JoAS Volume 9 No. 2 October 2024
DOI: https://doi.org/10.24073/joas.v9i2.59322

pISSN 2550-0910; eISSN 2579-4817
Available online at https://e-journal.unair.ac.id/JoAS

OPEN ACCESS

Journal of Aquaculture Science

Effect of the Booming Tilapia Cage Culture on The Water Quality in Selected Bays of The Bukavu Basin, Lake Kivu, Democratic Republic of The Congo

Gabriel Balagizi Baguma[1,2*], Christine Cocquyt[3], Venant Muderhwa Nshombo[4], Alfred Kabagale Cubaka[2], Alicet Bwanamudogo Irenge[1], Nelly Furaha Nakangu[2], Jean-Claude Balungwe Kadjunga[1], Désiré Balagizi Akonkwa[1], Mulongaibalu Mbalassa[1]

[1]Laboratoire d'Hydrobiologie, d'Aquaculture et Gestion des Ressources Naturelles, Département de Biologie, Domaines de Sciences et Technologie, Université Officielle de Bukavu, P.O. Box 570 BUKAVU, Sud-Kivu, DR Congo.

[2]Laboratoire de Physiologie Végétale et de Microbiologie Appliquée, Département de Biologie, Domaines de Sciences et Technologie, Université Officielle de Bukavu, P.O. Box 570 BUKAVU, Sud-Kivu, DR Congo.

[3]Research Department, Meise Botanic Garden, Nieuwelaan 38, B-1860 MEISE, Belgium.

[4]Departement of Biology, Centre de Recherche en Hydrobiologie CRH-Uvira, P.O. Box 73, Ville d'Uvira, Sud-Kivu, DR Congo.

Article info:

Submitted: 28 June 2024
Revised: 10 August 2024
Accepted: 22 August 2024
Publish: 28 October 2024

E-mail addresses:
gabrielbalagiz@gmail.com
*Corresponding author

ABSTRACT

This study aimed to assess the impact of the Nile Tilapia (*Oreochromis niloticus*) cage fish farming on the water quality in two selected bays of the Bukavu basin, Lake Kivu. Physicochemical parameters (pH, temperature, electrical conductivity, total dissolved solids, salinity, dissolved oxygen, transparency) were measured *in situ* using a COMBO HI 98129 multi-parameter probe, *PCE-PHD1* probe, and a Black and White Secchi disk. Water samples at different depths were collected using a Van-Dorn Sampler and phosphate, ammonia, nitrite, silicate, and chlorophyll-*a* were analyzed using a UV-VIS spectrophotometer. The results revealed that the pH, temperature, total dissolved solids, salinity, and transparency were significantly different ($p \leq 0.05$) between the bays with cages and at the control bay, which may be due to the low movement of water, and the density of fish inside the cages. The water nutrients such as phosphate, ammonia, nitrite, silicate, and primary productivity were significantly different ($p \leq 0.05$) within the bays with cages than at the control bay without cages. Overall, the results demonstrate that Tilapia cage culture contributes to the deterioration of water quality parameters accelerating the eutrophication process in Bukavu basin, Lake Kivu. Therefore, the study recommends relocating the cages to the bays not impacted by the anthropogenic activities from the catchment and regulating fish feeding according to the bioavailability of nutrients in the bays.

Keywords: Tilapia cage culture, *Oreochromis niloticus,* Water quality, Bukavu basin, Lake Kivu

INTRODUCTION

The number of fish farms is increasing worldwide to meet the global demand for fish as a food source for humans. According to the World Bank (2013), by 2030 two-thirds of the world's food fish consumption will be produced in fish farms. In Africa, Nile tilapia culture is practiced in 30 countries and their production increased by 95.4% from 27,000 mt in 1990 to 1,287,053 mt in 2019 (FAO, 2021). Tilapia cage culture is largely distributed in Lakes Volta, Malawi, Victoria, and recently in Lake Kivu to promote social, economic, and environmental resilience (Bunting, 2024). In 2021, the production of farmed Nile tilapia in DR Congo increased from 3,500 t in 2017 to 5100 t, representing 4% of national tilapia production (FAO, 2023). This activity can affect the water quality when the environmental laws are not strict to avoid the eventual adverse effects of aquaculture on environmental and ecosystem services and assets (El-Gayar & Leung, 2000; Montanhini & Ostrensky, 2015).

