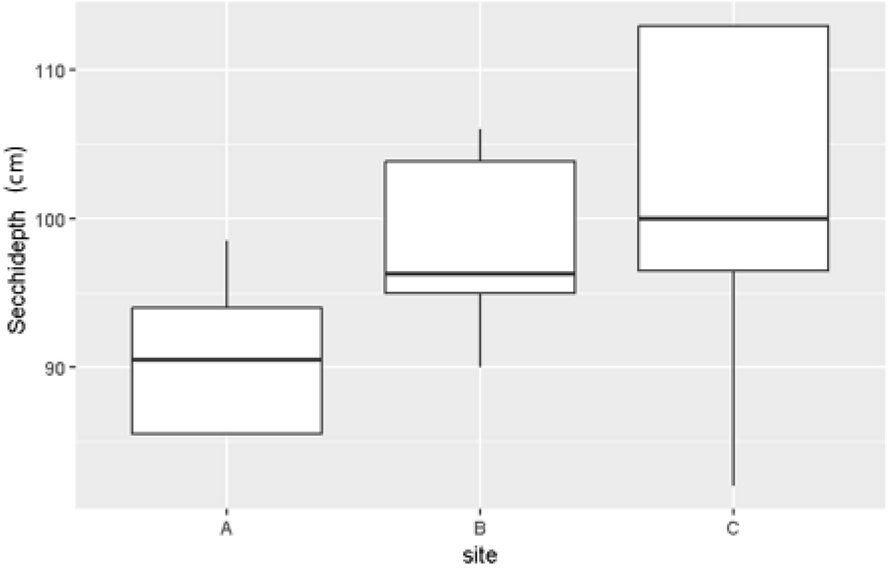

Figure 3: mean variation of secchi depth for the study sites.

There was a significant difference in Secchi depth between the sites ($F_{(2,574)} = 41.26$; $p<0.001$) According to the Posthoc, site A had significantly lower Secchi depth compared to site B and site C, site C had the highest.

4.1.3 pH

pH ranged from 6.78 at site A to 7.72 at site B as shown in *figure 5* below.

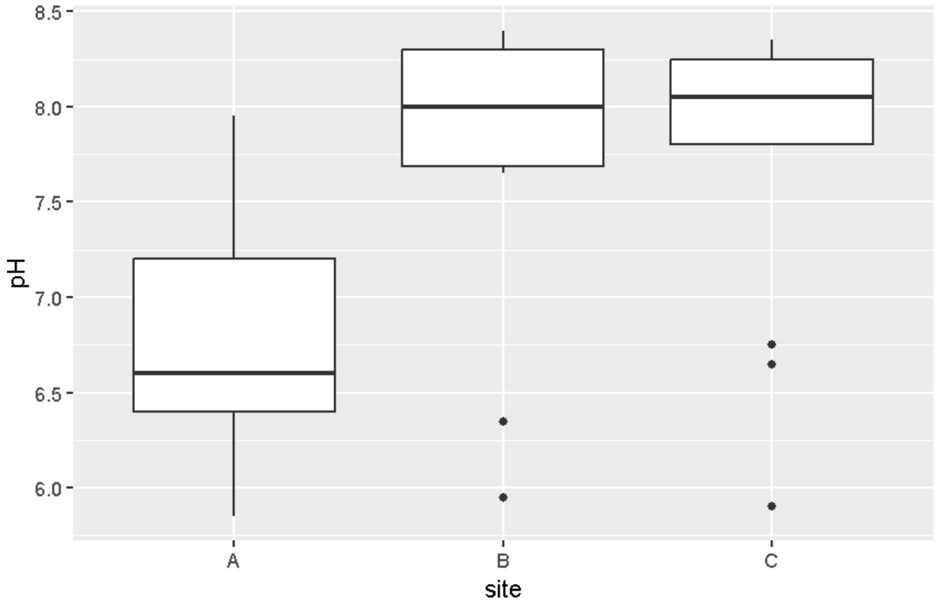

Figure 4: mean variation in pH of the study sites

There was a significant difference in pH between the sites ($F_{(2,87)} = 22.661; p<0.001$) According to the Posthoc, site A had significantly lower pH compared to site B and site C, site B had the highest.

The results above indicate minimal variation among the sites in the physico-chemical parameters (conductivity, secchidepth & pH) as shown below by the Post hoc test.

Table 2: results of the post hoc test for conductivity, secchi depth, & pH

SITE	CONDUCTIVITY (µScm^{-1})	SECCHI DEPTH (cm)	pH
A	94.83 a	91.91 b	6.78 b
B	96.68 a	97.16 a	7.72 a
C	90.50 b	98.62 a	7.70 a

4.1.4 Dissolved oxygen

DO ranged from 7.15 mg L^{-1} at site A to 7.27 mg L^{-1} at site C as shown in *figure 6* below.

