

# Relationship between physicochemical parameters and the abundance of zooplankton in Lake Mweru-Wantipa, Zambia

AONGOLA ANAMUNDA, HIEROMIN A. LAMTANE\*

Department of Animal, Aquaculture and Range Sciences, Faculty of Agriculture, Sokoine University of Agriculture, Morogoro, Tanzania.  
Tel.: + 255-23-26035114, \*email: hlamtan@suant.ac.tz

Manuscript received: 21 April 2022. Revision accepted: 19 June 2022.

**Abstract.** Anamunda A, Lamtane HA. 2022. Relationship between physicochemical parameters and the abundance of zooplankton in Lake Mweru-Wantipa, Zambia. *Intl J Bonorowo Wetlands* 12: 33-40. This study aimed to assess the abundance of zooplankton and their relationship with physicochemical parameters within Lake Mweru-Wantipa, Zambia. A National Park borders the lake on one side and settlements on the other, so four sampling stations were selected, two on each side of the lake. Five physicochemical parameters, including temperature, turbidity, salinity, pH, and dissolved oxygen, were measured monthly using portable instruments concurrently with a collection of duplet zooplankton samples at each sampling point at depths between 0.1m and 0.5m. All physicochemical parameters were significantly different between the two sites ( $p < 0.05$ ) apart from temperature and pH. A total of 13 genera of zooplankton were identified, belonging to four groups, namely, rotifers, cladoceran, copepods, and ostracods. The cladoceran had the highest number of species (6), followed by copepods (4) in both sites. However, the copepods had the largest contribution in abundance in both sites. The diversity was high in settlement areas, but the National Park had higher species richness. There was a significant difference in species diversity between the two sites ( $t=3.96$ ;  $p=0.001$ ). The most abundant group was the cyclopoid on both sides of the lake, followed by the *Moina* on the settlement site and the *Daphnia* sp. on the National Park site. The densities of *Molina*, *Simocephalus*, *Ceriodaphnia*, and *Cypris* were significantly different between the two sites ( $p < 0.05$ ). Except for copepods, all groups were significantly different between the two sites ( $p < 0.05$ ). Generally, the total zooplankton density was not significantly different between the two sites ( $t=0.73$ ;  $p=0.06$ ). The results showed that the zooplankton abundance was influenced by turbidity in settlement areas and pH in National park areas.

**Keywords:** Cladoceran, Mweru-Wantipa, physicochemical, zooplankton

## INTRODUCTION

Zooplankton consists of macro and microscopic animals and is an important food item for other aquatic animals in the higher trophic levels (Takarina et al. 2019). Zooplankton is an important water quality indicator due to their shorter life spans and different tolerance levels towards physicochemical parameters (Gajbhiye 2002). Research has shown that zooplankton species have different tolerance limits toward physicochemical parameters. Balakrishna et al. (2013) reported changes in zooplankton species densities affected by changes in physicochemical parameters across different seasons. According to Waikato Environmental Technical Report (2008) in New Zealand, the presence of rotifers can be used to grade the eutrophic status of the lakes.

Understanding zooplankton's variability patterns, both temporally and spatially, provides information on the processes affecting them. Physicochemical parameters have been reported as one of the sources of variation in species composition, abundance, diversity, and distribution of zooplankton. For example, Imaobong (2013) reported in Nigerian lakes, levels of eutrophication determined zooplankton species abundance and distribution. Variations in seasonal abundance and diversity because of changes in physicochemical parameters were also reported by Kedar et al. (2008). Similar studies have been conducted on the

relationship between zooplankton and physicochemical parameters in India and Nigeria (Goswami and Mankodi 2012).

Lake Mweru-Wantipa is a small lake found in Zambia. The lake is swampy and muddy; it has no water outlet, although a few small streams flow into it. The lake's boundary lies entirely within the Mweru-Wantipa National Park. Over the past decade, encroachments have been tolerated and have increased to a level where many permanent settlements on the eastern sides of the lake are now established. The lake is the main fish supplier to the residents of the Nsama and Kaputa Districts. Apart from fishing, the settlers diversified into other activities such as agriculture, logging, and charcoal production within the immediate catchment of the lake. Despite these stressors developing around it, the lake has received very little attention from researchers. Lake Mweru-Wantipa has displayed a series of fluctuations in water levels in the past, which variations in rainfall levels have not explained. The lake has also been known to have dried out almost completely in 1916 (Brelsford 1954). The only known study on Lake Mweru-Wantipa was on the biology and exploitation of small pelagic fishes by Mubamba (1989). There is limited published information on the zooplankton abundance and water quality of Lake Mweru-Wantipa.

The two districts of Nsama and Kaputa, that share Lake Mweru-Wantipa, are boarded by Nsumbu and Mweru-

Wantipa National Parks. As Tsetse fly infestations make the rearing of larger livestock impossible, Lake Mweru-Wantipa is the main supplier of animal protein, in the form of fish, to these districts. However, the growing population around the lake has led to overfishing and increasingly large areas close to the lake being opened for agricultural purposes, leading to deforestation in the lake's catchment area. These activities have increased siltation in the lake, as evidenced by the poor transparency of the lake itself. Studies on the relationship between zooplankton and physicochemical parameters have been done in nearby lakes (Nkotagu and Athuman 2007), but there is limited information on the zooplankton of Mweru-Wantipa.

This study aimed to determine the relationship between the physicochemical parameters and zooplankton abundance in Mweru-Wantipa Lake, Zambia. A zooplankton study and its relationship to physicochemical parameters will provide insight into the current limnological status of Lake Mweru-Wantipa, which has never been done. That will be valuable baseline information for researchers and government agencies interested in the management of the lake.

