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RESEARCH ARTICLE

A STUDY OF THE PHYSICAL-CHEMICAL CONDITIONS AND PLANKTON DIVERSITY IN THE LOWER KAFUE RIVER OF ZAMBIA

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ABSTRACT

The physical-chemical conditions, phytoplankton diversity and zooplankton diversity of the lower Kafue river were studied in January, 2020. The study was aimed at assessing the physical-chemical conditions of the lower part of the Kafue river and determine the phytoplankton diversity and zooplankton diversity in the lower Kafue River. The study sites that were sampled were Muyanganas at Kafue Fisheries Limited and Kasaka Fisheries Training Centre. Kafue Fisheries Limited is an aquaculture habitat while Muyanganas and Kasaka Fisheries Training Centre are non-aquaculture areas. Water samples were collected using a filtering water sampler. Collected water samples were preserved in 1000 mL plastic bottle by adding 5 mL of 4% formalin concentration. The phytoplanktons were counted using a PX Biological microscope. The plankton species were identified to genus level. Water samples collected from each study site were analysed in order to determine Temperature, pH and Dissolved Oxygen (DO) levels. These parameters were determined using an automated pH meter. The results of regression analysis showed that there was a significant regression of phytoplankton diversity on zooplankton diversity in the lower Kafue river ($p = 0.02$). However, there was no significant difference ($p=0.7451$) among the physical-chemical parameters within the study area. The results obtained implied that aquaculture has an impact on both phytoplankton and zooplankton diversity in the lower part of the Kafue river.

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INTRODUCTION

Aquaculture is currently one of the fastest growing sectors of agriculture in Zambia due to increased demand for fish. Currently aquaculture is taking place actively in Kafue River (Genschick *et al*., 2017). Aquaculture has many benefits such as employment creation, source of animal protein and economic revenue (Yalelo, 2012). Aquaculture introduces metabolic wastes from feed given to fish turns an oligotrophic river into a eutrophic river which is characterised by increased phosphorus and nitrogen levels which cause depletion of oxygen levels due to increase in organic matter in the aquatic habitat (Axlex et al., 1996). These inorganic nutrients accelerate algal growth and lead to changes in the aquatic ecosystem (Kalff, 2002). Phytoplankton are microscopic aquatic plants, occurring as unicellular, colonial or filamentous forms that occur as free-floating or suspended organisms in open or pelagic waters (Diehl *et al*., 2002).

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Phytoplankton form the bottom rung of the food chains in any aquatic ecosystem. Phytoplanktons are also the main primary producers in open waters. They are located in the pelagic zone of ponds, lakes, rivers and oceans where light penetrates. A zooplankton is a microscopic organism that feeds on phytoplanktons (Wetzel, 2001). Phytoplanktons and zooplanktons are susceptible to variations in a wide number of environmental factors including water temperature, light, water chemistry particularly pH, oxygen, salinity, toxic contaminants, food availability (algae, bacteria), and predation by fish and invertebrates (Wang and Liang, 2015). Phytoplankton abundance and taxonomic diversity depend on the abundance of nutrients in natural waters (Abu *et al*, 2015). Algal blooms affect water quality and aquatic life. Decay of algal blooms leads to low oxygen levels in aquatic habitats (https://en.wikipedia.org/wiki/Algal_bloom). The general objective of the study was to assess the physical-chemical conditions of the lower part of the Kafue river and determine the phytoplankton diversity and zooplankton diversity in the lower Kafue River. The specific objectives of the study were: (i) to determine the physical-chemical parameters of water of the lower Kafue river, (ii) to determine the phytoplankton diversity and zooplankton diversity of the lower Kafue river, and (iii) to determine any correlation between phytoplankton diversity and zooplankton diversity in the lower Kafue river. The main hypothesis that was tested was that there is no significant difference in the phytoplankton diversity and zooplankton diversity between the aquaculture and non-aquaculture areas of the lower part of the Kafue river.

Phytoplankton and zooplankton of the lower Kafue river: Some important genera of plankton species of the Kafue river include *Scenedesmus*, *Pediatrum*, *Gyrosigma, Fragilaria* and *Euglena* (Muncy, 1976; TARL, 2014).