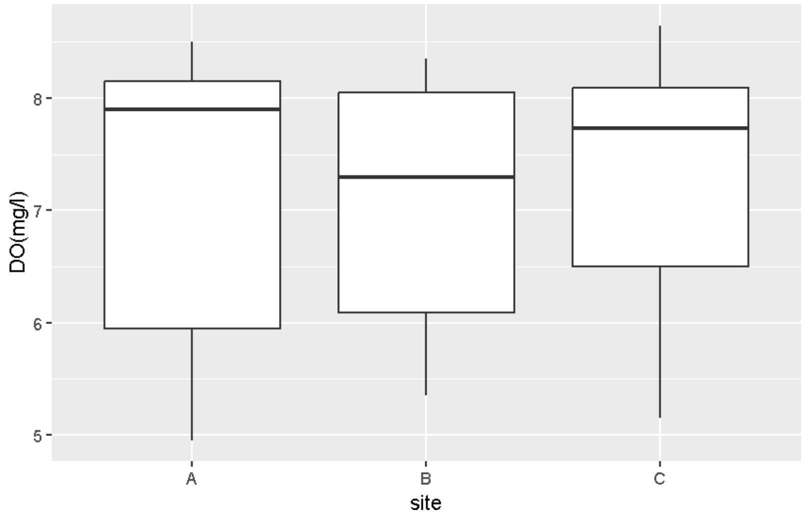

Figure 5: mean variation of Dissolved oxygen of the study sites

No significant differences in dissolved oxygen were found between the sites ($F_{(2,574)} = 1.839$; p=0.1598)

4.1.5 Variation of temperature with depth

Temperature showed a general decrease with depth in all the sites and thermal stratification was evident as shown in *figure 7* below.

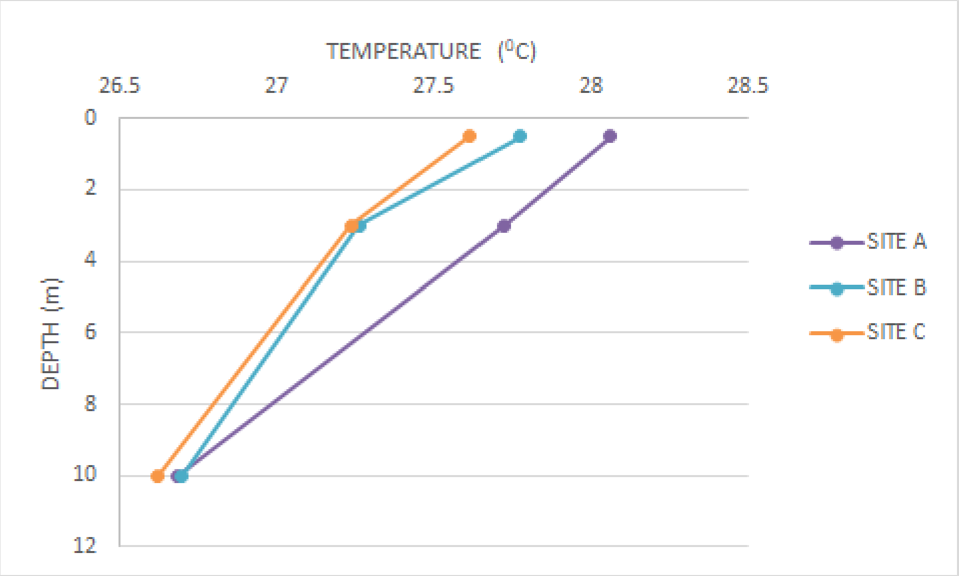

Figure 6: Variation of temperature with depth for site A, site B and site C

4.2 ABUNDANCE OF ZOOPLANKTON CLASSES

The zooplankton species community identified were grouped into three broad taxonomic groups (classes); that is Rotifers, Copepods and Cladocerans. A total 22 taxa were identified, three of which were Copepods, five cladocerans and fourteen rotifers.

The most abundant copepods were the *Copepod naupli* which is a developing stage for all copepods indicating that it was their breeding season and the least being *Calanoid copepods*.