## MATERIALS AND METHODS

### Description of the study area

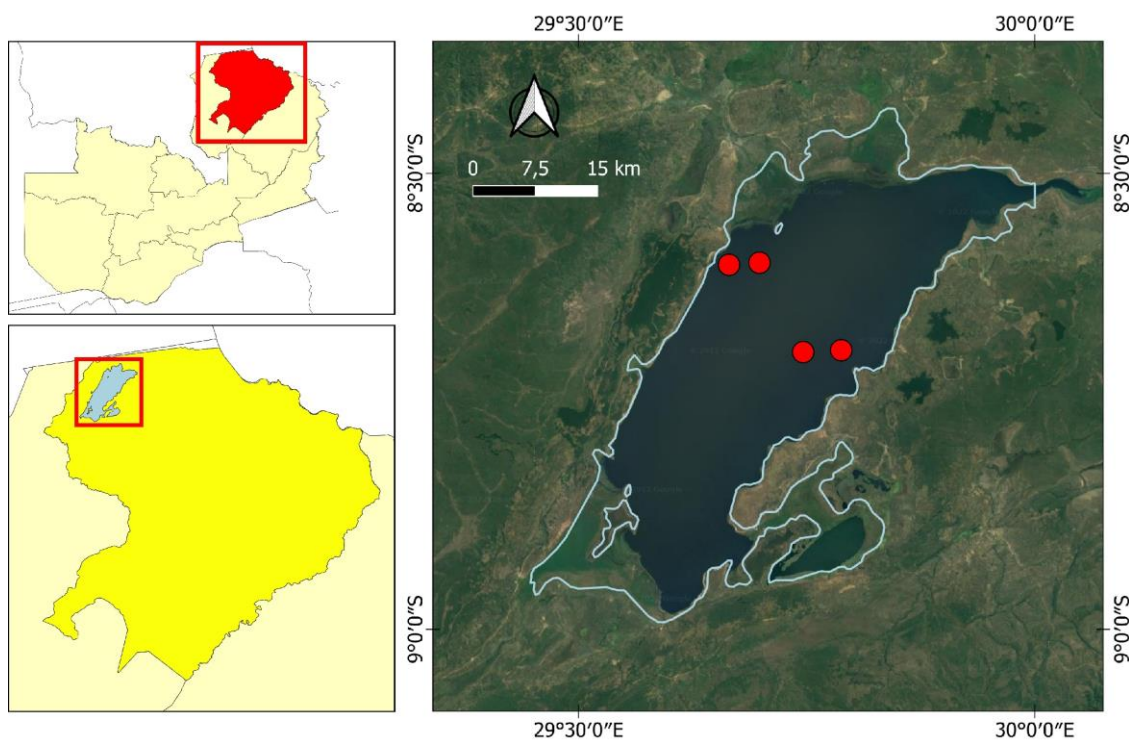
The research was conducted in Lake Mweru-Wantipa, in the Northern Province of Zambia. The lake is located between coordinates 8°10'S to 9°10'S and 29°00'E to 30°00'E. The lake's size is 73 km long and 43 km wide, with an average depth of two meters (Frame Survey Report 2004).

Though the lake has several inlets that bring in water, it has no outlet. The western side is boarded by a National park (Figure 1). The lake is shared by two districts, namely Nsama and Kaputa, whose main sources of livelihood are fishing and agriculture. The area falls within an agroecological zone (III) characterized by a humid subtropical climate with the warmest temperature of about 32°C in October and the coolest temperatures of about 5°C in July (Chabala et al. 2013). The districts normally experience dry and wet seasons; the dry season normally starts in May and runs through October, while the wet season starts from November to April. The region receives an average rainfall of 1000-1500 mm and has strong acidic soils with low nutrients caused by high rainfall (Paul 2008).

### Sampling design

Four sampling stations were chosen across the lake's midsection, two on the western side closer to the National Park and two on the eastern side closer to the human settlements. The sampling points were identified and marked using a geographical positioning system (GPS).

Table 1 shows the coordinates of the sampling stations and the depths of the water columns, respectively. The water samples were collected in the first week of the three sampling months, in the morning between 08hrs and 12hrs. The physicochemical parameters were measured at sampling sites concurrently with a collection of zooplankton water samples below the water surface. The first sampling occurred in the first week of November 2013, and the last was during the first week of January 2014.



**Figure 1.** The map of Lake Mweru-Wantipa, Zambia, and sampling points

**Table 1.** Zooplankton sampling points on the Lake Mweru-Wantipa, Zambia

|                   | National                      | Park                             | Settlement                       | Areas                            |
|-------------------|-------------------------------|----------------------------------|----------------------------------|----------------------------------|
| Sampling stations | 1                             | 2                                | 3                                | 4                                |
| GPS coordinates   | 08°36'0" S,<br>029°40'04.1" E | 08°37'54.3" S,<br>029°42'03.7" E | 08°40'19.8" S,<br>029°44'37.3" E | 08°41'23.0" S,<br>029°47'03.3" E |
| Water depth       | 0.64m                         | 0.95m                            | 2.0m                             | 2.3m                             |

### Data collection

#### Zooplankton sampling

A graduated 10 L bucket with a mouth diameter of 20 cm was used to sample zooplankton below the water surface at depths between 0.1 and 0.5 m. Each time, one bucket scope was taken vertically and filtered through a 100 µm zooplankton net. Samples were collected in duplicates. The zooplankton samples were stored in 100ml plastic bottles with 4% formaldehyde. The bottles were kept in cooler boxes and then transported to the laboratory of the Department of Fisheries in Mpulungu, Zambia.

#### Water quality parameters

Five physicochemical parameters were measured during sampling using portable electronic instruments. Dissolved oxygen (DO) and salinity were measured using YSI Model 54 ABP, model 54 ARC, and Salinometer HI 8033, respectively. Turbidity was measured with a Hach turbidity meter model 2100A with precision + Nephelometric Turbidity Units (NTU). pH was measured using a pH meter (WTH 323), while the temperature was measured using a Hanna temperature probe (HI 9143).

#### Zooplankton laboratory analysis

A Labovert FS microscope with a magnification of x40 was used to examine the zooplankton. Zooplankton was identified up to a generic level using identification guides by Utzugi and Mazingaliwa (2002). Standard Operating Procedure for Zooplankton Analysis guidelines by the United States Environmental Protection Agency (USEPA 2010) was used to analyze the zooplankton in the laboratory. Samples were thoroughly mixed, and a 1 mL subsample was withdrawn with a pipette. One ml subsamples that had fewer organisms were discarded until consistently high zooplankton numbers were achieved in the subsamples. A zooplankton counting chamber was used for counting the identified zooplankton species.