Scenedesmus: *Scenedesmus* is a genus of phytoplankton that belongs to a group of microscopic green algae that are either unicellular or colonial. *Scenedesmus* is an algal classified in phylum chlorophyta. It is non-motile and occurs in groups of four to thirty-two cells. When found in colonies, it has a smaller surface-to-volume ratio which limits nutrient intake and light harvesting. Phytoplankton classified in genus *Scenedesmus*, consists of algae whose cells are united to form tablet-shaped colonies (Figure 1). Often, the cells located at the ends are furnished with spines, have thick cell walls and mucilaginous in order to protect themselves from predators. *Scenedesmus* spines reduce sinking due to the velocity in the water body where they are usually found (https://en.m.wikipedia.org/Algal_bloom).

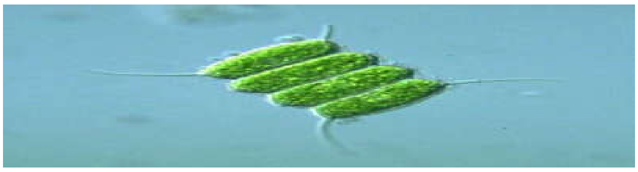

Figure 1. Structure of Scenedesmus (source: https://en.m.wikipedia.org/Algal_bloom).

Pediastrum: *Pediastrum* is a colonial green alga classified in phylum chlorophyta and family hydrodictyaceae (Figure 2). *Pediastrum* cells are united and arranged in a circular, plate-like, H-shaped or V-shaped colonies of concentric rings to form a net-like structure of the organism. These colonies have a high surface-to-volume ratio in order to prevent them from sinking. In this green algae, young cells are uninucleate while mature organisms are multicellular. *Pediastrum* is usually found in nutrient-rich aquatic habitats such as eutrophic lakes, rivers and sewer ponds most especially in summer and spring (https://www.sciencedirect.com).

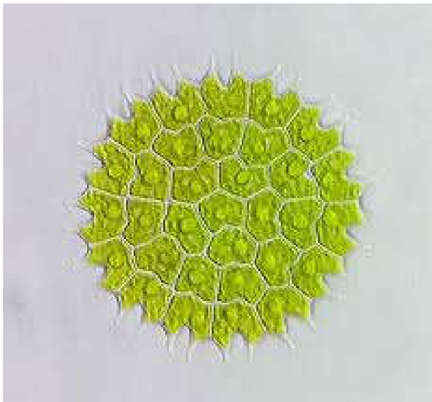

Figure 2: Structure of Pediastrum (source: https://www.sciencedirect.com)

Gyrosigma: *Gyrosigma* is a freshwater diatom that is classified in phylum chlorophyta and order navicula. This diatom can inhabit both freshwater and salt water aquatic habitats and it is able to photosynthesize. *Gyrosigma* (Figure 3) is a zooplankton that belongs to the algal group of the diatoms. Diatoms are characterized by a yellow-brownish colour due to the presence of accessory photosynthetic pigments. Cells of the genus *Gyrosigma* are marked by a sigmoid outline. As in all diatoms, the cell wall is silicified. Silification of the cell wall is not evenly but is some parts more expressed than in others resulting in a characteristic pattern of sculpture elements (https://www.sciencedirect.com).

Figure 3. Structure of *Gyrosigma* (source: https://www.sciencedirect.com).

Fragilaria: *Fragilaria* is a freshwater and saltwater protest that is classified in family fragilariaceae of kingdom protoctista. *Fragilaria* (Figure 4) is a colonial diatom. *Fragilaria* has cells that are arranged in a row to form band-shaped colonies which helps them to remain afloat. This algal is mainly found in colonies that form filaments of cells that are mechanically joined by protrusions on the face and in the centre of valves. The valves are composed of pectic organic materials that are impregnated with silica in an opaline state (https://www.sciencedirect.com).

Figure 4: Structure of Fragilaria (source: https://www.sciencedirect.com).

Euglena: *Euglena* is a genus of solitary but motile phytoplankton (Figure 5). *Euglena* cells can contract and expand like the body of worms and they have eyes. *Euglena* phytoplanktons are a transition between plants (presence of chlorophyll) and animals (motility) and they are classified in phylum protoctista. These algae have elongated, oval flagella which they use for locomotion.

Euglena may live in the dark using organic substance as food source, just like animals. *Euglena* (including green, photosynthesizing ones) need some specific organic compounds as vitamins that they cannot make themselves (https://www.sciencedirect.com).

Figure 5: Structure of Eugena (source: https://www. sciencedirect.com).