Many previous studies have shown that tilapia aquaculture in cages can affect water quality by modifying physicochemical parameters (Kashindye *et al.,* 2015), in addition to triggering increased nutrient levels (Mwebaza-Ndawula *et al.,* 2013; Montanhini & Ostrensky, 2015; Kundu *et al.,* 2017; Nabirye *et al.,* 2016; Musa *et al.,* 2022; Mawundu *et al.,* 2023). Furthermore, such conditions with high nutrient levels pose a risk of algal blooms (Mwamburi *et al.,* 2020). Therefore, it is important to correctly estimate the concentration of the nutrients that are deposited during the production of Tilapia which may be affecting the water quality parameters.

Installing cage farming in the Bukavu basin of Lake Kivu is now an economic priority and provides an urgent response to food insecurity (PAM, 2020). In Lake Kivu, algal and cyanobacterial growth may be seasonally limited by both ammonia and phosphate (Sarmento *et al.,* 2006; Darchambeau *et al.,* 2014). Therefore, both nutrients being added by Tilapia cage culture operation have the potential to stimulate primary productivity and to alternate the water quality (Musa *et al.,* 2022; Karikari *et al.,* 2021; Mawundu *et al.,* 2023).

The bays where cages are often installed may also be threatened by anthropogenic activities which can increase the nutrients, and source of high primary productivity (Montanhini & Ostrensky, 2015; Bisimwa *et al.,* 2022). Assessing the effects of Tilapia cage culture on the water quality of two selected bays in the southern Bukavu basin of Lake Kivu, namely Ndendere and Nguba bays, is important for protecting the water resource. However, the information on the impact of cage culture in different bays around Bukavu town is very patchy if not lacking. Cage Tilapia culture farmers of Bukavu use supplementary feeds from commercial and local manufactured. The uncontrolled feeding of Tilapia increases water nutrients (Montanhini & Ostrensky, 2015; Kundu *et al.,* 2018) and degrades the water quality in the bays where cages are installed (Kashindye *et al.*, 2015; Gondwe *et al.,* 2010).

Tilapia feces released inside the cages are a source of ammonia that contributes to the development of algal biomass (Mwamburi *et al.,* 2020) and to a risk of high primary productivity (Gondwe *et al.,* 2010). In addition, of the two bays under consideration with cages, namely Ndendere Bay has the highest anthropogenic activities while Nguba Bay has fewer anthropogenic activities (Baguma *et al.,* 2023). These activities could increase the nutrients (Montanhini & Ostrensky, 2015) in the bays where cages are installed than in the control bay. Therefore, the present study aimed to fill this gap to determine the effect of Tilapia cage culture on water physicochemical parameters, and nutrients and the primary productivity of the selected bays in the Bukavu basin, Lake Kivu.

MATERIAL AND METHOD

Study area

Lake Kivu, one of the East African Lakes in the Albertine Rift, has five main basins from north to south: North Basin, Idjwi Island East Basin, Kalehe Basin, Ishungu Basin, and Bukavu Basin (Akonkwa *et al.,* 2017). Bukavu basin is located in the extreme southern part of Lake Kivu (Hyangya *et al.,* 2021). It is bordered to the northwest by the Ibinja isthmus and to the southeast by Rwanda and the Rusizi River, which is the outlet of Lake Kivu into Lake Tanganyika (Tassi *et al.,* 2009). The basin lies between 28° 2′ 24″ and 28° 3′ 0″ South latitude, 2° 1′ 44.4″ and 2° 1′ 58.8″ East. For the present study, three bays have been selected in the Bukavu basin, namely Ndendere, Nguba, and control bays (Figure 1) which are currently threatened by anthropogenic activities from the catchment (Bisimwa *et al.,* 2022). Ndendere Bay had the highest number of cages and anthropogenic activities characterized by toilet release, soil fill, plastic waste, fishing, population agglomeration, etc. Nguba Bay had a few cages and anthropogenic activities characterized by fishing, less population agglomeration, and the presence of vegetation around the littoral of its shores. The control bay (without cages), namely Murhundu River Bay, located in the extreme north-west is less impacted by anthropogenic activities such as fishing, washing and dishes, organic and inorganic matters from the catchment of the river, and the presence of high vegetation around the bay.