#### Data processing and analysis

A Student *t*-test was used to determine the difference between the means of the zooplankton density and physicochemical parameters on the two sides of the lake. The biodiversity index used to determine the species diversity of zooplankton was Shannon-Weaver (1949) in Spellerberg and Fedor (2003). The Hutcheson (1970) *t*-test was used to determine the difference between the diversities between the two sides of the lake. Pearson's correlation (*r*) analysis was used to investigate whether there was a relationship between physicochemical parameters to zooplankton abundance. Finally, a multiple regression analysis was used to investigate the cause and

effect between the zooplankton abundance physicochemical parameters. The regression model used was  $Y_i = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + e_i$

#### Species diversity

Species diversity was calculated using the Shannon-Weaver Index (1949). The following formula was used;

$$H' = -\sum (P_i \cdot \ln(P_i)) \text{ where } P_i = n_i/N \text{ In} = \text{the natural log}$$

$P_i$  = Proportion of total sample belonging to the  $i^{\text{th}}$  specie  
 $n_i$  = total number of individuals in a specie

$N$  = total number of individuals

$E = H'/H_{\text{max}}$  where  $H_{\text{max}} = \ln(S)$  measures the species evenness

$(S)$  = the total number of distinct individual peaks within a profile (Species richness)

$E$  = measures the species evenness

$H_{\text{max}}$  = measures the maximum evenness the community can have; the closer this is to one, it means the community is optimally even.

$E_{\text{exp}} H$  = Effective Number of Species

#### Density estimation

The population density was calculated from known densities using the following formula by Tonapi (1980).

$$\text{Density} = (n) (v) / V \text{ Where;}$$

Density = Total no. of organization/liter of water filtered

$n$  = Average number of organisms in a 1 mL plankton sample  
 $v$  = Volume of concentrate plankton sample (ml)

$V$  = Volume of total water filtered through (L)

## RESULTS AND DISCUSSION

### Physicochemical parameters

#### Temperature

There was a slight difference in temperature between the two sampling sites (Table 2). However, there was no significant difference in water temperature between the study sites ( $t=0.586$ ;  $p=0.559$ ).

#### Turbidity

The mean and range of turbidity recorded from the settlement side and National Park are presented in Table 2. The highest turbidity value of 2.7 NTU was recorded on the settlement side, while the lowest value of 0.4 NTU was recorded on the National Park side. The difference in turbidity between the two sides of the lake was significant ( $t=-5.61$ ;  $p=0.001$ ).

### Water salinity

The lowest (3.5 ppt) and highest (4.6 ppt) salinity were recorded from the settlement and National park sides, respectively. There was a significant difference in salinity between National Park and settlement sides ( $t=12.569$ ;  $p=0.001$ ).

### pH

The highest pH value (9.9) during the study was recorded from both sides of the lake, while the lowest (9.2) was on the settlement side (Table 2). There was no significant difference in pH values between the two sites ( $t=-2.91$ ;  $p=0.06$ ).

### Dissolved oxygen

The lowest and highest dissolved oxygen concentration was 1.2 mg/L and 12.1 mg/L measured from the National Park and settlement side of the lake, respectively (Table 2). The oxygen concentrations on the settlement side were significantly higher than on the National Park side ( $t=-3.66$ ;  $p=0.001$ ).

### Zooplankton species composition and abundance

The present study recorded 13 zooplankton genera from four major groups, cladoceran, copepods, ostracods, and rotifers were recorded during the present study (Table 3). The National Park side of the lake had the highest number of genera compared to the settlement side. On both sides of the lake, the cladoceran had the highest number of individual groups, followed by copepods. Rotifers were absent from the settlement side of the lake. Table 4 shows that the cyclopoids had the highest relative abundance on both sides of the lake, followed by *Moina* on the settlement sides and *Daphnia* on the National Park side. The *Moina* ranked third on the National Park side. The lowest relative abundance was recorded as rotifers.

### Species diversity

Shannon Weaver's diversity index indicated a higher diversity of zooplankton on the settlement side. A Hutcheson  $t$ -test showed a significant difference in zooplankton species diversity ( $t=3.96$ ;  $p=0.001$ ) between the two study sites. The species richness was higher on the National Park sites compared to the settlement sites. The species evenness and the effective number of species were greater in the settlements (Table 5).

### The density of zooplankton in Mweru-Wantipa Lake, Zambia

Except for *Moina*, *Simocephalus*, *Ceriodaphnia*, and *Cypris*, all other species' densities were not significantly different between the study sites (Table 5). The copepods had the highest densities on both sampling sites, followed by cladoceran. The least density was rotifers recorded from both sites (Figure 2).  $T$ -tests showed that the densities of all the groups were significantly different between the sites except copepods ( $p=0.78$ ). Generally, the settlement had higher zooplankton densities than National Park (Figure 3). However, there was no significant difference in total

zooplankton density between the two sites ( $t=-0.729$ ;  $p=0.06$ ).

### Relationships between zooplankton and physicochemical parameters

Table 6 shows the relationships between the zooplankton and physicochemical parameters. Temperature, salinity, and pH showed a negative relationship with zooplankton abundance. Generally, except for turbidity and pH, there was no significant correlation between zooplankton abundance and physicochemical parameters. Significant relationships existed between total zooplankton and turbidity on the settlement and pH of the National park (Tables 8 and 9).