MATERIALS AND METHODS

Study area: The lower Kafue river is located between the geographical co-ordinates 24° 42'E, 11° 30'S and 28° 30'E, 17° 30'S and covers an approximate area of 156034.386 km^2. The main Kafue River in the Catchment area meanders approximately 100Km North-East of Solwezi town to its confluence with the Zambezi River in the lower Kafue Catchment in Chirundu District of Zambia and has a total length of 1,489.904 km (TARL, 2014). The study was conducted at three study sites within the lower part of the Kafue river. These were: Muyanganas (Study site 1), Kafue Fisheries Limited (Study site 2) and Kasaka Fisheries Training Centre (Study site 3). These study sites represent the different ecological sites within the lower Kafue river. The geographical co-ordinates of the various sampling points at the study sites are given in Table 1.

Table 1: Geographical co-ordinates of sampling points within the study sites

Study site	Grid reference		
	Sampling point	Latitude	Longitude
Muyanganas	A	28°14'10''	15°50'17''
	B	28°14'04''	15°50'21''
	C	28°13'54''	15°50'25''
Kasaka Fisheries Training Centre	A	28°12'59''	15°49'55''
	B	28°13'11''	15°50'03''
	C	28°13'26''	15°50'13''
Kafue Fisheries Limited	A	28°44'29''	15°44'29''
	B	28°44'21''	15°44'47''
	C	28°44'55''	15°44'21''

The location of the study sites is given in Figure 6 below

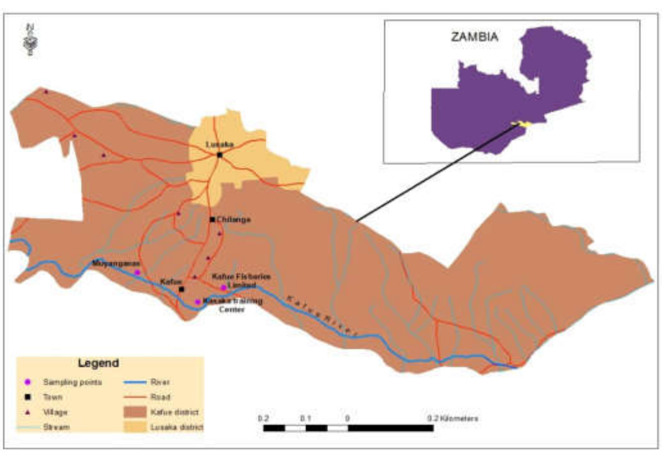

Figure 6: Location of the study sites (Muyanganas, Kafue Fisheries Limited and Kasaka Fisheries Training Centre)

Muyanganas lies on the north bank of the Kafue River. The average annual temperature at Muyanganas is 21.5°C. In a year, the rainfall received at Muyanganas averages 769 mm. Kasaka Fisheries Training Centre has a maximum high average temperature of 30°C in October and minimum low temperature of 22°C in June. Kafue Fisheries Limited receives medium rainfall ranging from 800mm to 1,000mm. The study areas are typical Miombo woodland (TARL, 2014).

Sample collection: Phytoplankton samples were collected using a filtering water sampler that was fitted with a plankton net (mesh size 105 μm) and preserved in 1000 mL plastic bottle by adding 5 mL of 4% formalin concentration. The preserved samples were kept undisturbed for 24 hours to allow the sedimentation of plankton suspended in the water to take place. After 24 hours, the supernatant was discarded carefully without disturbing the sediments and the final volume of the concentrated sample was measured.

Data collection: The collected water samples were analyzed at Chilanga Limnology Laboratory at the Department of Fisheries. Plankton were counted using a microscope (PX – 38 Series, Biological Microscope) according to Utermohl's (1958) and Venneaux, (1976) method. Utermohl's, (1958) method was utilised to identify and enumerate phytoplankton community from the different study sites. Each observed taxon was recorded. The algal species were identified at family level, and where possible also to genus or species level, by using pictorial charts and taxonomic keys (Prescott, 1978).Water samples were analysed from each depth in-situ in order to determine the following parameters: Temperature, pH and Dissolved Oxygen (DO) levels. These parameters were analysed using an automated pH meter. The collected data on phytoplankton diversity, zooplankton diversity and water physical-chemical parameters were analyzed in Statistix 9 Software (Analytical Software, 2009) to determine significant differences, if any.

RESULTS

Physical-chemical conditions at the study sites: The physical-chemical parameters of the lower Kafue river are given in Table 2 below. The results of One-way Analysis of Variance in Statistix 9 Software showed no significant difference (p=0.7451) among the physical-chemical parameters within the study area. This means that the physical-chemical parameters do not differ very much among the sampled study areas within the lower Kafue river.

