Heliyon 8 (2022) e10533

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Research article

The investigation of the zooplankton community in the newly formed Ribb Reservoir, Ethiopia: the tropical highland reservoir

Dagnew Mequanent [a,*], Minwyelet Mingist [a], Abebe Getahun [b], Wassie Anteneh [c], Banchiamlak Getnet [a], Solomon Birie [d]

[a] Department of Fisheries, Wetlands and Wildlife Management, College of Agriculture and Environmental Sciences, Bahir Dar University, P. O. Box 79, Bahir Dar, Ethiopia
[b] Department of Zoological Sciences, Addis Ababa University, P. O. Box 1176, Addis Ababa, Ethiopia
[c] Department of Biology, College of Science, Bahir Dar University, P.O. Box 79, Bahir Dar, Ethiopia
[d] Department of Biology, Debre Tabor University, Ethiopia

ARTICLE INFO

Keywords:
Diversity
Irrigation
Reservoir
Sustainable use of the resource
Plankton
Water quality

ABSTRACT

Understanding the composition, diversity, and abundance of the zooplankton community is crucial for better utilization of the Ribb Reservoir, as zooplankton are the second link in the food chain in aquatic systems (they are also excellent bioindicators of aquatic health, given their central food web position) and the reservoir also serves as a source of income for the fishers. Therefore, sampling including some water quality parameters was conducted twice in the four seasons: autumn, summer, spring, and winter, from September 2020 to August 2021, in the first week of September, December, February, March, May, June, and August. Most of the physicochemical parameter values recorded in this study indicated that they were within the range of standards for zooplankton community requirements. Of the 14 species identified, *Mesocyclops aequatorialis similis*, *Thermodiaptomus galebi*, and *Brachionus angularis* had the first, second, and lowest records, respectively. Species abundance showed a decrease from autumn to winter and then to spring and summer. Species richness (14), abundance (6736), Margalef's diversity index (1.48), Menhinick's diversity index (0.17), Simpson index (0.098), dominance index (0.902), Shannon index (2.47), equality index (0.934), and reciprocal Simpson index (10.2) of the species were calculated in the reservoir. Some of the proposed management measures include reservoir buffering, impact assessment of over-abstraction of water for irrigation, time series of water quality data, and the reservoir water level should be above the conduit.

1. Introduction

Plankton are microscopic organisms that live in the oceans, seas, and freshwater bodies (McManus and Woodson, 2012) and provide food for fish and other higher organisms (Lan Lan Smith et al., 2019). They also play a central role in the structure and function of freshwater ecosystems (Padedda et al., 2017). Scientists classify them either as plant producers of phytoplankton (mostly dominated by bacteria and protists) or as zooplankton animal consumers (Wiebe and Benfield, 2003). Zooplankton, like phytoplankton, are passive drifters that can't swim against water currents (Wiebe and Benfield, 2003). Zooplankton are part of the basis of aquatic food webs (Kiteresi et al., 2012). They connect primary producers and other trophic levels as mediators of the flow of energy between the trophic levels (Allan, 1976). Hence, it plays an important role in the nutrient cycle (Hudson et al., 1999) and also has a short life cycle (Allan, 1976). As they are used as a good ecological indicator (Simões et al., 2013) and their consumption is increasing from time to time (Brierley et al., 2007), their abundance, distribution, and community composition contribute well to the understanding and functioning of aquatic ecosystems. Therefore, diversity assessment of the newly built Ribb Reservoir (built on the Ribb River) is useful to understand the ecological quality of aquatic ecosystems.

Damming is the control of water for irrigation, hydroelectric power, and water supply (McCartney and Kleinschroth, 2019). They are mainly reservoir ecosystems that lie between the river and lake environments (Wetzel and Likens, 2000). Most rivers worldwide have been modified and regulated (Atazadeh et al., 2020), and dammed river ecosystems will undergo major changes (Oliveira et al., 2004), which will be followed by the formation of new habitats (McManus and Woodson, 2012); the emergence of a new zooplankton community in a new reservoir is

* Corresponding author.
E-mail address: dagnewm12@gmail.com (D. Mequanent).

https://doi.org/10.1016/j.heliyon.2022.e10533
Received 8 April 2022; Received in revised form 27 July 2022; Accepted 31 August 2022

inevitable (Madhu et al., 2007). It also affects aquatic ecology, upstream and downstream rivers, aquatic habitats, and breeding areas (Braghin et al., 2018; Helland-hansen and Holtedahl, 2005); changes in water temperature over the dam; and provides physical restrictions on water transport upstream and downstream of the dam (Braghin et al., 2018; Dougherty and Hall, 1995), resulting in the displacement of communities adapted to a new environment. Reservoirs can also provide favorable environments for plankton and fish communities (Dougherty and Hall, 1995). However, factors such as water runoff, storage time, and physicochemical parameters determine the biodiversity of the reservoir (Basu and Pick, 1997; Thorp and Casper, 2003).

As Bruinsma researched in 2017, agriculture is not too far behind in view of the ongoing decline in arable land that enables it to produce the food that is still needed to feed a still growing world population. Therefore, as Lorenzen et al. (2007) suggested, using aquatic resources as food to support human nutrition could solve this problem. Reservoirs in Ethiopia provide water for agriculture, industry, domestic use, and power generation and have the potential to play an important role in fish production and contribute significantly to the livelihoods of neighboring communities (Eskedar et al., 2007). For example, over 76 fishers rely on fishing in Ribb Reservoir (Mequanent et al., 2021, 2022b). However, the benefits can only be sustainable if ecosystems are well protected (da Costa et al., 2017; de Groot et al., 2010). The investigation of the reservoir system, for example, the determination of zooplankton, is crucial for this study.

The diversity and abundance of zooplankton communities are mainly influenced by the availability of resources in the ecosystem (Effendi et al., 2016), and a lack of monitoring of freshwater bodies has contributed to the progressive degradation of their biodiversity (Degefu et al., 2014). To protect biodiversity, it is therefore essential to document the natural state of reference ecosystems before harmful effects become visible. Studying the biodiversity of the Ribb Reservoir zooplankton community is important to conserving and increasing the benefits of resources such as fishing and other reservoir uses, as unfortunately, the zooplankton communities of the reservoir and the river (the Ribb River on which the reservoir was built) and environmental variables have not been documented for comparison and reference purposes. Therefore, the current study aimed to investigate the species composition, abundance, and diversity (qualitatively and quantitatively) and some physicochemical properties of the Ribb Reservoir, which were necessary to provide the scientific community with some important basic information.

2. Materials and methods

2.1. The study area

The Ribb Reservoir is located in the Lake Tana Sub-basin (15,320 km^2), in the northeastern part of the Blue Nile Basin, which originated from Lake Tana (Lake Tana is in this sub -basin) (ADSWE: LUPESP, 2015), and it was dammed in 2017 on one of the main tributaries of Lake Tana, the Ribb River. During the rainy season, the river rises and flows several meters deep, depending on rainfall, and fills the dam (reservoir). However, during the dry season, a lot of water is diverted or pumped out for irrigation from the reservoir, and during peak rainfall times, the reservoir water flows out (excess water overflow) via the spillway. The dam is an earthen, stone rubble dam with a ridge length of 800 m, the deepest part of 73.5 m, and a dam crest height of 1945 m above sea level. A total filling volume of 7.8 million m^3, a storage volume of 234 million m^3, dead storage of 27 million cubic meters, a side canal overflow (duration of 683 m), a ridge length of 107 m, and a ridge height of 1940 m above sea level (Ministry of Water and Energy, 2010) (Figure 1). It is home to 11 fish species, most of which are endemic but vulnerable *Labeobarbus* species (Mequanent et al., 2022a, 2022b).

The rivers Melo, Hamuswenz, and Ribb constantly supply the reservoir with fresh water. By supplying these freshwater rivers, the reservoir can be qualitatively and quantitatively in good condition. The sub-basin has four seasons (autumn, winter, spring, and summer) and has a unimodal rainfall pattern from June to the beginning of September, but the rest of the months are almost dry season/time. The average annual rainfall varies from 816 to 2344 mm, and the smallest was 815 mm. The average annual temperature of the area varies from 7.26 °C to 23.4 °C. The highest temperature of the seasons occurred from March to May, while the lowest occurred from July to September (ADSWE: LUPESP, 2015). The upper highlands (elevation up to 4109 m), which is the start of the reservoir watershed and the origin of the rivers (the three rivers that feed the reservoir), have the lowest mean average temperature, while the lower (elevation below 1800 m) has the highest mean temperature.