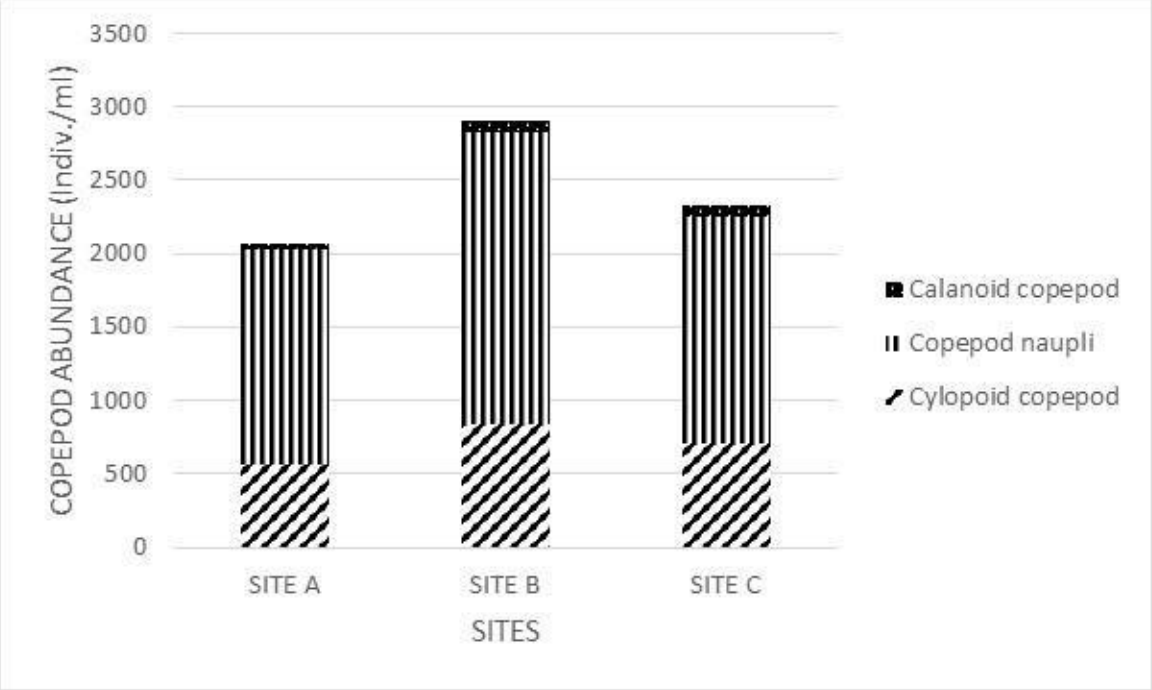

Figure 7: Abundance of copepods in site A, site B and site C

There was no significant difference in the abundance of copepods among the sites (kruskal-Wallis test p=0.8)

Among the rotifers, *Keratella spp* were most abundant and the least being *Synchaeta spp*.