**Table 2.** Summary of water quality parameters in Lake Mweru-Wantipa, Zambia

| Parameters      | National Park           |           | Settlement areas         |           |
|-----------------|-------------------------|-----------|--------------------------|-----------|
|                 | Mean                    | Range     | Mean                     | Range     |
| Depth (m)       | 0.8 ± 0.2               | 0.6-0.1   | 2.1 ± 6                  | 2.0-2.3   |
| Temp. (°C)      | 27.8 ± 3.7 <sup>a</sup> | 19.8-31.4 | 27.4 ± 0.79 <sup>a</sup> | 26.5-28.8 |
| Turbidity (NTU) | 1.4 ± 0.6 <sup>a</sup>  | 0.4-2.2   | 1.95 ± 0.5 <sup>b</sup>  | 1.4-2.7   |
| Salinity (ppt)  | 4.1 ± 0.3 <sup>a</sup>  | 3.9-4.6   | 3.6 ± 0.2 <sup>b</sup>   | 3.5-4.0   |
| pH              | 9.5 ± 0.2 <sup>a</sup>  | 9.2-9.9   | 9.6 ± 0.3 <sup>a</sup>   | 9.2-9.9   |
| DO (mg/L)       | 5.6 ± 3.1 <sup>a</sup>  | 1.2-9.4   | 7.6 ± 2.6 <sup>b</sup>   | 4.4-12.1  |

Note: Means within the same row with different superscript letters differ significantly at  $p<0.05$ , DO = dissolved oxygen

**Table 3.** Zooplankton groups composition in the Lake Mweru-wingtip, Zambia

| Taxonomic group | Total no. of taxa |    | Percentage composition |     |
|-----------------|-------------------|----|------------------------|-----|
|                 | NP                | ST | NP                     | ST  |
| Cladocera       | 6                 | 5  | 46                     | 56  |
| Copepoda        | 4                 | 3  | 31                     | 33  |
| Rotifer         | 2                 | 0  | 15.4                   | 0   |
| Ostracoda       | 1                 | 1  | 7.6                    | 11  |
| Total           | 13                | 9  | 100                    | 100 |

Note: NP = National park, ST = settlement areas

**Table 4.** Zooplankton composition in percentages of Lake Mweru-Wantipa in Zambia

| Taxa      | Genus               | Settlements | National park |
|-----------|---------------------|-------------|---------------|
| Cladocera | <i>Moina</i>        | 20          | 12.1          |
|           | <i>Daphnia</i>      | 11.1        | 10.3          |
|           | <i>Simocephalus</i> | 2.5         | 0.4           |
|           | <i>Ceriodaphnia</i> | 2.5         | 1             |
|           | <i>Crystallina</i>  | 1.6         | 1.2           |
| Copepoda  | <i>Chydorus</i>     | 0           | 0.2           |
|           | Cyclopoid           | 38.8        | 46.6          |
|           | Calanoid            | 11.8        | 14            |
|           | <i>Ergasilus</i>    | 4.7         | 4.3           |
|           | <i>Angusilus</i>    | 0           | 0.2           |
| Rotifer   | <i>Branchionus</i>  | 0           | 1             |
|           | <i>Conochilus</i>   | 0           | 0.2           |
| Ostracoda | <i>Cypris</i>       | 6.8         | 8.4           |

**Table 5.** Diversity, species richness, and evenness of zooplankton in Lake Mweru-Wantipa, Zambia

| Diversity index parameter   | Sampling stations |            |
|-----------------------------|-------------------|------------|
|                             | National park     | Settlement |
| Species diversity ( $H'$ )  | 1.50              | 1.76       |
| Species richness            | 13                | 9          |
| Species evenness ( $E'$ )   | 0.58              | 0.76       |
| Effective number of species | 5                 | 6          |

Note:  $H'$  = is the Shannon Weaver diversity index

**Table 6.** The density of zooplankton species in the Lake Mweru-Wantipa, Zambia

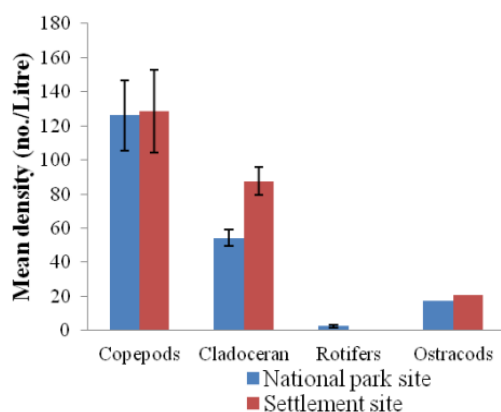
| Taxa      | Genus               | Settlement              | National park            |
|-----------|---------------------|-------------------------|--------------------------|
| Cladocera | <i>Moina</i>        | 46.7±16.86 <sup>a</sup> | 20.67±15.63 <sup>b</sup> |
|           | <i>Daphnia</i>      | 25.4±5.55 <sup>a</sup>  | 28.8±3.51 <sup>a</sup>   |
|           | <i>Simocephalus</i> | 6.25±6.25 <sup>a</sup>  | 1.67±1.64 <sup>b</sup>   |
|           | <i>Ceriodaphnia</i> | 5.84±3.67 <sup>a</sup>  | 2.08±2.1 <sup>b</sup>    |
|           | <i>Crystallina</i>  | 3.75±2.45 <sup>a</sup>  | 2.5±2.49 <sup>a</sup>    |
|           | <i>Chydorus</i>     | -                       | 0.5±0.42                 |
| Copepod   | Cyclopoid           | 90.4±12.16 <sup>a</sup> | 88.75±21.18 <sup>a</sup> |
|           | Calanoid            | 27.5±12.06 <sup>a</sup> | 27.5±7.1 <sup>a</sup>    |
|           | <i>Ergasilus</i>    | 10.84±5.65 <sup>a</sup> | 10±4.08 <sup>a</sup>     |
|           | <i>Angusilus</i>    | -                       | 0.5±0.42                 |
| Rotifer   | <i>Branchionus</i>  | -                       | 2.08±1.63                |
|           | <i>Conochilus</i>   | -                       | 0.4±0.42                 |
| Ostracod  | <i>Cypris</i>       | 20.9±7.19 <sup>a</sup>  | 17.16±7.56 <sup>b</sup>  |

Note: Means within the same row with different superscript letters differ significantly at  $p < 0.0$