2.2. Sampling

From September 2020 to August 2021, sampling was carried out on two consecutive days in the first week of September, November, December, February, March, May, June, and August (twice in the four seasons: autumn, summer, spring, and winter). A plankton net with a mesh size of 40 μm and a diameter of 30 cm was used to collect zooplankton samples in the sublittoral near the dam axis, in the northern, western, and eastern parts of the reservoir, as well as open or pelagic areas of the reservoir (Figure 2), using a standardized method presented in Elliott et al. (1985). The nets were drawn horizontally for sampling at a single depth and lowered to different water depths of 0.5 m, 1.0 m, and 1.5 m for the coastal stations and 1 m, 2 m, and 3 m for the pelagic stations. Direct water samples were also taken to include the small-sized species. Excess water was removed from the sample to concentrate cells and sub-samples of the same volume from different locations, each collected in 100 ml plastic bottles and treated with a 7% formalin solution for each sampling and saved for analysis. The reason for our survey is that reservoir volume varies with the seasons; during the dry season, mainly from July to May, water is withdrawn for irrigation. This resulted in a greatly reduced volume of the reservoir up to the conduit. The five sites converge (almost very close to pelagic), and the species distribution decreases as the volume of water in the reservoir decreases, i.e., plankton runoff with water. The details were discussed in the data analysis section. After the zooplankton sampling, around 11.30 am, the water transparency (Secchi depth, SDD) was measured with a white Secchi disc (Ø25 cm). At the same time, a portable multi-parameter probe (YSI Professional Plus, Ohio, USA) was used to simultaneously measure physicochemical parameters such as temperature, pH, conductivity, and dissolved oxygen concentration (DO) at each site and time. Stakeholder meetings were also conducted (with Ribb Dam workers, fisheries, and locals).

2.3. Data analysis

Therefore, since the reservoir was created for irrigation, the amount of water decreases during the dry season, mainly from January to May (Figure 3b); when the demand for irrigation water is at its highest, water drains out via conduit. The reservoir, on the other hand, reaches its maximum water storage capacity during the main rainy season (June to August), at which point it flows out via the spillway, as shown in Figure 3(c and d). During these periods, zooplankton species move with the water from the reservoir, affecting plankton species and populations. Plankton (algal) blooms occur when there is no water runoff from the reservoir, mainly from September to November, as shown in Figure 3(a). Similarly, water quality parameters are also affected by these events.

Most researchers, such as Forsblom et al. (2019),Veerendra et al. (2012), Rodrigo et al. (2003), and Ibarbalz et al. (2019), found that abiotic variables directly affect plankton biomes, abundance, and distribution. So, we did the analysis of the data based on the annual average of the samples because the sampling was done twice in the four seasons (only eight points). Thus, instead of using PCA, we have used descriptive statistics such as initial movement and frequency distribution for this

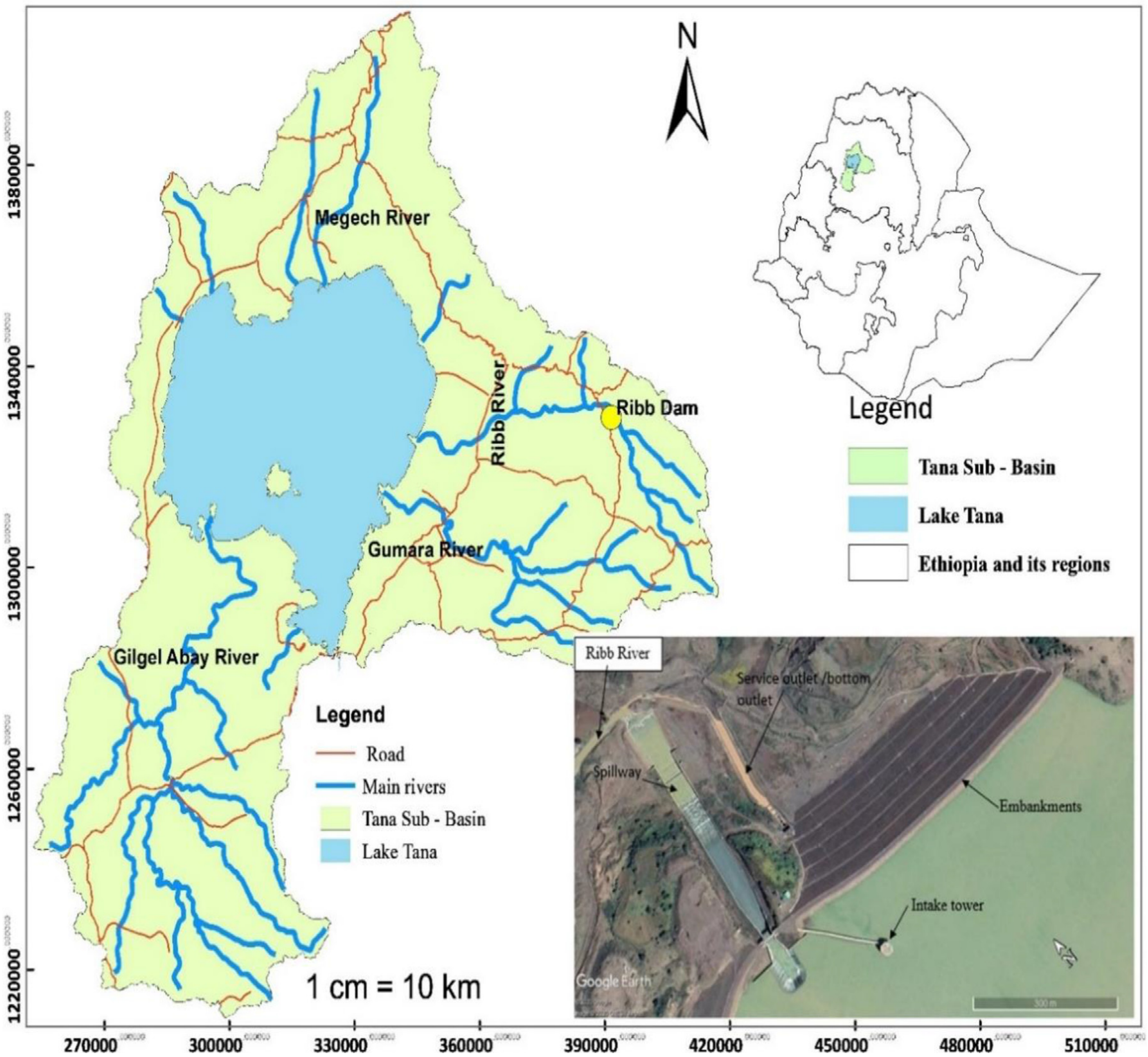

Figure 1. Map of the study area.

study. The properties of the physical and chemical variables in the dry and wet seasons were analyzed graphically (Figure 4).

However, to show what is happening, we have done species composition and abundance in accordance with the four seasons: autumn, winter, spring, and summer, as seen in Figure 6. The overall abundance of zooplankton species was also analyzed (Figure 5).

Analysis for qualitative and quantitative studies as used by most researchers (Ahmed et al., 2003; Gutkowska et al., 2012; Prasannatha et al., 2019; Sarker et al., 2020) has been used by taking 40 ml from 100 ml of concentrate. After thoroughly mixing the samples with a wide-mouth pipette, a 40 mL sample was placed in a streak glass lens and Petri dish on the inverted microscope at 20× and 50× magnification (Dhargalkar and Verlecar, 2004), and the samples were identified down to the genus or species level. That is, the individuals in each liter of water sample were counted as separate groups using a counting grid; in the counting grids/chambers, the individuals/liters were counted using monographs and keys according to Korinek (1999), Dang et al. (2015), and Fernando (2002). The procedure was repeated eight times for each sampling time. Identification was based on Ward and Whipple (1959), Tonapi (1960), Mellanby (1975), and Bhuyan et al. (2020). The final estimate of zooplankton abundance was estimated and calculated according to Wetzel and Likens (2000). Quantitative analysis was followed by the total count method of Welch (1948).