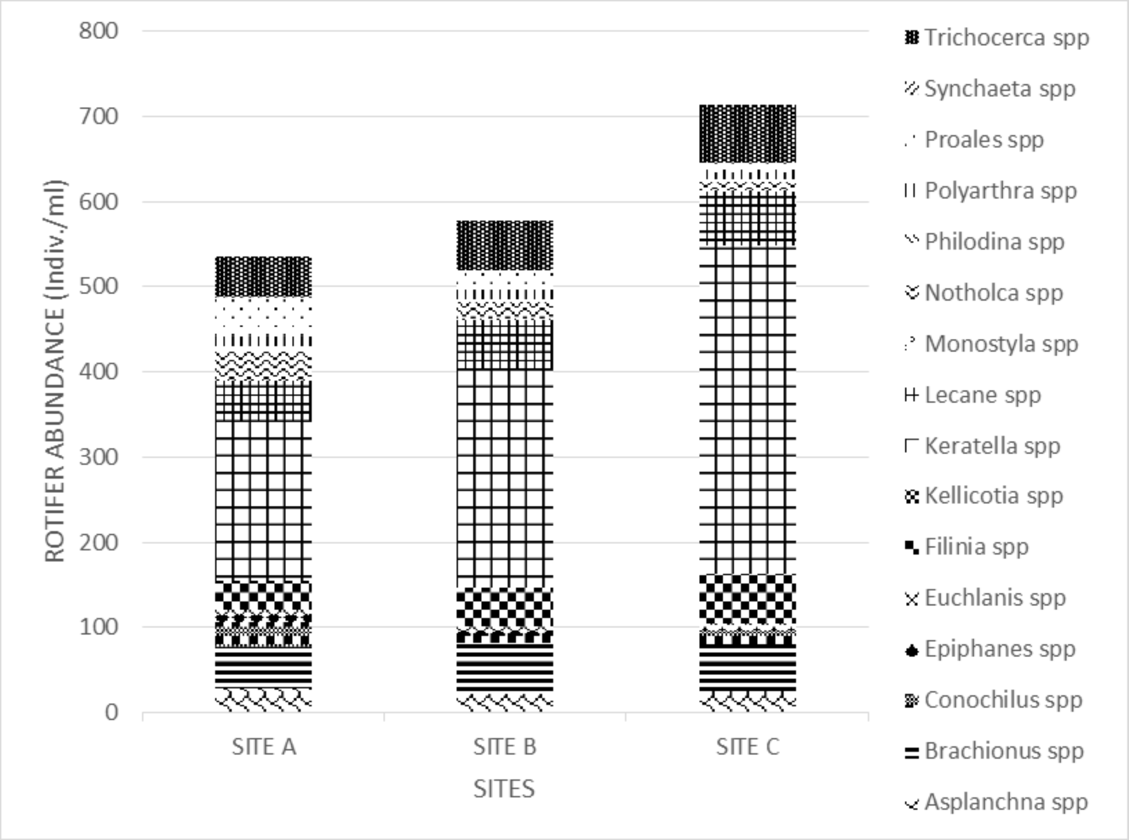

Figure 8: Abundance of rotifers in site A, site B and site C

There was no significant difference in the abundance of Rotifers among sites (Kruskal-Wallis test p=0.41)

Among the cladocerans, *Diaphanosoma spp* were most abundant and the least being *Alona spp*.

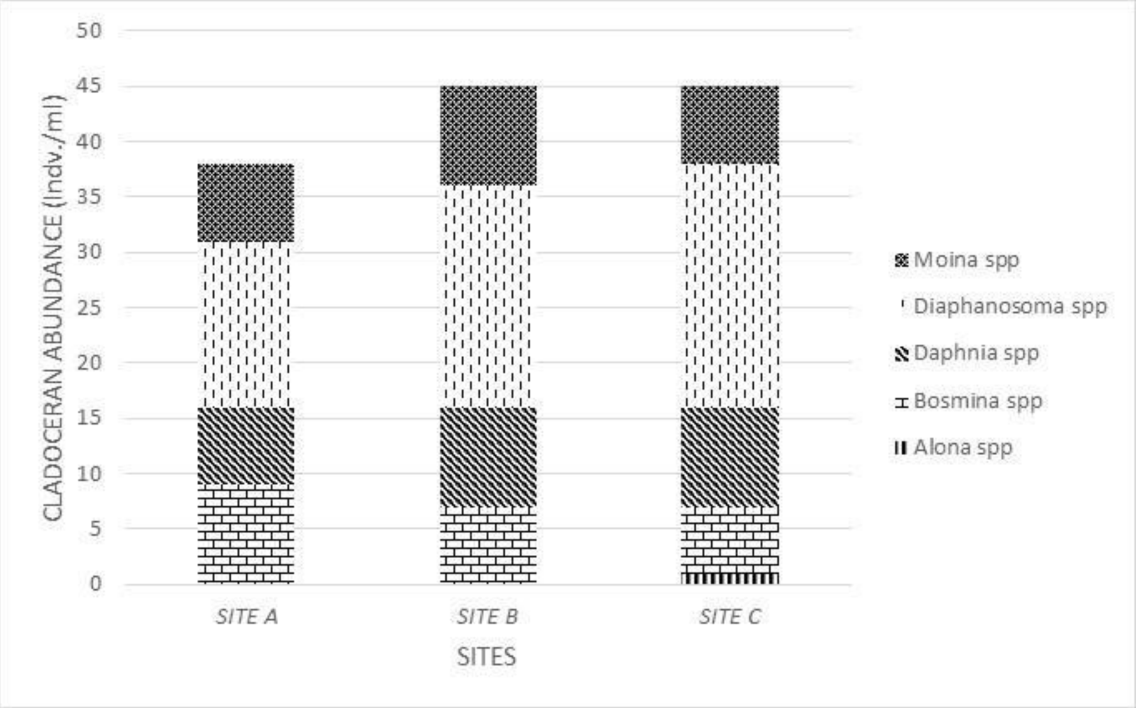

Figure 9: Abundance of cladocerans in site A, site B and site C

There is no significant difference in the abundance of cladocerans among sites (Kruskal-Wallis test p=0.98)

Rotifers had the highest species richness in all the sampling sites while Copepods were the most abundant (highest density) in all the three sampling study sites, followed by Rotifers and finally the Cladocerans with the least abundance, as shown in *table 3* below.