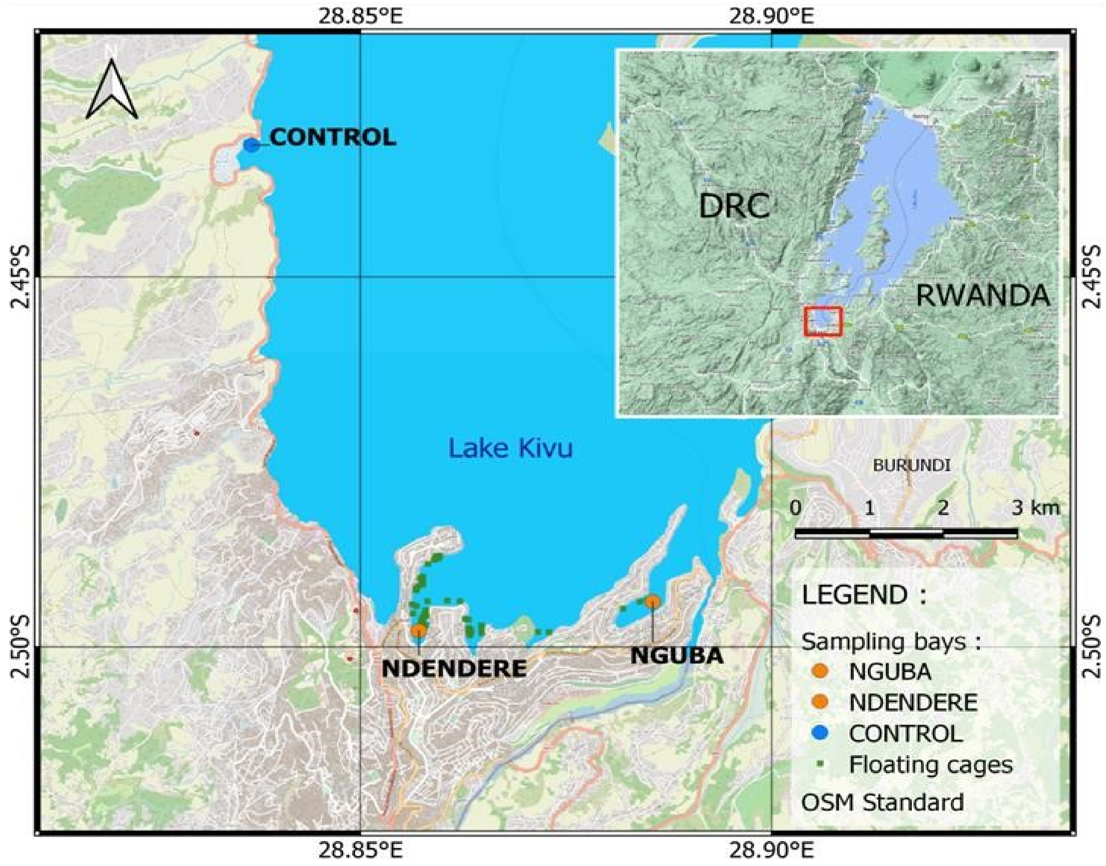

Figure 1. Location of sampling bays in the Bukavu basin, Lake Kivu

Sampling and water quality parameters analysis

Sampling was carried out from February to September 2021, i.e. one sample per month: four months for the dry season (May to August) and four months for the rainy season (February to April plus September). At each sampling bay, physicochemical parameters, namely water electrical conductivity (EC), temperature (T), pH, total dissolved solids (TDS), dissolved oxygen (DO), and salinity were measured *in situ* at the water surface using a HI 98129 Combo pH & EC/TDS meter and a *PCE-PHD1* multi-parameter probe (APHA, 2005). In the bays with cages, 3 points have been sampled in up-cage, mid-cage, and down-cage. In the control bay, the 3 points have been sampled less than 6 m of distance of macrophyte. The measurements were taken three times a day: morning (6-8 am), midday (11 am-1 pm), and evening (4-6 pm). Water transparency was estimated using a black & white Secchi Disc Wildco (P/N 58-B20, S/N2710) (Boyd, 1982).