Species diversity measures (diversity indices) have been used to describe the structure of the zooplankton community (Dhargalkar and Verlecar, 2004). Such a variety of measurements were made according to Simpson (1949), Odum (1971), Clifford and Stephenson (1975), Whittaker (1977), and Krebs (1989), who showed indicators of the diversity, dominance, and uniformity of plankton species.

$$A)\ Margalef's\ diversity\ index: D_{Mg} = \frac{S-1}{\ln N}$$

where N = the total number of individuals in the sample and S = the number of species recorded.

$$B)\ Menhinick''s\ diversity\ index = D_{Mn} = \frac{S}{\sqrt{N}}$$

where N = the total number of individuals in the sample and S = the number of species recorded.

$$C)\ The\ dominance\ index\ (D): D = \sum_{i=1}^{s} (ni/N)^2$$

where: D = Simpson dominance index; ni = number of individuals = ith; N = total number of individuals; S = the number of genera or species.

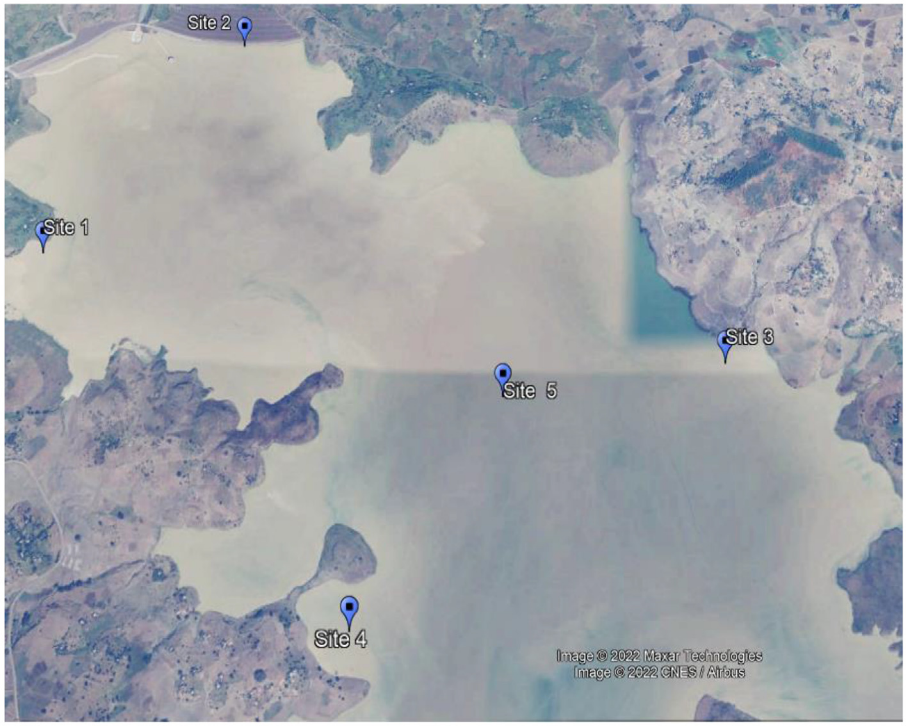

Figure 2. Map of Ribb Reservoir and the sampling sites (Google Earth Image).

Figure 3. The Ribb Reservoir during the seasons: Plankton (algae) blooms occur when there is no water runoff from the reservoir, i.e., in autumn (September to November (a); winter (dry season), reservoir volume decreases (b); summer (rainy season), especially late July to August, water overflows via spillway (c); and spring (nearly dry season), water discharge via conduit (d). As a result, the volume decreases and both outflows also allow plankton outflow from the reservoir, affecting the quality and quantity of the plankton. At the beginning of summer, mainly from June to July, the reservoir volume gets recovered (increases) and looks turbid (d) because the inflowing rivers like Melo, Ribb, and Hamuswenz come from the unprotected catchment area and carry a high sediment load.

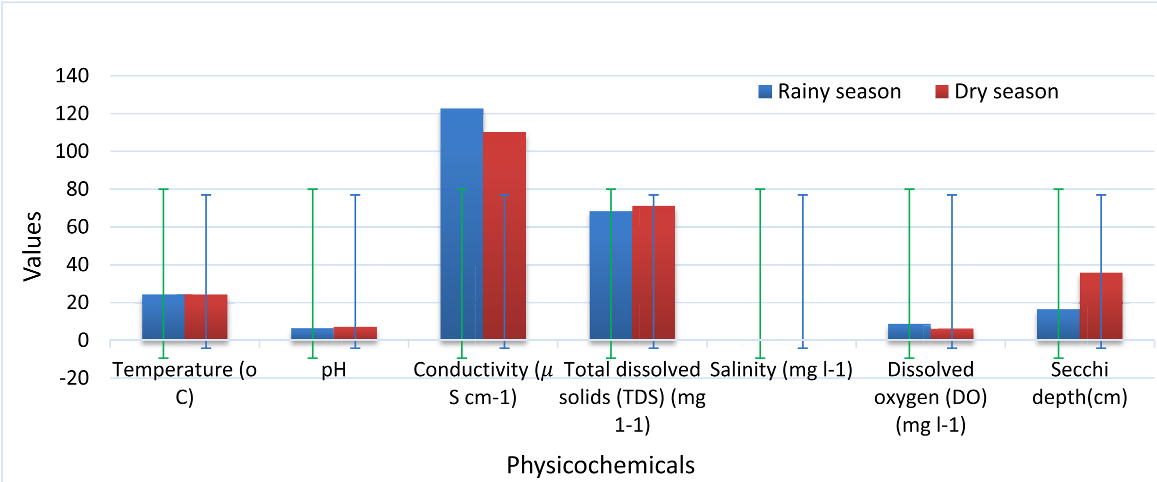

Figure 4. The characteristics of the physicochemical variability in the dry and rainy seasons are described. The study area has two main seasons (dry and rainy seasons) and four secondary seasons (autumn, winter, spring, and summer). Since the study area is in the tropics, specifically in the fully tropical zone in the Ethiopian case, there are 13 months of sunshine. So, as you can easily see from the chart, the fluctuations were not that big. However, to see the variability in the monthly data requires sampling six times a month.

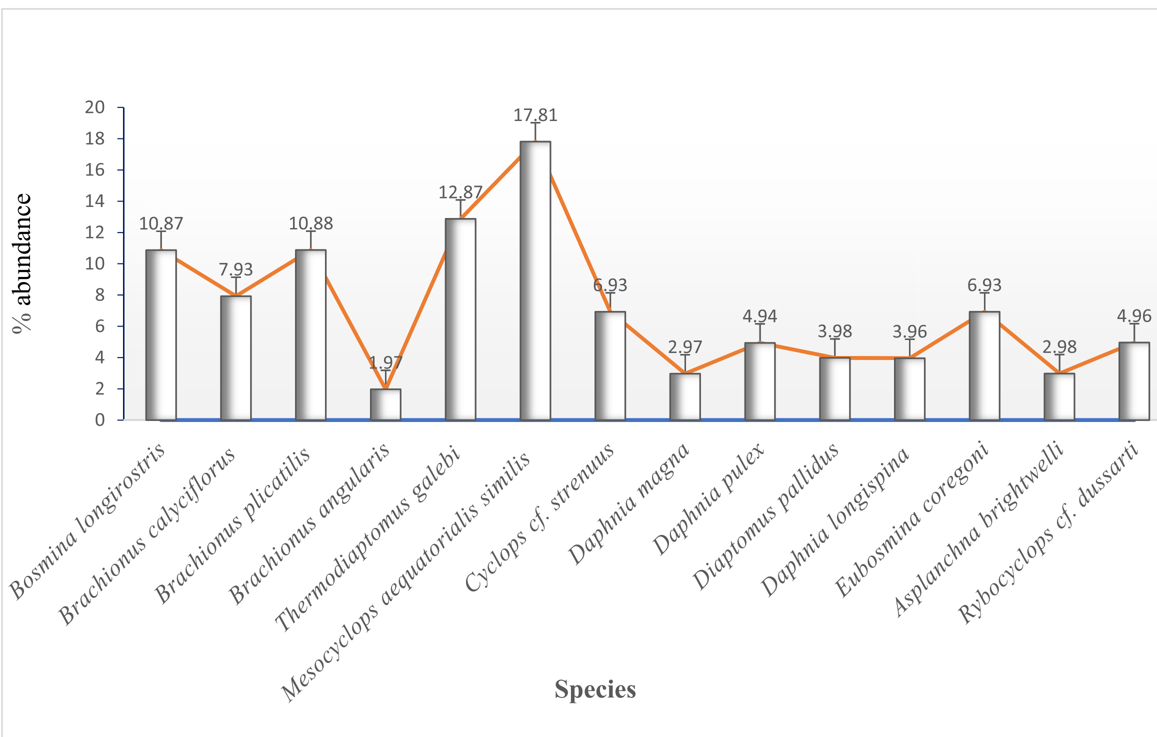

Figure 5. The relative total abundances of identified zooplankton species in the Ribb Reservoir measured in percent per year.