Table 3: Density(Indiv./ml) of zooplankton species in site A, site B and site C

Class	**Genus**	**Site A**	**Site B**	**Site C**
Cladoceran	*Bosmina*	1	1	1
	Daphnia	1	1	1
	Diaphanosoma	2±1	2±1	2±1
	Moina	1	1	1
	Alona	---	---	1
Copepod	*Calanoid*	4±3	8±7	7±5
	Naupli	122±91	165±137	130±86
	Cyclopoda	47±36	70±66	59±48
Rotifer	*Asplanchna*	2±1	2±1	3±1
	Brachionus	4±4	5±5	5±5
	Conochilus	2±2	1	2±2
	Epiphanes	1	1	1
	Euchlanis	1	1	1
	Filinia	3±3	4±4	6±8
	Keratella	16±12	21±21	33±34
	Lecane	4±3	5±5	5±4
	Notholca	3±4	3±2	2±2
	Philodina	1	1	1
	Polyarthra	1	1	1
	Proales	5±4	2±2	2±1
	Synchaeta	1	---	---
	Trichocerca	4±2	5±3	6±7
	Kellicotia spp	---	1	---
	Monostyla spp	---	1	1

4.3 DIVERSITY OF ZOOPLANKTON CLASSES

The species diversity calculated as the Shannon-Wiener diversity index showed a range of 2.81 to 4. 31 as shown in *table 3* below. Rotifers showed the highest diversity indices while copepods showed the lowest diversity indices as shown in *table 4* below.

Table 4: Diversity of Cladocerans, Copepods & Rotifers for site A, site B and site C

	Shannon Weaver diversity index		
Class	Site A	Site B	Site C
Cladocerans	3.4	3.41	3.3
Copepods	2.88	2.85	2.81
Rotifers	4.31	3.96	3.98

Cladocerans had the highest diversity index in site B and the lowest in site C

Copepods had the highest diversity index in site A and the lowest in site C

Rotifers had the highest diversity index in site A and the lowest in site B

4.4 RELATIONSHIP BETWEEN PHYSICO-CHEMICAL PARAMETERS AND ABUNDANCE OF CLADOCERANS.

An over-dispersion test was conducted in R version 4.4.1 at p=0.05

```
Dispersion ratio = 0.447
  Pearson's Chi-Squared = 41.118
                p-value =      1
```

Null deviance: 31.959 on 96 degrees of freedom

Residual deviance: 30.690 on 92 degrees of freedom

The positive relationship between dissolved oxygen and the abundance of cladocerans was not significant (p=0.787)

The positive relationship between temperature and the abundance of cladocerans was not significant (p=0.782)

The negative relationship between conductivity and the abundance of cladocerans was not significant (p= 0.529)

The negative relationship between pH and the abundance of cladocerans was not significant (p=0.500)

4.5 RELATIONSHIP BETWEEN PHYSICO-CHEMICAL PARAMETERS AND ABUNDANCE OF COPEPODS.

An over-dispersion test was conducted in R version 4.4.1 at p=0.05

Dispersion ratio = 94.406
Pearson's Chi-Squared = 9535.033
p-value = < 0.001

Over-dispersion detected

(Dispersion parameter for quasipoisson family taken to be 94.40627)
Null deviance: 9905.0 on 105 degrees of freedom
Residual deviance: 8621.1 on 101 degrees of freedom

The negative relationship between dissolved oxygen and the abundance of copepods was not significant (p=0.6359)

There was a significant positive relationship between temperature and the abundance of copepods (p=0.0100).

The positive relationship between conductivity and the abundance of copepods was not significant (p=0.4043)

The positive relationship between pH and the abundance of copepods was not significant (p=0.6392)

4.6 RELATIONSHIP BETWEEN PHYSICO-CHEMICAL PARAMETERS AND ABUNDANCE OF ROTIFERS.

An over-dispersion test was conducted in R version 4.4.1 at p=0.05

```
Dispersion ratio =   17.184
  Pearson's Chi-Squared = 6340.891
               p-value = < 0.001
```

Over-dispersion detected

```
(Dispersion parameter for quasipoisson family taken to be 17.18399)
 Null deviance: 3276.6  on 373  degrees of freedom
Residual deviance: 2953.0  on 369  degrees of freedom
```

The positive relationship between dissolved oxygen and the abundance of Rotifers was not significant (p=0.821)

There was a significant positive relationship between temperature and the abundance of Rotifers (p=0.014).

The negative relationship between conductivity and the abundance of rotifers was not significant (p=0.982).

The positive relationship between pH and the abundance of rotifers was not significant (p=0.978).

5 DISCUSSION

5.1 PHYSICO-CHEMICAL PARAMETERS

The results obtained indicate minimal variation in the physico-chemical parameters between site A, site B and site C. suggesting that the modest depth of the research area and the daily wind-induced mixing of the lake water may be responsible for the slight differences in the physico-chemical parameters between the sampling stations (Meremo *et al.*, 2022). Additionally, rains cause Lake Victoria's water levels to rise, which increases mixing (Akurut *et al*. 2017).

According to Nabirye *et al*. (2016), the minimal variation in the physico-chemical parameters is caused by the fish's comparatively low overall weight per unit volume of water; and that the effects may occasionally not be seen in the area around cage fish farms due to the extremely dynamic physical environment of these facilities.