At each bay, one liter of water was collected with a Van Dorn sampler at the surface, 5 m, 15 m, and 20 m depth, and stored in polyethylene bottles for nutrients and Chl-*a* analysis. The water bottles were stored in a cool box at 4°C and brought to the laboratory. Chl-*a* was analyzed according to the standardized protocol of UNEP & WHO (2004). Nutrient analysis was performed using the UV-Vis spectrophotometric method according to Stainton *et al.* (1977) and APHA (2005) at the Laboratory of Chemistry and Environment of the Université Officielle de Bukavu (DR Congo).

Data processing of measured parameters

Data were processed with R software (R Core Team, 2019) and Excel. The Chl-*a* concentration was calculated according to UNEP & WHO (1996) equation:

$$Chl - a = \frac{26.73*(663a-665b)*Ve}{Vs*l} \quad \text{mg.m}^{-3}$$

Where;

Ve = volume of acetone extract in liter,
Vs = volume of water sample in m^{-3} and l = path length of the bowl in cm 26.73 being the conversion coefficient

The following calculations were performed for corrections of Chl-*a* concentration at different wavelengths, *i.e.* 663a-750a = corrected absorbance 663a nm after acidification and 665b-750b = corrected absorbance 665b nm before acidification.

Statistical analysis of the data

Analysis of variance (one and two-way ANOVA) was used to determine the effect of Tilapia cage culture on the water quality parameter between the sampling bays, season, and depth. Significantly different bays mean were separated using Tukey post hoc analysis (Millot, 2009). In the case of non-parametric ANOVA, the Kruskal-Wallis test (Millot, 2009) was used for the comparison of means, and the Dun test (Dinno, 2022) for multiple comparisons. The packages *ggplot2* (Wickham *et al.,* 2022) and *ggpubr* (Kassambara, 2020) were used to produce box plots of inter-bays variations in water quality parameters combined with analyses of comparisons of means along the sampled season and water depth.

RESULT

Effect of Tilapia cage culture on the water quality parameters in the selected bays of Bukavu basin

The results (Table 1) show that surface water was alkaline in all three bays, but the pH was significantly higher (*p* < *0.0001)* in the control bay than in the two bays with fish cages. The water temperature in the control bay was significantly ($p < 0.0001$) warmer (24.2 ±0.8 ˚C) and contained high levels of TDS and salts, 543.7 ±12.6 ppm and 0.08 ±0.02 ppt, respectively. No significant variations were detected in the CE and the DO between the sampling bays. Water was found to be highly significantly ($p < 0.0001$) more transparent (3.6 ±0.41m) in the control bay than in the two bays with cages**.** These results indicate a significant variation in physico-chemical parameters between the bays where the cages were installed and the control bay. Comparison of nutrient concentrations and Chl-*a* levels showed highly significant differences ($p < 0.001$ and/or $p < 0.0001$) among the bays sampled (Table 1). In particular, nutrient concentrations and primary productivity almost doubled for all measured nutrients (NH^{4+}, NO^{2}-, SiO^{2}, and Chl-*a*), in bays with cages compared to the control bay. These findings underline the significant impact of tilapia farming in cages on the excessive nutrient concentrations observed in bays where cages are installed.

Table 1. Mean values (Mean±SD) of physiochemical parameters, nutrients, and Chl-*a* in the selected bays, Bukavu Basin, Lake Kivu: The statistical analysis results (ANOVA) are also shown in this table: *** Highly significant (β<0.0001),** Very significant (β<0.001), * Significant (β<0.05) and ns: Not significant (β>0.05). The code a & b represented the statically difference.