D)The Shannon index (H') : $H' = -\sum_{n=i}^{n} pi \ln pi$

where: H' = Shannon-Wiener diversity index; pi = ni/N; ni = number of individual species = ith; N = total number of individuals.

E) The Equitability index : $E = \frac{H'}{H\ \text{maxs}}$

where E = Evenness index, H = Diversity index, H_{max} = ln S, S = Number of species found.

F) The Simpson's index of diversity and Simpson's reciprocal index: The Simpsons diversity index 1- D is a measure of diversity that takes into account the number of species occurring and the relative frequency of each species, and the Simpsons reciprocal index 1/D takes into account the number of equally occurring categories (Supriatna 2018; Ulfah et al., 2019).

According to Chakrabarty et al. (2017), the investigation of the physicochemical properties is important as a benchmark for the assessment of water quality in zooplankton communities. Therefore, the values were analyzed into a minimum, maximum, average ±SD (standard

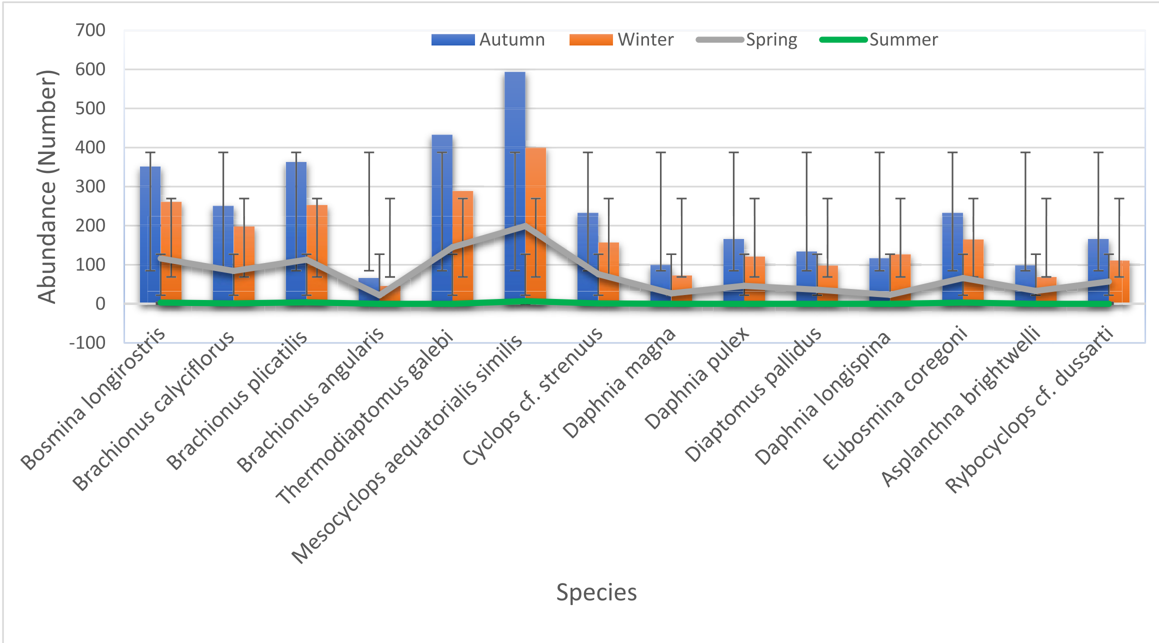

Figure 6. Zooplankton abundance distributions in Ribb Reservoir along four seasonal variations (autumn, winter, spring, and summer).

deviation), 1st quartile, and 3rd quartile. Analysis of this study was performed using R-Software (physicochemical properties) and Excel.

3. Results

3.1. Physicochemical characteristics

The annual mean values of some important water quality parameters of the reservoir were recorded as follows: Temperatures ranged from 22.5 to 26.17 °C (averaged 23.82 ± 1.38 °C) and 22.88 °C (1st quartile) and 24.79 °C (3rd quartile) values. The pH ranged from 5.49 to 7.22 (averaged 6.36 ± 0.64), 5.83 (1st quartile), and 6.8 (3rd quartile) values. Conductivity (μS cm^{-1}) ranged from 30.3 to 191.10 (averaged 121.53 ± 62.17), 96.69 (1st Quartile), and 176.10 (3rd quartile) values. Total dissolved solids (mg 1^{-1}) ranged from 15.06 to 112 (an average of 69.65 ± 35.20), 59.63 (1st quartile), and 92.58 (3rd quartile) values. Dissolved oxygen (mg l^{-1}) ranged from 5.35 to 12.44 (averaged 8.84 ± 3.54), 5.45 (1st quartile), and 12.08 (3rd quartile) values. Salinity and Secchi depth values are also listed in Table 1.

3.2. Species composition

Investigations on qualitative and quantitative analysis of zooplankton revealed that a total of 14 species of zooplankton were identified during the study (the first in the reservoir and not in the river), comprising Cladocera, Copepods, and Rotifers. Of the three taxa, Cladocera had the highest numerical frequency at 42.86%, and the others were second at 28.57%. Cladocera had the most species (6), followed by Copepods and Rotifers in order of importance (Table 2).

As can be seen in Table 3, species abundance decreased over the four seasonal times from autumn to summer, then to spring, and finally to zero in winter (Table 3).

Mesocyclops aequatorialis similis (17.81%), *Thermodiaptomus galebi* (12.87), *Brachionus plicatilis* (10.88), and *Brachionus angularis* (1.97%), were the first, second, third, and least abundant species, respectively (Figure 5).

3.3. Biodiversity index

The reservoir's average (of the seasons) zooplankton biodiversity indexes were: richness (14), abundance (6736), Margalef's diversity index (1.48), Menhinick's diversity index (0.17) Simpson index (0.098), dominance index (0.902), Shannon index (H′) (2.47), equitability/evenness index (0.934), reciprocal Simpson index (10.2), and average population size (481) as seen in Table 4.

4. Discussion

4.1. Physicochemical characteristics

The study of physicochemical parameters in the Ribb Reservoir has been very important for determining the water quality of zooplankton communities, as these factors influence the primary production of zooplankton (Bhuyan et al., 2020; Mojumder et al., 2020; Mozumder et al., 2010; Ndebele-Murisa et al., 2010; Pourafrasyabi and Ramezanpour, 2014). It has a direct or indirect impact on the biodiversity of water bodies (Kuczyńska-Kippen, 2020; Mozumder et al., 2010; Ndah et al., 2022; Paul et al., 2017). In fact, reservoir size and morpho-epigraphic factors also determine production (Cestti and Malik, 2012). The physicochemical cycles are crucial for the diversity of

Table 1. Some physicochemical parameters of the reservoir.