Table 2. Physical-chemical parameters at the study sites

Study site	Physical-chemical	parameter		
	Temp (°C)	Do (ppm)	pH	Sech (m)
Muyanganas	28.4	80	7.9	½
Kasaka Fisheries Training Centre	27.5	90	8.0	½
Kafue Fisheries Limited	26	32	7.5	½

Phytoplankton diversity within the lower Kafue river: The phytoplankton diversity of the different study sites within the lower Kafue river are given in Table 3 below. The results of the One-way Analysis of Variance calculated using Statistix 9.0 Software showed that there was a significant difference (p=0.0001) among the phytoplankton diversities of the three study areas.

Table 3. Phytoplankton diversity among the study site

Study site	Muyanganas	Kasaka Fisheries Training Centre	Kafue Fisheries Limited
A	7	6	10
B	6	6	10
C	7	5	11

The means were then separated using the Least Significant Difference (LSD) All-Pairwise Comparisons Test in order to show the mean that was statistically different from others. The results of the LSD Test showed that the mean phytoplankton diversity at Muyanganas (6.6667) and the mean phytoplankton diversity at Kasaka Fisheries Training Centre (95.6667) are statistically similar, that is why the diversities were classified in the same statistical group (B). The mean phytoplankton diversity of Kafue Fisheries Limited (10.333, group A) was statistically different from the means of phytoplankton diversity at Muyanganas and Kasaka Fisheries Training Centre.

Zooplankton diversity within the lower Kafue river: The phytoplankton diversity of the different study sites within the lower Kafue river are given in Table 3 below. The results of the One-way Analysis of Variance calculated using Statistix 9.0 Software showed that there was a significant difference ($p=0.0001$) among the zooplankton diversities of the three study areas.

The results of LSD test conducted to show which mean is statistically different from the others showed that the mean zooplankton diversity at Kasaka Training Centre (2.333 B) and Muyanganas (1.333B) are statistically similar to each other but different from the mean zooplankton diversity at Kafue Fisheries Limited (11.667 A).

Table 4. Zooplankton diversity among the study site

Study site	Muyanganas	Kasaka Fisheries Training Centre	Kafue Fisheries Limited
A	1	1	12
B	1	2	13
C	2	4	10

Correlation between phytoplankton diversity and zooplankton diversity: The consolidated data of phytoplankton diversity and zooplankton diversity in the lower Kafue river is given in Table 5 below. There was significant regression of phytoplankton diversity on zooplankton diversity ($p=0.02$). This implies that zooplankton diversity is affected by phytoplankton diversity. The linear equation that described the relationship between phytoplankton diversity and zooplankton diversity is: Zooplankton diversity = -10.198 + 2.026 Phytoplankton diversity.

Table 5: Phytoplankton diversity and zooplankton diversity in the lower Kafue river

Serial number	Phytoplankton diversity	Zooplankton diversity
1	7	1
2	6	1
3	7	2
4	6	1
5	6	2
6	5	4
7	10	12
8	10	13
9	11	10

DISCUSSION

Physical-chemical parameters of the lower Kafue river: The study found that physical-chemical conditions at Muyanganas and Kasaka Fisheries Training Centre were very similar to each other but slightly different from the conditions at Kafue Fisheries Limited (Table 2). This can be attributed to the fact that Kafue Fisheries Limited is an aquaculture area while Muyanganas and Kasaka Fisheries Training Centre are non-aquaculture areas. The feed that is given to cultured fish reduces the amount of dissolved oxygen by promoting algal blooms at Kafue Fisheries Limited. Muyanganas and Kasaka Fisheries Training Centre that are not exposed to external influx of nutrients are expected to have high dissolved oxygen levels hence the results obtained. The habitats at Muyanganas and Kasaka Fisheries Training Centre can thus be termed as oligotrophic-meaning that they are nutrient-poor. The habitat at Kafue Fisheries Limited is a eutrophic habitat, meaning that it is nutrient-rich (Bronmark and Hansson, (2005). The results obtained from this study are consisted with the findings of Alvin *et al.*, (2016) who found that abiotic factors reduce the amount of dissolved oxygen in an aquatic ecosystem. Abu *et al.*, (2015) also found low dissolved oxygen levels in the aquaculture pods of Bangladesh. The lowest pH seen at Kafue Fisheries Limited is attributed to the chemicals from feed that is given to fish in the aquatic body. Chemicals from feed lower water temperature and pH; but increase the amount of dissolved solutes in water. Increase in dissolved solutes in a water body is inversely proportional to dissolved oxygen levels in an aquatic ecosystem (Chikungu, 2019). Physical–chemical parameters such as turbidity, nutrients and depth play a pivotal role in determining abundance of certain phytoplankton groups and taxa in a given area with prevailing resources (Alvin *et al*, 2016).