The observed low Secchi depth of the sites is brought about by the fact that shallow water basins frequently experience the resuspension of sediments from the bottom into the water column (Meremo *et al*. 2022).

Conductivity is significantly higher in site A and site B whereas secchi-depth and pH are significantly lower at sight A. This is attributed to the wastes from fish cages which sediment and decompose hence altering the water chemistry in the vicinity of the cages.

The measured physico-chemical parameters show an optimum range suitable for sustaining fish and the entire aquatic biota of lake Victoria, according to similar results by Ndawula *et al.* (2013)

5.2 SPECIES ABUNDANCE

There is no observed variation in the species abundance among the sites. This is because the number of stocked cages for the farm are few and the majority of the cages were unstocked Again, tende Bay has another cage fish farm in the vicinity, the effect which is spread in the entire Bay.

Predatory fish species selectively feed on larger zooplankton species (Vincent *et al*. 2012, Waya *et al*. 2014), hence the observed low species abundance of the Cladocerans. Furthermore, the high turbidity with greater amounts of suspended solids can obstruct the filtration systems of larger Cladocerans and make it more difficult for them to ingest food, which lowers their abundances (Meremo *et al*. 2022).

However, their presence is brought about by reduced predation, which may be related to increased turbidity, hence hindering the ability of predators like zooplanktivorous fish to see (Vincent *et al.* 2012).

The numerical abundance of copepods is higher than that for both Rotifers and Cladocerans. This is so because they possess the most robust and longest appendages and the hardest exoskeleton for quick swimming in the search for food, and their small size favours them in eluding predators (Waya *et al*. 2014).

Compared to site B and site C, site A had lower species abundance of zooplankton because of lower secchi depth (high turbidity) which according to (Maria *et al*. 2009), materials suspended in the water column encumber the locomotory and respiratory structures of zooplankton and also hinder sunlight for algal photosynthetic production

Compared to Rotifers, Copepoda and Cladocera are more susceptible to decreased water quality (Safina *et al.*2022). The presence of rotifer species of the genus Brachionus like (*B. angularis, calyciflorus, B. plicatilis*) and the Cladoceran Moina micrura indicate a eutrophic environment (Vincent *et al*. 2012). However, the presence of *Calanoid copepods* (Gazonato Neto *et al.* 2014) and rotifers of the genus trichocerca (Vincent *et al*. 2012) which are indicators of oligotrophy shows that Lake Victoria’s water is still able to support life.

5.3 SPECIES DIVERSITY

The results indicate high species diversity of rotifers in all sites. This is so because of their adaptability to severe environments (Yona 2018), their flexible eating habits, and their success in reproducing in the eutrophic waters of Lake Victoria (Waya *et al*. 2014).

Rotifers have a short life cycle, quick response to environmental fluctuations, and higher turnover rates (Gazonato Neto *et al.* 2014).

The observed high species diversity of rotifers is in agreement with Meremo *et al.* (2022) who concluded that in Lake Victoria, rotifers are the most prevalent and diversified zooplankton population. Similar findings were obtained by (Waya *et al.* 2014) in Shirati bay of Tanzania, who also substantiates the fact that one attribute of tropical lakes is their high diversity of rotifers.

Rotifers consume tiny particles like bacteria (Vincent *et al.* 2012) and organic debris, which are frequently prevalent in eutrophic conditions (Waya *et al.* 2014).

Nano-phytoplankton is replaced by micro-phytoplankton in conditions with a higher trophic status (Gazonato Neto *et al*. 2014), providing more food for the rotifers.

5.4 RELATIONSHIP BETWEEN PHYSICO-CHEMICAL PARAMETERS AND ABUNDANCE OF CLADOCERANS.

The positive relationship between temperature and the abundance of Cladocerans was not significant. This is similar to the results obtained by (Qin *et al*. 2021) where temperature increases caused *Ceriodaphnia cornuta* to grow larger faster, reproduce more successfully, and experience a considerable reduction in time to first reproduction. In the study by (Amarasinghe *et al*. 1997) the growth rate of the cladoceran population was positively influenced by temperature. However the results contradict those of (Lingampally *et al*. 2018), who reported a negative correlation between temperature and abundance of Cladocerans.

The positive relationship between dissolved oxygen and the abundance of Cladocerans was not significant. This is similar to the results obtained by (Nebeker *et al*. 1992) where the cultured crustaceans performed differently under varrying concetrations of dissolved oxygen. When the crustaceans were subjected to insufficient dissolved oxygen, they showed low reproductive ability, mortalitues were recorded and they sought more oxygen by swimming to the water surface.