Parameters	Minimum	Maximum	Average ±SD	1st Quartile	3rd Quartile
	Values				
Temperature (° C)	22.5	26.17	23.82 ± 1.38	22.88	24.79
pH	5.49	7.22	6.36 ± 0.64	5.83	6.8
Conductivity (μS cm^{-1})	30.3	191.10	121.53 ± 62.17	96.69	176.10
Total dissolved solids (TDS) (mg 1^{-1})	15.06	112	69.65 ± 35.20	59.63	92.58
Salinity (mg l^{-1})	0.05	0.08	0.056 ± 0.01	0.05	0.06
Dissolved oxygen (DO) (mg l^{-1})	5.35	12.44	8.84 ± 3.54	5.45	12.08
Secchi depth (cm)	4	84.00	22.56 ± 27.06	5.19	27.99

Table 2. Recorded zooplankton species and their taxonomic classification in the Ribb Reserviour

Cladocera	Copepods	Rotifers
Daphnia magna	*Thermodiaptomus galebi*	*Asplanchna brightwelli*
Daphnia pulex	*Mesocyclops aequatorialis similis*	*Brachionus calyciflorus*
Diaptomus pallidus	*Cyclops* cf. *strenuus*	*Brachionus plicatilis*
Daphnia longispina	*Rybocyclops* cf. *dussarti*	*Branchionus angularis*
Bosmina longirostris		
Bosmina coregoni		
Frequency of species 42.86%	28.57%	28.57%

ecosystems (Svobodová et al., 1993; Cline, 2019), and life is also sensitive to fluctuations (Boyd and Lichtkoppler, 1979; Chakrabarty et al., 2017; Svobodová et al., 1993). Thus, the temperature of the reservoir ranged from 22.5 to 26.17 °C, with an average value of 23.82 ± 1.38 °C (Table 1). Different species have different temperature tolerance ranges (Shammi and Bhatnagar, 2010), and temperature has a significant impact on chemical and biological processes and reactions, doubling for every 10 °C increase (Boyd and Lichtkoppler, 1979).

Although the pH of the water body increases during the day and decreases at night due to carbon dioxide related to photosynthesis and metabolic activities (Boyd and Lichtkoppler, 1979), the reservoir pH ranged from 5.49 to 7.220, with an average value of 6.36 ± 0. 64, which is considered to be the ideal environment (Table 1). This is because aquatic plants and animals can't tolerate pH values below 5.0 and above 9.0 (Shammi and Bhatnagar, 2010; Twomey et al., 2009).

The detected dissolved solids ranged from 15.06 to 112 and averaged 69.65 ± 35.20 mg l^{-1} (Table 1), which is far greater than the standard range of 10–20 mg/l recommended by Davis (1993). The average salinity of 0.056 ± 00.011 mg l^{-1}, as shown in Table 1, is within the acceptable range since, according to Twomey et al. (2009), the salinity of fresh water is less than 0.2 mg l^{-1}.

Dissolved oxygen is the most important variable for water quality (Boyd and Lichtkoppler, 1979), and it varies depending on species and stage of life. Levels below 3 mg l^{-1} are stressful for most aquatic organisms, and values of 5–6 mg l^{-1} are usually required to fulfill their biological functions (LaMotte, 1994). Therefore, the available DO in the reservoir ranged from 5.35 to 12.440 mg l^{-1}, with an average of 8.84 ± 3.54 mg l^{-1} being sufficient (Table 1).

4.2. Species composition

As shown in Table 2, the occurrence of Cladocera had the highest abundance of the three taxa at 42.86%, which was similar to Pampoo Pond (Singh et al., 2021) but differs from Koka Reservoir, where Rotifers were dominant (Fasil et al., 2011). The occurrence of *Mesocyclops aequatorialis similis* at first and *Brachionus angularis* at least abundant might not always be true, because according to most studies such as Richardson (2009), Mojumder et al. (2020), Kuczyńska-Kippen (2020), Ndah et al. (2022), and Paquette et al. (2022), plankton diversity changes rapidly due to the short lifespan of days to weeks and because of other factors such as climatic conditions. Similar to studies conducted by Imoobe and Akoma (2008) and Imoobe and Christopher (2009) in Lake Tana, the zooplankton species reported in this study were a mixture of tropical and temperate species. This is most likely because of the low water temperature of the reservoirs, which is related to their location at an elevation near Mount Guna (which is about 4120 m above sea level).

As seen in Table 3 and Figure 6, species quantity and quality decreased over the course of a year (in the four seasons: from autumn to winter, then to spring and summer). There is no doubt that there have also been much-anticipated changes in biodiversity index values in relation to seasonal temporal changes. The change could be mainly related to the decrease in water volume and conditions with the change of seasons themselves. In the summer (the rainy season in the area), excess water flows over the spillway, and in the dry season, it is used for

Table 4. The average values of biodiversity indexes (species richness, abundance Simpson index, dominance index, Shannon index (H′), equitability, and the reciprocal Simpson index).

No.	Biodiversity measures	Values
1	Richness	14
2	Abundance (in number)	6736
3	Margalef's diversity index	1.48
4	Menhinick's diversity index	0.17
5	Simpson index	0.098
6	Dominance index	0.902
7	Shannon index (H′)	2.47
8	Equitability index	0.934
9	Reciprocal Simpson index	10.20
10	Average population size	481

Table 3. Abundance, abundance (%) of zooplankton species in four seasons (the autumn, summer, spring, and winter).

Species	The seasons of the year of the study area								Total frequency
	Autumn		Winter		Spring		Summer		
	Abundance	% abundance	Abundance	% abundance	Abundance	% abundance	Abundance	% abundance	
Bosmina longirostris	352	48.09	261	35.66	116	15.85	3	0.41	732
Brachionus calyciflorus	251	47.00	198	37.08	84	15.73	1	0.19	534
Brachionus plicatilis	363	49.52	253	34.52	113	15.42	4	0.55	733
Brachionus angularis	66	49.62	45	33.83	22	16.54	0	0	133
Thermodiaptomus galebi	433	49.94	289	33.33	145	16.72	0	0	867
Mesocyclops aequatorialis similis	594	49.50	400	33.33	199	16.58	7	0.58	1200
Cyclops cf. *strenuus*	233	49.89	157	33.62	76	16.27	1	0.21	467
Daphnia magna	100	50.00	73	36.50	27	13.50	0	0	200
Daphnia pulex	166	49.85	121	36.34	46	13.81	0	0	333
Diaptomus pallidus	134	50.00	98	36.57	36	13.43	0	0	268
Daphnia longispina	117	43.82	127	47.57	23	8.61	0	0	267
Eubosmina coregoni	233	49.89	165	35.33	66	14.13	3	0.64	467
Asplanchna brightwelli	99	49.25	69	34.33	33	16.42	0	0	201
Rybocyclops cf. *dussarti*	166	49.70	111	33.23	57	17.07	0	0	334
Total									6736

irrigation (water is allowed to drain through the conduit; it is at a height of 23 m). In addition, the other possible reason for the change was that during the sampling period (in spring), water was released and disturbed for maintenance of the dam. During these times, species flowed downstream from the reservoir into the Ribb River. Aside from the temporal or season, the high level of agricultural activity in the catchment, which uses chemicals such as artificial fertilizers, may also play an important role in species change, as reported by Mozumder et al. (2010) and Mojumder et al. (2020) in other water bodies. This change in species quantitatively and qualitatively was also similar to what most investigators reported; for example, Murrell (2004), Benedetti et al. (2019), Shi et al. (2020), Mojumder et al. (2020), and Ndah et al. (2022).

Similar to the report by Mequanent et al. (2022b), the water level of the reservoir during the main irrigation season is important for supporting biodiversity. Of course, the depth under the conduit can support the stand. Similarly, Niyoyitungiye et al. (2020b) and Dhargalkar and Verlecar (2004) emphasize that water level is important for the plankton community. Environmental changes like other systems can affect the reservoir ecosystem, similar to what most researchers agreed on, as reported in reports by Niyoyitungiye et al. (2020a, 2020b), Kuczyńska--Kippen (2020), Benedetti et al. (2019), Shi et al. (2020), Mojumder et al. (2020), and Ndah et al. (2022). If the water is pumped from below the conduit (dead storage), it could severely affect reservoir systems and fishers' incomes, as the reservoir provides a livelihood for the local population through fishing, as reported by Mequanent et al. (2022b), and also for the other water use sectors.