Phytoplankton and zooplankton diversity in the Lower Kafue river: The diversity of phytoplankton at Muyanganas was found to be similar to that at Kasaka Fisheries Training Centre but different from Kafue Fisheries Limited. This is expected because Kafue Fisheries Limited is an aquaculture habitat while Muyanganas and Kasaka Fisheries Training Centre are non-aquaculture aquatic ecosystems. An aquaculture habitat is expected to have a higher phytoplankton diversity than a non-aquaculture habitat. This is because phytoplankton abundance depends upon the supply of nutrients which is are readily available at Kafue Fisheries Limited. The abundance of phytoplankton increases with increasing nutrient concentration. This finding is in tandem with similar research conducted by Abu *et al.*, (2005) in the ponds of Bangladesh, Onyema (2007) in Nigeria and Chikungu (2019) in Lake Kariba of Zambia. The differences in phytoplankton abundance also indicate the differences in habitat quality among the three habitats.

Habitats that are nutrient-rich have a higher phytoplankton diversity than nutrient-poor habitats (Reynolds *et al.*, 2000; Wetzel, 2001). Therefore, the habitat at Kafue Fisheries is the most nutrient-rich hence the high abundance and diversity of phytoplankton. A similar research by Alvin *et al.*, (2016) on phytoplankton composition found that an increase in eutrophication leads to a proliferation of phytoplankton in an aquatic habitat. Increase in phytoplankton abundance and diversity may be harmful to an aquatic habitat because certain species of phytoplankton classified as dinoflagellates and diatoms such as *Noctilica scintillans* and *Skeletonema costitum* discolour water and cause fish death.

These phytoplanktons produce biotoxins that cause 'red tides' and produce harmful algal blooms (Bruce *et al*., 2015). The abundance and diversity of phytoplankton at Kafue Fisheries Limited can further be attributed to the nature of the habitat. Muyanganas and Kasaka Fisheries Training Centre had low phytoplankton diversity because these habitats are riverine in nature. Riverine habitats have low phytoplankton abundance and diversity because phytoplankton organisms are sensitive to velocity and turbulence of water flow in rivers. Water currents and mechanical stresses inhibits the development of new planktons (Wetzel, 2001). Alvin *et al*., (2016) also found that agitated waters generally support little phytoplankton. The riverine nature of Muyanganas and Kasaka Fisheries Training Centre explains why there were many small planktons such as cyanobacteria than large phytoplanktons such as diatoms. Bruce *et al*., (2015) also found that winds and water currents reduce on large phytoplanktons but promote the abundance of small ones. A high abundance of phytoplankton is advantageous in that phytoplanktons support the aquatic food web and provides food to all organisms ranging from microscopic, animal-like zooplanktons to the multi-ton whales. The significant difference in zooplankton diversity among the three study sites is explained by the fact that zooplanktons feed on phytoplanktons. This implies that Kafue Fisheries Limited which had a high diversity of phytoplankton was also expected to have a higher zooplankton diversity than Muyanganas and Kasaka Fisheries Training Centre.

Correlation between phytoplankton diversity and zooplankton diversity: Regression analysis confirmed that phytoplankton diversity affects zooplankton diversity (Table 5).This result is expected because zooplankton feeds on phytoplankton. This implies that an increase in phytoplankton diversity will trigger an increase in zooplankton diversity. This result is in tandem with earlier studies by Wetzel (2001), Zambia Department of Fisheries (2008) and Alvin *et al*., (2016).

Conclusion

It was found that aquaculture has an effect on physical-chemical conditions of aquatic ecosystems. That is why physical-chemical conditions at the two non-aquaculture areas that were sampled-Muyanganas and Kasaka Fisheries Training Centre were similar to each other but different from the aquaculture sampling study site at Kafue Fisheries Limited. It is further noted that aquaculture has an effect on both phytoplankton and zooplankton diversity hence the similarity in phytoplankton and zooplankton diversities at Muyanganas and Kasaka Fisheries Training Centre which are non-aquaculture areas. The most abundant phytoplankton in the lower Kafue river was found to be the cyanobacterium *Microcystis novacekii*. The most abundant zooplankton in the lower Kafue river was found to be a rotifer called *Monostyla bulla* from family Lecanidae.

Copyright declaration

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