**Table 7.** The Pearson coefficient of correlation of total zooplankton and physicochemical parameters in Lake Mweru-Wantipa, Zambia

| Particulars      | Co-efficient of correlation (r) | P value | Remarks |
|------------------|---------------------------------|---------|---------|
| Turbidity        | 0.380                           | 0.000   | S       |
| Temperature      | -0.046                          | 0.63    | NS      |
| pH               | -0.327                          | 0.000   | S       |
| Dissolved oxygen | 0.151                           | 0.115   | NS      |
| Salinity         | -0.149                          | 0.121   | NS      |

Note: NS: Not Significant, S: Significant

**Figure 2.** Mean densities of major zooplankton groups from studied sites in Lake Mweru-Wantipa, Zambia**Table 8.** Regression analysis for zooplankton and physicochemical parameters on the settlement area in Lake Mweru-Wantipa, Zambia

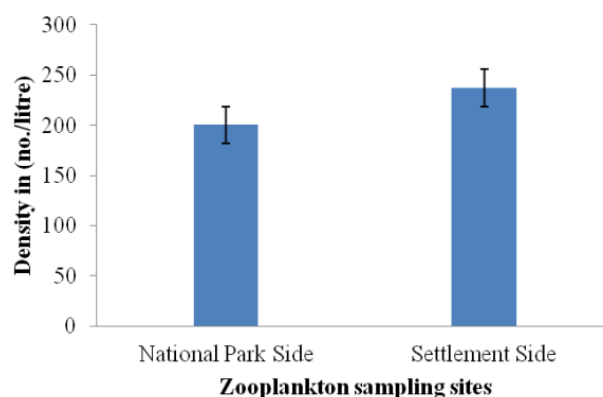
| Predictor        | Coefficients | P-value | Remark |
|------------------|--------------|---------|--------|
| Constant         | -77.7        | 0.47    | S      |
| Turbidity        | 11.86        | 0.04    | S      |
| Temperature      | 0.37         | 0.81    | NS     |
| pH               | 6.08         | 0.49    | NS     |
| Dissolved oxygen | -0.33        | 0.51    | NS     |
| Salinity         | -0.40        | 0.96    | NS     |

Note: S = Significant, NS = Not Significant

**Table 9.** Regression analysis for zooplankton and physicochemical parameters on the National park area in Lake Mweru-Wantipa, Zambia

| Predictor        | Coefficient | P-value | Remark |
|------------------|-------------|---------|--------|
| Constant         | 200.70      | 0.06    | NS     |
| Turbidity        | 2.70        | 0.64    | NS     |
| Temperature      | 0.89        | 0.47    | NS     |
| pH               | -23.59      | 0.04    | S      |
| Dissolved oxygen | 0.61        | 0.57    | NS     |
| Salinity         | 0.08        | 0.99    | NS     |

Note: S = Significant, NS = Not Significant

**Figure 3.** The density of zooplankton in sampling sites in Lake Mweru-Wantipa, Zambia

## Discussion

### Physicochemical parameters

Lake Mweru-Wantipa is a shallow and small lake bordered by a National Park on the western side, while the lake's eastern, southern, and northern sides are settlement areas. The major economic activities in the settlement areas are agriculture and fishing. The fisheries frame survey report of Lake Mweru-Wantipa by the Zambia Central Statistical Office (Frame Survey Report 2004) showed that there had been an immense increase in the number of fishing villages around the lake. Improper agriculture practices and deforestation lead to land degradation and alteration of the physicochemical parameters of the lake. Yorke and Margai (2007) reported that population growth and developmental activities along water bodies in many

sub-Saharan countries have been responsible for negative changes in water quality parameters.

The marginal temperature differences in water between the two studied sides of the lake were probably due to the lake's shallowness (Table 2). The depth of water bodies can potentially affect variations in physicochemical parameters, including temperature and dissolved oxygen. Shallow waters generally warm easier and quicker compared to deeper lakes. Stefanidis and Papastergiadou (2012) studied Greek lakes and reported that variations in some water quality parameters could be due to morphometric measurements of water bodies. The homogeneity in temperature in shallow lakes has been achieved through regular mixing and stirring. This phenomenon has been recorded in other shallow lakes, including Edward and George in Uganda (Otim 2005).

The higher turbidity recorded from the settlement side of the lake is probably due to improper agriculture practices and deforestation. Agricultural activities along the lake's catchment lead to erosion and hence high turbidity in the lake from the runoff. High turbidity has been reported in the Birim river basin in Ghana (Ansa and Asante 2000) and Lake Victoria (Scheren et al. 2001) due to improper agricultural activities. Conversion of land to agriculture has been reported as one of the drivers of the deterioration of aquatic systems (Yorke and Magai 2007; Rucha et al. 2011) in India and Ghana. Removing vegetative cover means loose soil is washed into aquatic systems, creating turbid and eutrophic conditions.

Relatively lower water depth on the National Park side contributed to high salinity (Table 2). Shallow areas are generally more prone to drying up due to evaporation, and the salts become concentrated as the water drops. Saravanakumar et al. (2007) reported that changes in salinity could be due to the loss of water through evaporation and rainfall in India. Surprisingly, salinity levels recorded in the present study (Table 2) were like those in brackish waters reported along the estuaries in Sri Lanka (Gammanpila 2010). However, salinity levels below 5.0 ppt are within the freshwater range (USEPA 1986), as lakes are considered saline when salinity is above 3 ppt.

The stirring and mixing of the lake and its small size could also be attributed to the uniformity in pH values across the lake. Small size, low depth, and wind have been reported as parameters promoting water mixing (Omundi et al. 2014) in the small water bodies of Kenya. The present findings on pH values (Table 2) were like those obtained by Otim (2005) in the Nile basin in Uganda. However, the mean pH values obtained in the present study (Table 2) were slightly above the optimum aquatic range of 6.5 to 9.0 (USEPA 1986). The higher pH values could probably be explained, in part, because of higher primary production. The green color was observed on the entire surface of the lake during the sampling period. Tucker and Dabramo (2008) state that waters with high algae content result in intense photosynthesis during the day; thereby, carbon dioxide is used up in the process resulting in high pH values. A similar finding was reported by Sarvala et al. (1999) in Lake Tanganyika. In contrast, lower pH values (6.3 to 6.9) were reported in Lake Bangweulu, Zambia

(Kolding 2011). Higher pH levels (>10) are harmful as they increase ammonia toxicity to fish and other organisms in aquatic systems (Rossana 2013).