The qualitative and quantitative characteristics of zooplankton change with the change of seasons. However, the reservoir's average zooplankton biodiversity index values, such as the dominance index (0.902) and Shannon index (H′) (2.47), showed that the reservoir was in good condition. Ecologists use diversity indexes as an important tool to understand community structure in terms of richness, uniformity, or the total number of individuals in existence (Allan, 1975); a central concept in a measure of ecosystem health (Daly et al., 2018); since the health status of an aquatic ecosystem largely depends on the diversity and density of zooplankton inhabiting the body of water (Dutta, 2021). Zooplankton species richness can vary based on several factors, including geographic region, trophic type, morphometric characteristics, or even the origin of a body of water (Duggan et al., 2002; Vijayakumari et al., 2018). It also depends on the extent of anthropogenic transformation in the vicinity of a pond (Bhuyan et al., 2020; Kuczyńska-Kippen, 2020) and phychochemical charactrestics (Mozumder et al., 2010; Niyoyitungiye et al., 2020a, 2020b). According to the biodiversity index, zooplankton is less diverse in the tropics than in temperate zones (Fernando, 1980).

In the current study, Ribb Reservoir zooplankton showed that the ecosystem was stable, that there were more ecological niches, that the environment was less hostile, and that there were complex food webs. This is possibly one of the most important components supporting reservoir fisheries since the occurrence of the 11 fish species identified by Mequanent et al. (2022b). For example, according to Staub et al. (1970), the Shannon diversity index (H′) = 1 indicates heavy pollution, H' = 1–2 indicates moderate pollution, and H' = 3–4.5 indicates light pollution. The mean range of values for the Shannon diversity index for the current reservoir was 2.47 (Table 4). This showed that there was light pollution of the reservoir water body during the study period. This is due to water abstraction from the reservoir for irrigation and overflow over the spillway, despite being a poorly managed catchment area with high use of inorganic fertilizer, agricultural practices, and pollutants from towns such as Debre Tabor and Hamusit that could affect the water quality of the reservoir. According to Paquette et al. (2022), agricultural runoff pollution contains higher concentrations of nutrients and ions, which are significant predictors of zooplankton diversity and aggregation. The outflow of water from the reservoir through these two mechanisms is important to controlling the physicochemical characteristics of the reservoir. The constant supply of fresh water from the rivers Melo, Hamuswenz, and Ribb may also be good for the qualitatively and quantitatively good condition of the reservoir. However, a systematic study of zooplankton-based indices of the reserve's ecological change and water quality is necessary.

5. Conclusions and recommendations

5.1. Conclusions

From the study, it can be concluded that the physicochemical properties of the reservoir were in the standard range for the suitability of the existing zooplankton community, whose biodiversity index values such as richness, abundance, and the Simpson index showed that the ecosystem was stable and had moderate ecological niches. This may be due to the regulation of the physical and chemical properties of the reservoir by water with an extraction from the reservoir and a constant supply of fresh water mainly from the three rivers (Melo, Hamuswenz and Ribb rivers). However, the situation may not last long as the government may not put good management of the reservoir into practice as it has no previous experience with the sub-basin. The reduced amount of backwater due to discharge via the canal and overflow via the spillway were the reasons for the decrease in species richness from autumn to summer. The temporal changes in the qualitative and quantitative characteristics of zooplankton have been associated with the reduced water volume of the reservoir. This survey can also be used as a benchmark for future research as it is the first survey of the reservoir, which is also a good indicator for the start of management. However, holistic studies are needed to draw the best conclusions, including sedimentation, continuous monthly data collection, and the impact of irrigation practices on the reservoir system.

5.2. Recommendations

We need to make sure that the irrigation project and other aquatic benefits are equally important. For example, fishing. Based on observations made during field visits and stakeholder meetings, the following recommendations were made:

1. Conservation of soil and water in the catchment area.
2. The water level of the reservoir should always be about 30 m or higher than the height of the conduit by adjusting the irrigation crop calendars before the water level reaches the line, as the reservoir struggles with low water levels, especially during periods of high water demand (from late February to early May).
3. Establishing a buffer zone around the reservoir is necessary to prevent anything from entering the reservoir (since this is barren land for anything to enter).
4. Irrigation practices should take into account the general condition of the reservoir ecosystem (droughts and other extreme climate events).

Declarations

Author contribution statement

Dagnew Mequanent Tesema: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper. Minwyelet Mingist & Abebe Getahun: Conceived and designed the experiments; Contributed reagents, materials, analysis tools or data; Wrote the paper. Wassie Anteneh: Contributed reagents, materials, analysis tools or data. Banchiamlak Getne & Solomon Birie: Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data.

Funding statement

This work was supported by the Blue Nile Institution of Bahir Dar University.

Data availability statement

The data that has been used is confidential.

Declaration of interest's statement

The authors declare no conflict of interest.

Additional information

Supplementary content related to this article has been published online at https://doi.org/10.1016/j.heliyon.2022.e10533.

Acknowledgements

We gratefully acknowledge the Blue Nile Institution of Bahir Dar University for providing funding for the research.