The negative relationship between conductivity and the abundance of Cladocerans was not significant. This was because of the large size of Cladocerans that makes them intolerant to elevated salinity (Moffett *et al.* 2023), Similar results were obtained by (Soto & De Los Rios, 2006) where there was an inverse relationship between conductivity and cladocerans of the genus Daphnia.

The negative relationship between pH and the abundance of Cladocerans was not significant. This is in agreement with (El-Deeb Ghazy *et al.* 2011) who reported survival and growth of the cultured zooplankton crustaceans at pH range 4.66 to 10.13, and that the species' ability to survive, grow, reproduce, and feed was shown to be negatively impacted by the effects of sub-lethal hydroxyl ions .

5.5 RELATIONSHIP BETWEEN PHYSICO-CHEMICAL PARAMETERS AND ABUNDANCE OF COPEPODS.

There was a significant positive relationship between temperature and the abundance of Copepods. This was so because the copepods are grasping feeders that consume much of the various food items compared to other zooplankton (Anamunda & Lamtane, 2022), and cyclopoid copepods are carnivorous predating upon the smaller species of rotifers and Cladocerans (Gazonato Neto *et al.* 2014). Therefore they require elevated temperature for fast action of digestive enzymes

The negative relationship between dissolved oxygen and the abundance of Copepods was not significant. This was so because the copepods' respiration rate increases with temperature, hence consuming more oxygen (Heine *et al.* 2019). Copepods are robust swimmers in the search for food (Waya *et al*. 2014) hence they require more oxygen for generation of energy through respiration.

Dissolved oxygen is one of the essential parameters for copepod surviving, growth and reproduction. Insufficient dissolved oxygen retards the hatching of diapause copepod eggs and increases mortality of the crustaceans (Jyothibabu *et al*. 2018). Since copepods lack the proteins that bind oxygen to improve survival in low-oxygen environments, reduced oxygen levels significantly impair the hatching success of copepod eggs in a number of species as well as the production of eggs, somatic rates of growth, and dietary intake (Roman & Pierson, 2022).

Both conductivity and pH showed a positive and not significant relationship with the abundance of Copepods. This was so because of the minimal effect that conductivity and pH have on copepods. Both conductivity and pH influence the ionic concentration of water (Omach *et al*. 2023) and Copepods have a tough exoskeleton which enables them to stay in varying concentration of ions. Similar results were obtained by (Kurbatova, 2005), where low abundance of the zooplankton was observed under conditions of low pH

5.6 RELATIONSHIP BETWEEN PHYSICO-CHEMICAL PARAMETERS AND ABUNDANCE OF ROTIFERS.

There was a significant positive relationship between temperature and the abundance of Rotifers. This is similar to the results of (Qayyum *et al*. 2012) who asserts that Rotifers thrive in an environment with wide fluctuation in temperature and they reproduce faster at increasing trends of temperature. Rotifers are vigorous feeders at elevated temperature, spawn many eggs and exhibit rapid intrinsic rate of growth (Yona, 2018).

The positive relationship between dissolved oxygen and the abundance of Rotifers was not significant. This was so because the rotifers generally feed on phytoplankton, which are produced in the process of photosynthesis where oxygen is always prevalent. The results are however in contradiction with (Qayyum *et al*. 2012) who reported a negative correlation between dissolved oxygen and the rotifer species under study.

The negative relationship between conductivity and the abundance of Rotifers was not significant. This was because of the observed high numerical abundance of *Trichocerca* Rotifers, which according to (Vincent *et al*. 2012) are reported to thrive in high oxygen concentration and since increase in conductivity is associated with reduced dissolved oxygen (Sekiranda & Kiggundu, 2005), the abundance of rotifers lowers.

The observed positive relationship between pH and the abundance of Rotifers was not significant, this is in agreement with (Vincent *et al*. 2012) who states that low pH eradicates some Rotifers like those of the genus *Brachionus.* Similar results were obtained by (Maria *et al*. 2009) where there was a positive relationship between the rotifera community and water parameters, pH inclusive.

6 CONCLUSION

From the above study, L. Victoria water of Tende Bay has not faced too much eutrophication because of the equal species abundance of the zooplankton community and minimal variation in the water quality parameters.

Changes in the parameters pertaining to water quality are anticipated to have an impact on the distribution and quantity of zooplankton, which serves as a vital source of food for fish in the lake.

The values reported in this study for the chosen physicochemical characteristics fell within acceptable bounds for both maintaining aquatic life and drinking water, as well as within ranges reported as typical for freshwater ecosystems.

7 RECOMMENDATION

Long-term research on the impact of fish cages on physico-chemical parameters is still required in order to evaluate future management choices for fish farming in Ugandan water bodies, even though the study's results showed good water quality in terms of physico-chemical parameters Therefore fish cage operations can continue under control and by implementing of solutions like integrated multitrophic aquaculture.