Significant differences in dissolved oxygen between the study sites might have been due to biotic and abiotic factors in the lake. Occasional short-duration winds that swept the water surfaces were observed several times a day during the sampling period. These could lead to spatial differences within shorter distances. The differences in water depth could contribute to differences in dissolved oxygen levels since photosynthesis is one of the major sources of dissolved oxygen. The National Environmental Monitoring Standards (NEMS 2013) reported that dissolved oxygen is negatively affected by salinity; thus, the lower oxygen levels in the National Park site could have also been due to the significantly higher salinity observed in the present study (Table 2). The present findings are like those obtained in Lake Tanganyika by Sarvala et al. (1999). The dissolved oxygen levels recorded in the present study (Table 2) were within the natural background level of 5.0 to 7.0 mg/L, which supports aquatic life.

#### *Zooplankton species composition and diversity*

The cladoceran dominated species number in the present study, followed by copepods, which concurs with the findings of Abubakar (2013) in Nguru Lake, Nigeria. Ghidini et al. (2009) conducted a similar study in Brazil and concluded that since most cladoceran species are herbivorous and phytoplankton feeders, they can develop in many freshwater environments. Kishe-Machumu et al. (2008) reported that cladoceran is more vulnerable to predation owing to their large size, conspicuous eyes, and mode of movement, making them more attractive prey and easy targets for capture. The low transparency of Lake Mweru-Wantipa could have led to less predation, thus allowing cladoceran to flourish.

Lake Victoria has also reported the dominance of copepods among zooplankton in freshwater (Ajouu et al. 2011; Ngupula 2013). In the present study, the cyclopoids (Table 6) showed higher relative abundance than other zooplankton. Similar findings have been reported by Silva (1998) in Chilean inland waters, respectively. Cyclopoids can survive in most freshwater habitats in the Neotropics. Their feeding behavior can explain this; they are grasping feeders that generally eat more of a variety of food compared to other zooplankton (Irvine and Waya 1992). At the same time, calanoids are limited by their selective and herbivorous nature. Due to their benthic nature, ostracods are not commonly captured in zooplankton studies (Martens et al. 2008).

Contrary to the present study (Table 6), Devaraju (2015) found four taxa of ostracods of 14 taxa in a major tropical lake within the Mandya District, Karnataka. Rotifers constituted the lowest contribution among all zooplankton in the present study (Table 4). In contrast, rotifers were among the dominant taxa in Lake Victoria Basin (Waya and Chande 2004). Rotifers appear to be protected from predation owing to their diminutive size, which offers low caloric value as prey besides being not easily visible to the predators.

The Shannon Weaver diversity index showed a higher diversity of zooplankton on the settlement side, and the Hutcheson *t*-test showed a significant difference between the two sides. The diversity difference could be due to the high species evenness on the settlement side (Table 5). Also, higher salinity in the National Park site could have been responsible for the low diversity of zooplankton. Nielsen et al. (2003) reported that zooplankton diversity was reduced at salinities between 1 to 5 ppt. Low species richness on the settlement side (Table 5) could reflect the high turbidity compared to National Park areas. Ghidini et al. (2009) made a similar observation in a study of eutrophic shallow reservoirs in Brazil. The species richness in the present study (Table 5) was generally poor compared to other studies conducted elsewhere (Ezekiel et al. 2011).

#### *Zooplankton density*

Differences in zooplankton densities were observed between the two studied sites (Table 6). These could have been due to the differences in physicochemical parameters and depth between the two sites (Table 2). The lower densities of rotifers on the National Park side and absence in settlement areas compared to other groups could be attributed to higher turbidity in the lake, which was significantly high in settlement areas, and to salinity and pH, which were significantly higher in settlement areas. These factors are well known for limiting the abundance and diversity of zooplankton (Harris and Vinobaba 2012). Contrary to the present findings (Table 6), Gammanpila (2010) reported higher proportions of rotifers (11% to 37%) compared to other groups of zooplankton in a Sri Lankan lagoon. However, similar results of zooplankton total densities in studied sites have been reported by Gammanpila (2010) in Sri Lanka. The higher copepod density compared to other zooplankton has been reported by Ekwu, and Sikoki (2005) found crustacean compositions of 74% in a lower estuary in Nigeria. High densities of cyclopoids in freshwater have been reported by Ngupula (2013), who found that cyclopoids dominated by 73%. In contrast to the present findings, the highest contribution of *Moina* was reported by Abubakar (2013) in Nguru Lake, as crustaceans were 65%, of which 41% were cladocerans dominated by *Moina*.

#### *Relationships between zooplankton, abundance, and physicochemical parameters*

The regression analysis revealed a positive and significant relationship between turbidity and zooplankton on the settlement side (Tables 7 and 8). This significant positive relationship may have been contributed by a higher significant abundance of *Moina*, *Ceriodaphnia*, and *Cypris* in the settlement areas (Table 6), which also had significantly high turbidity (Table 2), which could be partly explained by the reduction of the ability of the visual predators to see prey (zooplankton) in turbid waters, thus allowing larger zooplankton to flourish. That was also observed in small lakes in the Lake Victoria basin; low transparency makes these lakes support a high abundance of zooplankton than Lake Victoria with higher transparency (Ngupula 2013). However, in the present

study (Table 7), an opposite relationship was observed between zooplankton and pH. Those suggest that high pH contributes to the lower densities of zooplankton. However, contrary to the present findings, Beenamma and Sadanand (2011) reported a positive relationship between zooplankton and pH in India. In addition, Tenner et al. (2005) reported that pH values ranging from 6 to 8.5 are associated with medium productivity.