References

ADSWE:LUPESP, 2015. Tana Sub-Basin Land Use Planning and Environmental Study Projects: Fisheries and Wetlands Resource Assessment. Bahir Dar, Ethiopia.
Ahmed, K.K.U., Ahamed, S.U., Hossain, M.R.A., Ahmed, T., Barman, S., 2003. Quantitative and qualitative assessment of plankton: some ecological aspect and water quality parameters of the river Meghna, Bangladesh. Bangldesh J. Fish. Res 7, 131–140.
Allan, J.D., 1975. The distributional ecology and diversity of benthic insects in cement creek , Colorado. Ecology 56, 1040–1053.
Allan, J.D., 1976. Life history patterns in zooplankton. Am. Nat. 110, 165–180.
Atazadeh, E., Barton, A., Razeghi, J., 2020. Importance of Environmental Flows in the Wimmera Catchment. Southeast Australia.
Basu, B.K., Pick, F.R., 1997. Phytoplankton and zooplankton development in a lowland, temperate river. J. Plankton Res. 19, 237–253.
Benedetti, F., Jalabert, L., Sourisseau, M., Beker, B., Cailliau, C., Desnos, C., Elineau, A., Irisson, J.O., Lombard, F., Picheral, M., Stemmann, L., Pouline, P., 2019. The seasonal and inter-annual fluctuations of plankton abundance and community structure in a North Atlantic Marine Protected Area. Front. Mar. Sci. 6, 1–22.
Bhuyan, M.S., Sharif, M.A.S., Islam, M.Md., Mojumder, I.A., Das, M., Islam, S.Md., 2020. Fresh/river water zooplankton in Bangladesh: a critical review. Environ. Anal. Ecol. Studies 7, 716–749.
Boyd, C.E., Lichtkoppler, F., 1979. Water Quality Management in Pond Fish Culture Research and Development Series, International Center for Aquaculture. Auburn University, Auburn, Alabama.
Braghin, L. de S.M., Almeida, B. de A., Amaral, D.C., Canella, T.F., Gimenez, B.C.G., Bonecker, C.C., 2018. Effects of dams decrease zooplankton functional β-diversity in river-associated lakes. Freshw. Biol. 63, 721–730.
Brierley, B., Carvalho, L., Davies, S., Krokowski, J., 2007. Guidance on the quantitative analysis of phytoplankton in Freshwater Samples. Rep. SNIFFER 1–24.
Cestti, R., Malik, R.P.S., 2012. Indirect economic impacts of dams. Water Res. Develop. Manag. 19–35.
Chakrabarty, M., Banerjee, A., Mukherjee, J., Rakshit, N., Ray, S., 2017. Spatial pattern analysis of zooplankton community of Bakreswar reservoir, India. Energy Ecol. Environ 2, 198–206.
Clifford, H.T., Stephenson, W., 1975. Measurements of Biodiversity - Marine Biodiversity. Academic Express, London.
Cline, D., 2019. Water Quality in Aquaculture -Freshwater Aquaculture 1–5.
da Costa, N.K.R., de Paiva, R.E.C., da Silva, M.J., Ramos, T.P.A., Lima, S.M.Q., 2017. Ichthyofauna of Ceará-Mirim River basin, Rio grande Do Norte State, Northeastern Brazil. Zookeys.
Daly, A.J., Baetens, J.M., de Baets, B., 2018. Ecological diversity: measuring the unmeasurable. Mathematics 6.
Dang, P.D., Khoi, N.V., Nga, L.T.N., Thanh, D.N., Hai, H.T., 2015. Identification Handbook of Freshwater Zooplankton of the Mekong River and its Tributaries. Mekong River Commission.
Davis, J., 1993. Survey of aquaculture effluents permitting and 1993 standards in the South. Regional Aquaculture Center, SRAC, USA, p. 4.
de Groot, R.S., Alkemade, R., Braat, L., Hein, L., Willemen, L., 2010. Challenges in integrating the concept of ecosystem services and values in landscape planning, management and decision making. Ecol. Complex. 7, 260–272.
Degefu, F., Herzig, A., Jirsa, F., Schagerl, M., 2014. First limnological records of highly threatened tropical high-mountain crater lakes in Ethiopia, 7, pp. 365–381.
Dhargalkar, V.K., Verlecar, X.N., 2004. Zooplankton methodology, collection & identification. In: A Field Manual. National Institute of Oceanography, pp. 1–16.
Dougherty, T.C., Hall, A.W., 1995. Major impacts of irrigation and drainage projects. Environ. Impact Assess. Irrig. Drainage Proj. 9–14.
Duggan, I.C., Green, J.D., Shiel, R.J., 2002. Distribution of rotifer assemblages in North Island, New Zealand, lakes: relationships to environmental and historical factors. Freshw. Biol. 47, 195–206.
Dutta, T.K., 2021. Zooplankton diversity indices for the assessment of perennial freshwater body in bishnupur, bankura, West Bengal. Biosci. Biotechnol. Res. Commun 14, 1821–1824.
Effendi, H., Kawaroe, M., Lestari, D.F., Mursalin-Permadi, T., 2016. Distribution of phytoplankton diversity and abundance in mahakam delta, east Kalimantan. Procedia Environ. Sci. 33, 496–504.
Elliott, J.M., Downing, J.A., Rigler, F.H., 1985. A manual on methods for the assessment of secondary productivity in fresh waters. J. Anim. Ecol. 54, 675.
Eskedar, T., Seyoum, M., Dagne, T., Daba, T., Zenebe, T., 2007. Observation on thelimnology and fishery of Gilgel gibe reservoir. In: Proceedings of the 15th Annual Conference of the Ethiopian Society of Animal production(ESAP) Held in Addis Ababa, Ethiopia. October 8 to 10, 2008.
Fasil, D., Kibru, T., Gashaw, T., Fikadu, T., Aschalew, D., Aschalew, L., 2011. Some limnological aspects of Koka reservoir, a shallow tropical artificial lake, Ethiopia. J. Recent Trends Biosci. 1, 94–100.
Fernando, C.H., 1980. The species and size composition of tropical freshwater zooplankton, with special reference to the oriental Region (South East Asia). Int. Rev. Gesamten Hydrobiol. 65, 411–426.
Fernando, C.H., 2002. A Guide to Tropical Freshwater Zooplankton - Identification, Ecology and Impact on Fisheries -, Illustrate. Backhuys Publishers, Leiden, Netherlands.
Forsblom, L., Engström-Öst, J., Lehtinen, S., Lips, I., Lindén, A., 2019. Environmental variables driving species and genus level changes in annual plankton biomass. J. Plankton Res. 41, 925–938.
Gutkowska, A., Paturej, E., Kowalska, E., 2012. Qualitative and quantitative methods for sampling zooplankton in shallow coastal estuaries. Ecohydrol. Hydrobiol. 12, 253–263.
Helland-hansen, E., Holtedahl, T., 2005. Hydropower Development: Environmental Effects. Norwegian university of science and technology department of hydraulic and environmental engineering.
Hudson, J.J., Taylor, W.D., Schindler, D.W., 1999. Hudson et al. 1999 Planktonic nutrient 461, pp. 1998–2000.
Ibarbalz, F.M., Henry, N., Brandão, M.C., Martini, S., Busseni, G., Byrne, H., Coelho, L.P., Endo, H., Gasol, J.M., Gregory, A.C., Mahé, F., Rigonato, J., Royo-Llonch, M., Salazar, G., Sanz-Sáez, I., Scalco, E., Soviadan, D., Zayed, A.A., Zingone, A., Labadie, K., Ferland, J., Marec, C., Kandels, S., Picheral, M., Dimier, C., Poulain, J., Pisarev, S., Carmichael, M., Pesant, S., Acinas, S.G., Babin, M., Bork, P., Boss, E., Bowler, C., Cochrane, G., de Vargas, C., Follows, M., Gorsky, G., Grimsley, N., Guidi, L., Hingamp, P., Iudicone, D., Jaillon, O., Karp-Boss, L., Karsenti, E., Not, F., Ogata, H., Poulton, N., Raes, J., Sardet, C., Speich, S., Stemmann, L., Sullivan, M.B., Sunagawa, S., Wincker, P., Pelletier, E., Bopp, L., Lombard, F., Zinger, L., 2019. Global Trends in marine plankton diversity across Kingdoms of life. Cell 179, 1084–1097 e21.
Imoobe, T.O.T., Akoma, O.C., 2008. Assessment of zooplankton community structure of the Bahir dar Gulf of Lake Tana, Ethiopia. EJESM 1.
Imoobe, O.T.T., Christopher, A.O., 2009. Spatial variations in the composition and abundance of zooplankton in the Bahir dar Gulf of Lake Tana, Ethiopia. Afr. J. Ecol. 48, 72–77.
Kiteresi, L.I., Okuku, E.O., Mwangi, S.N., Ohowa, B., Wanjeri, V.O., Okumu, S., Mkono, M., 2012. The influence of land-based activities on the phytoplankton communities of Shimoni-Vanga system, Kenya. Int. J. Environ. Res. 6, 151–162.
Korinek, V.A., 1999. Guide to Leminetic Species of Cladocera of African Inland Waters (Crustacean, Branchiopoda). No. 1, 53. The International Association of Theoretical and Applied Limnology. SIL.
Krebs, C.J., 1989. Ecological Methodology. HarperCollins, New York.
Kuczyńska-Kippen, N., 2020. Response of Zooplankton Indices to Anthropogenic Pressure in the Catchment of Field Ponds, 12. Water, Switzerland.
LaMotte, 1994. The Monitor's Handbook A Reference Guide for Natural Water Monitoring. LaMotte.
Lan Smith, S., Mandal, S., Priyadarshi, A., Chen, B., Yamazaki, H., 2019. Modeling the combined effects of physiological flexibility and micro-scale variability for plankton ecosystem dynamics. In: Encyclopedia of Ocean Sciences, Third. ed. Academic Press.
Lorenzen, K., Smith, L., Nguyen, K.S., Burton, M., Garaway, C., 2007. Management of Impacts of Irrigation Development on Fisheries: Guidance Manual, p. 161.
Madhu, N.v., Jyothibabu, R., Balachandran, K.K., Honey, U.K., Martin, G.D., Vijay, J.G., Shiyas, C.A., Gupta, G.V.M., Achuthankutty, C.T., 2007. Monsoonal impact on planktonic standing stock and abundance in a tropical estuary (Cochin backwaters - India). Estuar. Coast Shelf Sci. 73, 54–64.
McCartney, M., Kleinschroth, F., 2019. Dams can mimic the free flow of rivers, but risks must be managed. The Conversation 1–7.
McManus, M.A., Woodson, C.B., 2012. Plankton distribution and ocean dispersal. J. Exp. Biol. 215, 1008–1016.
Mellanby, H., 1975. Animal life in freshwater. In: Trowbridge & Esher, sixth ed. Burn Ltd, Fedowood.
Mequanent, D., Mingist, M., Getahun, A., Anteneh, W., 2021. Impact of irrigation practices on Gilgel Abay, Ribb and Gumara fisheries, Tana sub-basin, Ethiopia. Heliyon 7, e06523.
Mequanent, D., Mingist, M., Getahun, A., Anteneh, W., 2022a. Spawning migration of Labeobarbus species of Lake Tana across the Gilgel Abay River Weir, Ethiopia: the challenges to fish spawning migration and proposed management solutions. Lakes & Reserv.: Sci., Policy and Manag. Sustain. Use 27.
Mequanent, D., Mingist, M., Getahun, A., Anteneh, W., Hailu, B., 2022b. The newly built Ribb Reservoir fisheries, Tana Sub-basin, Ethiopia: new fishery establishment, diversity, production, challenges and management. Aquaculture, Fish and Fisheries 2, 189–201.
Ministry of Water and Energy, MWE, 2010. Environmental and Social Impact Assessment of about 20,000 Ha Irrigation and Drainage Schemes at Megech Pump (Seraba). In:

Ribb and Anger Dam: Environmental and Social Impact Assessment of the Ribb Irrigation and Drainage Project.
Mojumder, I.A., Kibria, M.M., Bhuyan, M.S., 2020. A baseline taxonomic study of zooplankton in the lower Halda River, Bangladesh. Global J. Zoology 5.
Mozumder, P.K., Banu, M.A., Naser, M.N., Ali, Md.S., Alam, M., Sack, R.B., Colwell, R.R., Huq, A., 2010. Occurrence of Protozoans & Their Limnological Relationships in Some Ponds of Mathbaria, Bangladesh, 29. University Journal of Zoology, Rajshahi University, pp. 69–71.
Murrell, M.C., Lores, E.M., 2004. Phytoplankton and zooplankton seasonal dynamics in a subtropical estuary: importance of cyanobacteria. J. Plankton Res. 26, 371–382.
Ndah, A.B., Meunier, C.L., Kirstein, I.V., Göbel, J., Rönn, L., Boersma, M., 2022. A systematic study of zooplankton-based indices of marine ecological change and water quality: Application to the European marine strategy framework Directive (MSFD). Ecol. Indicat. 135, 3.
Ndebele-Murisa, M.R., Musil, C.F., Raitt, L., 2010. A review of phytoplankton dynamics in tropical African lakes. South Afr. J. Sci. 106, 13–18.
Niyoyitungiye, L., Giri, A., Mishra, B., 2020a. Assessment of physico-chemical characteristics of water at selected stations of Lake Tanganyika, Africa with special emphasis on pisciculture purposes. Int. J. Basic and Appl. Biol. 6, 211–217.
Niyoyitungiye, L., Giri, A., Mishra, B.P., 2020b. Quantitative and qualitative analysis of phytoplankton population in relation to environmental factors at the targeted sampling stations on the Burundian littoral of Lake Tanganyika to cite this version : HAL Id : hal-02462816 Quantitative and qualitative. HAL Archives-Ouvertes 8, 110–121.
Odum, E.P., 1971. Fundamentals of Ecology, third ed. W.B. Saunders Co., Philadelphia, pp. 1–574.
Oliveira, E.F., Goulart, E., Minte-Vera, C.v., 2004. Fish diversity along spatial gradients in the itaipu reservoir, Paraná, Brazil. Braz. J. Biol. 64, 447–458.
Padedda, B.M., Sechi, N., Lai, G.G., Mariani, M.A., Pulina, S., Sarria, M., Satta, C.T., Virdis, T., Buscarinu, P., Lugliè, A., 2017. Consequences of eutrophication in the management of water resources in Mediterranean reservoirs: a case study of Lake Cedrino (Sardinia, Italy). Glob. Ecol. Conserv 12, 21–35.
Paquette, C., Gregory-Eaves, I., Beisner, B.E., 2022. Environmental drivers of taxonomic and functional variation in zooplankton diversity and composition in freshwater lakes across Canadian continental watersheds. Limnol. Oceanogr. 67, 1081–1097.
Paul, T.T., Palaniswamy, R., Manoharan, S., Unnithan, U., UK, S., 2017. Management strategies for reservoirs fisheries. J. Aquacult. Res. Dev. 8.
Pourafrasyabi, M., Ramezanpour, Z., 2014. Phytoplankton as bio-indicator of water quality in sefid Rud river, Iran (south of caspian sea). Caspian J. Environ. Sci. 12, 31–40.
Prasannatha, A., Neeraja, B., Kamraju, M., 2019. Quantitative analysis of zooplanktons of fresh water ecosystem in dindi reservoir , Telangana , India quantitative analysis of zooplanktons of fresh water ecosystem in dindi reservoir , Telangana , India. Int. J. Res. Anal. Rev. 6, 462–466.
Richardson, A.J., 2009. Encyclopedia of ocean sciences:plankton and climate. In: Encyclopedia of Ocean Sciences, Second ed. Academic Press.
Rodrigo, M.A., Rojo, C., Armengol, X., 2003. Plankton biodiversity in a landscape of shallow water bodies (Mediterranean coast, Spain). Hydrobiologia 506–509, 317–326.
Sarker, S., Yadav, A., Akter, M., Shahadat Hossain, M., Chowdhury, S.R., Kabir, Md.A., Sharifuzzaman, S.M., 2020. Rising temperature and marine plankton community dynamics: is warming bad? Ecol. Complex. 43, 100857.
Shammi, Qj., Bhatnagar, S., 2010. Applied fisheries statistics. Agrobios (India). Jodhpur, India.
Shi, Y., Wang, J., Zuo, T., Shan, X., Jin, X., Sun, J., Yuan, W., Pakhomov, E.A., 2020. Seasonal changes in zooplankton community structure and distribution pattern in the Yellow sea, China. Front. Mar. Sci. 7.
Simões, N.R., Colares, M.A.M., Lansac-Tôha, F.A., Bonecker, C.C., 2013. Zooplankton species richness-productivity relationship: confronting monotonic positive and hump-shaped models from a local perspective. Austral Ecol. 38, 952–958.
Simpson, E.H., 1949. Measurement of diversity. Nature 163, 688.
Singh, S., Usmani, E., Dutta, R., Kumari, V., Praveen, S., Priya, S., Gupta, B., Mohommad, A., 2021. Study on zooplankton diversity and physico chemical parameter of Pampoo pond of madhupur, Jharkhand, India. Int. J. Adv. Life Sci. Res. 4, 34–44.
Staub, R., Hofstaler-Hass, I.J., 1970. The Effect of Industrial Effluents of Memphis and Shelbycountry on Primary Plankton Production. In: Biosciences.
Supriatna, J., 2018. Biodiversity indexes: value and evaluation purposes. E3S Web of Conferences 48, 1–4.
Svobodová, Z., Lloyd, R., Máchová, J., Vykusová, B., 1993. Water quality and fish health. EIFAC (Eur. Inland Fish. Advis. Comm.) Tech. Pap. 54, 59.
Thorp, J.H., Casper, A.F., 2003. Importance of biotic interactions in large rivers: an experiment with planktivorous fish, Dreissenid mussels and zooplankton in the St Lawrence River. River Res. Appl. 19, 265–279.
Tonapi, G.T., 1960. Fresh Water Animals of India: an Ecological Approach. Oxford & IBH, New Delhi.
Twomey, L.J., Piehler, M.F., Paerl, H.W., 2009. Priority parameters for monitoring of freshwater and marine systems, and their measurement. In: Daniels, L. (Ed.), Environmental Monitoring. Eolss Publishers Co.Ltd., Oxfored, United Kingdom, p. 318.
Ulfah, M., Fajri, S.N., Nasir, M., Hamsah, K., Purnawan, S., 2019. Diversity, evenness and dominance index reef fish in Krueng Raya water, Aceh besar. IOP Conf. Ser. Earth Environ. Sci. 348.
Veerendra, D.N., Thirumala, S., Manjunatha, H., Aravinda, H.B., 2012. Zooplankton diversity and its relationship with physico-chemical parameters in mani reservoir of western Ghats, region, Hosanagar Taluk, shivamoga. J. Urban Environ. Eng. 6.
Vijayakumari, V., Prasad, G., Moses, S.A., 2018. Selecting a suitable diversity index for a Tropical Ramsar Wetland Site. Lakes & Reserv.: Sci., Policy and Manag. Sustain. Use 23.
Ward, Edmondson, Henry Baldwin, W.T., 1959. Fresh-water Biology.
Welch, P.S., 1948. Limnological Methods. McGraw-Hill Companies, New York. McGraw-Hi. ed.
Wetzel, R.G., Likens, G.E., 2000. Limnological Analysis. Springer, New Delhi third ed.
Whittaker, R.H., 1977. Evolution of species diversity in land communities. Evol. Biol. 10, 1–67.
Wiebe, P.H., Benfield, M.C., 2003. From the Hensen net toward four-dimensional biological oceanography. Prog. Oceanogr. 56, 7–136.