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9 Appendix

ANOVA for pH

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	19.35239	2	9.676194	22.66098	1.2E-08	3.101296
Within Groups	37.14883	87	0.426998			
Total	56.50122	89				

ANOVA table for conductivity

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	737.3722	2	368.6861	4.107051	0.019751	3.101296
Within Groups	7809.908	87	89.76906			
Total	8547.281	89				

ANOVA table for Temperature

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	2.002667	2	1.001333	1.858937	0.161975	3.101296
Within Groups	46.86333	87	0.538659			
Total	48.866	89				

ANOVA Table for DO

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.149502	2	0.074751	0.058178	0.943519	3.101296
Within Groups	111.7835	87	1.284868			
Total	111.933	89				

RELATIONSHIP BETWEEN PHYSICO-CHEMICAL PARAMETERS AND ABUNDANCE OF CLADOCERANS.

An over-dispersion test was conducted in R version 4.4.1 at p=0.05

Dispersion ratio = 0.447

Pearson's Chi-Squared = 41.118

p-value = 1

AIC	BIC	logLik	Deviance	df.resid
250.1	263.3	-120.1	240.1	92

Conditional model:

	Estimate	Standard error	z value	p value
(Intercept)	-0.295424	5.293916	-0.056	0.955
Dissolved oxygen	0.042879	0.158528	0.270	0.787
Temperature	0.055379	0.199913	0.277	0.782
Conductivity	-0.005697	0.009040	-0.630	0.529
pH	-0.098000	0.145170	-0.675	0.500

Null deviance: 31.959 on 96 degrees of freedom

Residual deviance: 30.690 on 92 degrees of freedom

Both dissolved oxygen and temperature show an insignificant positive relationship with the abundance of cladocerans (p=0.787) and (0.782) respectively.

Both conductivity and pH show an insignificant negative relationship with the abundance of cladocerans (p= 0.529) and (p=0.500) respectively.

RELATIONSHIP BETWEEN PHYSICO-CHEMICAL PARAMETERS AND ABUNDANCE OF COPEPODS.

An over-dispersion test was conducted in R version 4.4.1 at p=0.05

Dispersion ratio = 94.406
Pearson's Chi-Squared = 9535.033
p-value = < 0.001

Over-dispersion detected

Coefficients:

	Estimate	Standard error	Z value	P value
(Intercept)	-14.34645	6.70591	-2.139	0.0348 *
Dissolved oxygen	-0.09685	0.20396	-0.475	0.6359
Temperature	0.64449	0.24560	2.624	0.0100 *
Conductivity	0.01002	0.01197	0.837	0.4043
pH	0.08788	0.18687	0.470	0.6392

(Dispersion parameter for quasipoisson family taken to be 94.40627)
Null deviance: 9905.0 on 105 degrees of freedom
Residual deviance: 8621.1 on 101 degrees of freedom

NOTE: values with (*) are significant that is P<0.05.

There is an insignificant negative relationship between dissolved oxygen and the abundance of copepods (p=0.6359)

There is a significant positive relationship between temperature and the abundance of copepods (p=0.0100).

Both conductivity and pH show an insignificant positive relationship with the abundance of copepods (p=0.4043) and (p=0.6392)

RELATIONSHIP BETWEEN PHYSICO-CHEMICAL PARAMETERS AND ABUNDANCE OF ROTIFERS.

An over-dispersion test was conducted in R version 4.4.1 at p=0.05

Dispersion ratio = 17.184
Pearson's Chi-Squared = 6340.891
p-value = < 0.001

Over-dispersion detected

Coefficients:

	Estimate	Standard error	Z value	P value
(Intercept)	-1.277e+01	5.671e+00	-2.251	0.025 *
Dissolved oxygen	4.058e-02	1.790e-01	0.227	0.821
Temperature	5.110e-01	2.070e-01	2.469	0.014 *
Conductivity	-2.306e-04	1.016e-02	-0.023	0.982
pH	4.416e-03	1.621e-01	0.027	0.978

(Dispersion parameter for quasipoisson family taken to be 17.18399)
Null deviance: 3276.6 on 373 degrees of freedom
Residual deviance: 2953.0 on 369 degrees of freedom

NOTE: values with (*) are significant that is P<0.05.

There is an insignificant positive relationship between dissolved oxygen and the abundance of Rotifers (p=0.821)

There is a significant positive relationship between temperature and the abundance of Rotifers (p=0.014)

There is an insignificant negative relationship between conductivity and the abundance of rotifers (p=0.982)

There is an insignificant positive relationship between pH and the abundance of rotifers (p=0.978).