In conclusion, turbidity, salinity, and dissolved oxygen significantly differed between the two studied sites. The settlement recorded a higher diversity index than the National Park site. Apart from *Moina*, *Simocephalus*, *Ceriodaphnia*, and *Cypris*, the density of all species was not significantly different between the two studied sites. Turbidity and pH were significantly positively and negatively correlated with zooplankton abundance, respectively.

## REFERENCES

- Abubakar MM. 2013. Biodiversity and abundance of fish and plankton of Nguru Lake, Northeastern Nigeria. *J Biol Agric Healthcare* 5: 2224-3208.
- Ajouni N, Ukaonu SU, Oluwajoba EO, Mbawuiki BE, Williams AB, Myade EF. 2011. The abundance and distribution of plankton species in the Bony Estuary; Nigeria. *Agric Biol J North Am* 2 (6): 1032-1037. DOI: 10.5251/abjna.2011.2.6.1032.1037.
- Ansa-Asare OD, Asante KA. 2000. The water quality of Birim River in Southeast Ghana. *West Afr J Appl Ecol* 1: 23-33. DOI: 10.4314/wajae.v1i1.40567.
- Balakrishna D, Reddy TR, Reddy KV, Samatha D. 2013. Physicochemical parameters and plankton diversity of Ghanpur Lake, Warangal, A.P. India. *Intl J Zool Res* 3 (1): 44-48.
- Beenamma J, Sadanand M. 2011. Monthly changes in the abundance and biomass of zooplankton and water quality parameters in Kukkarahalli in lake of Mysore, India. *J Environ Biol* 32: 551-557.
- Brelford WV. 1954. The problem of Mweru Wantipa. *Northern Prov J* 2 (2): 4.
- Chabala LM, Kuntashala E, Kaluba P. 2013. Characterization of temporal changes in rainfall, temperature, flooding hazard and dry spells over Zambia. *Univers J Agric Res* 1 (4): 134-144. DOI: 10.13189/ujar.2013.010403.
- Devaraju TM. 2015. Studies on crustacean zooplanktons in major lakes of Mandya, District Karnataka. *J Intl Acad Res Multidiscip* 3 (5): 343-351.
- Ekwu AO, Sikoki FD. 2005. Species composition and distribution of zooplankton in lower cross river estuary, Nigeria. *Afr J Appl Zool Environ Biol* 7: 5-10. DOI: 10.4314/ajazeb.v7i1.41137.
- Ezekiel EN, Ogamba EN, Abowe JFN. 2011. The zooplankton species composition and abundance in Sombreiro River, Niger Delta, Nigeria. *Asian J Agric Sci* 3 (3): 200-204.
- Frame Survey Report. 2004. Lake Mweru-Wantipa Pilot Fishery Survey. Zambia Central Statistical Office, Lusaka, Zambia.
- Gajbhiye SN. 2002. Zooplankton study methods, importance, and significant observations. In: Quadros (eds). *Proceedings of the National Seminar on Creeks, Estuaries and Mangroves*. Thane, 28 November to 30 November. [India]
- Gammanpila M. 2010. Hydrography, nutrients and abundance and distribution of zooplankton in Negambo Lagoon, Sri Lanka. *Sri Lanka J Aquat Sci* 15: 13-24. DOI: 10.4038/sljias.v15i0.5447.
- Ghidini AR, Moacyr SJ, Gilmar PN, Lineu DB. 2009. Distribution of planktonic cladocerans crustacean: Branchiopoda of a shallow eutrophic reservoir Panama State, Brazil). *Pan-Am J Aquat Sci* 43 (3): 294-305.
- Goswami AP, Mankodi PC. 2012. Study on zooplankton of Fresh Water Reservoir Nyari-II Rajkot District, Gujarat, India. *ISCA J Biol Sci* 1 (1): 30-34.

- Harris JM, Vinobaba P. 2012. Impact of water quality on species composition and seasonal fluctuation of plankton of Batticaloa Lagoon, Sri Lanka. *Jl Ecosyst Ecograph* 2 (4): 6.
- Hutcheson T. 1970. A test for comparing diversities based on the Shannon formula. *J Theor Biol* 29: 151-154. DOI: 10.1016/0022-5193(70)90124-4.
- Imaobong E. 2013. Effect of physicochemical parameters on zooplankton species and density of a tropical rainforest in Niger Delta, Nigeria using canonical analysis. *Intl J Eng Sci* 2 (4): 13-21.
- Irvine K, Waya R. 1992. Predatory behavior of the cyclopoid copepod mesocyclops aquatorialis aquatorialis in Lake Malawi, a deep tropical lake. *Verhandlungen Intl Verein Limnologie* 25: 877-881. DOI: 10.1080/03680770.1992.11900271.
- Kedar GT, Patil GP, Yeole SM. 2008. Effect of physicochemical factors on the seasonal abundance of zooplankton population in Rishi Lake. *Proceedings of Taal, the 12<sup>th</sup> World Lake Conference* 88-91.
- Kishe-Machumu MA, Witte F, Wanink J. 2008. Dietary Shift in benthivorous cichlids after the ecological changes in Lake Victoria. *Anim Biol* 58 (4): 407-417. DOI: 10.1163/157075608X383700.
- Kolding J. 2011. A Brief Review of the Bangweulu Fishery Complex. Report Prepared for the Bangweulu Wetlands Project, Department of Biology, University of Bergen, Norway.
- Martens K, Schon I, Claude M, David HJ. 2008. Global diversity of Ostracods (Ostracoda, Crustacea) in freshwater. *Fresh Water Animal Assessment. Hydrobiologia* 595: 185-193. DOI: 10.1007/s10750-007-9245-4.
- Mubamba R. 1989. The biology and exploitation of small pelagic fishes in Zambia. Department of Fisheries, PO Box 350100, Chilanga, Zambia. Symposium on Biology, Stock Assessment and Exploitation of Small Pelagic Species in the African Lakes Region in Bujumbura, Burundi from 25 to 28 November 1992.
- NEMS. 2013. Dissolved Oxygen Recording, Measurement, Processing and Achieving on Dissolved Oxygen. National Environmental Monitoring Standards New Zealand data version 1: 48
- Ngupula GW. 2013. How does increased eutrophication and pollution in Lake Victoria waters impacts zooplankton? *J Environ Ecol* 4 (2): 151-164. DOI: 10.5296/jee.v4i2.4397.
- Nielsen DL, Brock MA, Crossle K, Harris K, Healey M, Jarosinski I. 2003. The effect of salinity on aquatic plant germination and zooplankton hatching from two wetland sediments. *Freshw Biol* 48: 2214-2223. DOI: 10.1046/j.1365-2427.2003.01146.x.
- Nkotagu HH, Athuman CB. 2007. The limnology of the Lake Tanganyika sub-catchment. Geology Department, University of Dar es salaam. *Tanzania J Sci* 33: 19-26. DOI: 10.4314/tjs.v33i1.44272.
- Omundi R, Kimbenya, Nyameveya, Ouma H, Machua SK, Ogari Z. 2014. Recent limnological changes and their implication on fisheries in Lake Baringo, Kenya. *J Ecol Nat Environ* 6 (5): 154-163. DOI: 10.5897/JENE2014.0438.
- Otim M. 2005. Baseline Study of the Status of Water Quality Monitoring in Uganda. Nile Basin Initiative and Nile Transboundary Environment Action Project-Nile Basin National Water Quality Monitoring Baseline Study Report for Uganda.
- Paul BS. 2008. Profile of Zambia's Small Holder. Where and Who are the Potential Beneficiaries of Agricultural Commercialization. World Bank Report no. 36573-ZM.62
- Rossana S. 2013. Understanding Water Quality Parameters to Better Manage Your Pond. Department of Extension Animal Sciences and Natural Resources, New Mexico State University, Guide no.104: 4pp.
- Rucha RJ, Warthe M, Shared D, Ritesh V, Tapan C. 2011. Monitoring changes in land use land cover of Yamuna riverbed in Delhi: A multi-temporal analysis. *Intl J Remote Sens* 32 (24): 9547-9558. DOI: 10.1080/01431161.2011.565377.
- Saravanakumar A, Rajikumar M, Serebiah SJ, Thivakaran GA. 2007. Abundance and seasonal variations of zooplankton in the arid zone mangrove of Gulf Kachchh-Gujarat, west coast of India. *Pak J Biol Sci* 10 (20): 3525-3532. DOI: 10.3923/pjbs.2007.3525.3532.
- Sarvala J, Salomen K, Javinen M, Aro E, Huttula T, Kotrilainena P, Kurk H, Langenberg V, Maunini P, Peltonen A, Plisnier PD, Vourinen I, Molsa H, Lindqvist OV. 1999. Trophic structure of Lake Tanganyika: Carbon flows in the pelagic food web. *Hydrobiologia* 407: 45-58. DOI: 10.1007/978-94-017-1622-2\_15.
- Scheren PAGM, Mirambo V, Lemmens AMC, Katima JHY, Jansee FJJG. 2001. Assessment of pollution sources and socio-economic circumstances related to the eutrophication of Lake Victoria. Paper Presented at LVEMP Conference, Kisumu, Kenya.
- Silva VM. 1998. Diversity and distribution of the free living freshwater cyclopodia (Copepod: Crustacea) in Neotropics. *Braz J Biol* 68: 1099-1106. DOI: 10.1590/S1519-69842008000500016.
- Spellerberg IF, Fedor PJ. 2003. A tribute to claude Shannon (1916-2001) and a plea for more rigorous use of species richness, species diversity and the Shannon Wiever Index. *Glob Ecol Biogeogr* 12: 177-179. DOI: 10.1046/j.1466-822X.2003.00015.x.
- Stefanidis K, Papastergiadou E. 2012. Relationships between Lake Morphometry, water quality and aquatic macrophytes in Greek lakes. *Fresenius Environ Bull* 21: 3018-3926.
- Takarina ND, Nurliansyah W, Wardhana W. 2019. Relationship between environmental parameters and the plankton community of the Batuhideung Fishing Grounds, Pandeglang, Banten, Indonesia. *Biodiversitas* 20: 171-180. DOI: 10.13057/biodiv/d200120.
- Tenner CC, Cragga RJ, Sukias JP, Park JBK. 2005. Comparison of maturation ponds and constructed wetlands as the final stage of an advanced pond system. *Water Sci Technol* 51 (12): 307-314. DOI: 10.2166/wst.2005.0489.
- Tonapi GT. 1980. *Freshwater Animals of India an Ecological Approach*. Oxford and IBH. Publishing Company New Delhi, India.
- Tucker CS, Dabramo LR. 2008. *Managing pH in Freshwater Ponds*. South Regional Aquaculture Centres (SRAC) Publication no.4604: 6pp.
- USEPA. 1986. *Quality criteria for water, office of water regulations and standards, Washington, DC EPA/440/5-86-001: 477pp*.
- USEPA. 2010. *Standard Operating Procedures for Zooplankton Analysis. Sampling and Analytical Procedures. Revision No.3: 20pp*.
- Utzugi K, Mazingaliwa K. 2002. *Field guide to Zambian Fishes, Planktons, and Aquaculture*. Japan International Cooperation Agency, Japan.
- Waikato Environmental Technical Report. 2008. *Zooplankton Composition and Water Quality Assessment of Seventeen Lakes Using Rotifer Community Composition*. Environmental Waikato-Regional Council, New Zealand.
- Waya RK, Chande AI. 2004. Species composition and biomass estimate of zooplankton in some water bodies within lake Victoria Basin. *Tanzania J Sci* 30 (11): 43-52. DOI: 10.4314/tjs.v30i1.18386.
- Yorke C, Magai FM. 2007. Monitoring land use change in the Densu river basin Ghana using GIS and Remote Sensing Methods. *Afr Geogr Rev* 85-93. DOI: 10.1080/19376812.2007.9756203.