	CONTROL			NDENDERE			NGUBA			Stat
Parameters	Min	Max	Mean ±SD	Min	Max	Mean ±SD	Min	Max	Mean ±SD	*β*
pH	9	11.7	10.3±0.74^{a}	9.3	10.51	9.84±0.34^{b}	8.7	11.3	9.96±0.7^{b}	0.01*
Temp (°C)	22.7	25.5	24.2±0.8^{a}	21.6	24.8	23.4±0.77^{a}	22.4	25.2	23.8±0.7^{b}	0.006***
CE (µs.cm^{-1})	1168	1485	1358.5±77.57^{a}	977	1578	1271.2±178.5^{a}	928	1550	1260.6±190.1^{a}	0.31 ^{ns}
TDS (ppm)	524	584	543.7±12.6^{a}	485	678	532.1±32.12^{b}	417	559	523.7±29.3^{b}	0.01*
Salt (ppt)	0.06	0.12	0.08±0.02^{a}	0.05	0.13	0.07±0.02^{b}	0.05	0.1	0.07±0.01^{ab}	0.04*
OD (%.mg.l)	42	64	58.1±5.51^{a}	50	67.7	59.6±4.9^{a}	46	65.1	58.2±4.4^{a}	0.62 ^{ns}
Transp (m)	3	4.51	3.6±0.41^{a}	2.35	3.87	2.9±0.33^{a}	2.5	3.92	3.2±0.41^{ab}	0.0000***
PO_4^{3-} (mg.l^{-1})	0.04	0.98	0.32±0.26^{a}	0.07	1.8	0.59±0.47^{b}	0.04	1.8	0.60±0.45^{b}	0.007**
NH_4^{+} (mg.l^{-1})	0.11	0.5	0.34±0.13^{a}	0.28	1.29	0.47±0.25^{b}	0.21	0.9	0.56±0.21^{b}	0.0001***
NO_2^{-} (mg.l^{-1})	0.07	0.58	0.19±0.18^{a}	0.07	0.91	0.33±0.30^{b}	0.07	1.18	0.47±0.50^{b}	0.008***
SiO_2 (mg.l^{-1})	1.98	4.15	2.73±0.59^{a}	1.97	7.95	4.63±1.74^{b}	2.51	6.98	4.04±1.05^{b}	0.001**
Chl-*a* (mg.m^{-3})	1.34	13.4	4.39±2.22^{a}	3.24	20.89	8.37±4.45^{b}	3.25	17.61	7.84±3.79^{b}	0.0005***

Min=Minima, Max=Maxima, SD= Standard deviation, pH=Potential Hydrogen, Temp= Temperature, CE= Electrical conductivity, TDS= Total dissolved solid, Salt = Salinity, OD= Oxygen dissolved, NH_4^{+}= Ammonia, PO_4^{3-} = Phosphate NO_2^{-}=Nitrite, SiO_2=Silicate, Chl-a = Chlorophyll *a*.

Effect of season on water quality parameters in selected bays

In the bays with cages, the electrical conductivity (CE), Total Dissolved Solids (TDS), salt, dissolved oxygen, and transparency were lower in the dry season and increased considerably in the rainy season. The pH, temperature, dissolved oxygen and transparency were very high during the rainy but low in the dry season at the control bay. The comparison between dry and rainy seasons was different significantly ($p \leq 0.05$) for pH at Ndendere Bay and for the TDS at the control bay). In the bays with cages, the dry and rainy seasons were significantly different for ammonia at Nguba Bay and for silicate at Ndendere (***p=0.01****). The bays with cages contained an excessive level of phosphate and silicate during the rainy than the dry season. In these bays, the ammonia and nitrite increased in the dry and decreased in the rainy seasons. The bays with cages had a higher concentration of Chl-*a* during the dry season than at the control bay (Figure 2). There was no seasonal effect on ammonia,

 pISSN 2550-0910; eISSN 2579-4817
Available online at https://e-journal.unair.ac.id/JoAS

phosphate, silicate, and Chl-*a* in the sampled bays. These results lead us to understand that implementing Tilapia cage culture, will impact significantly the water quality parameters.

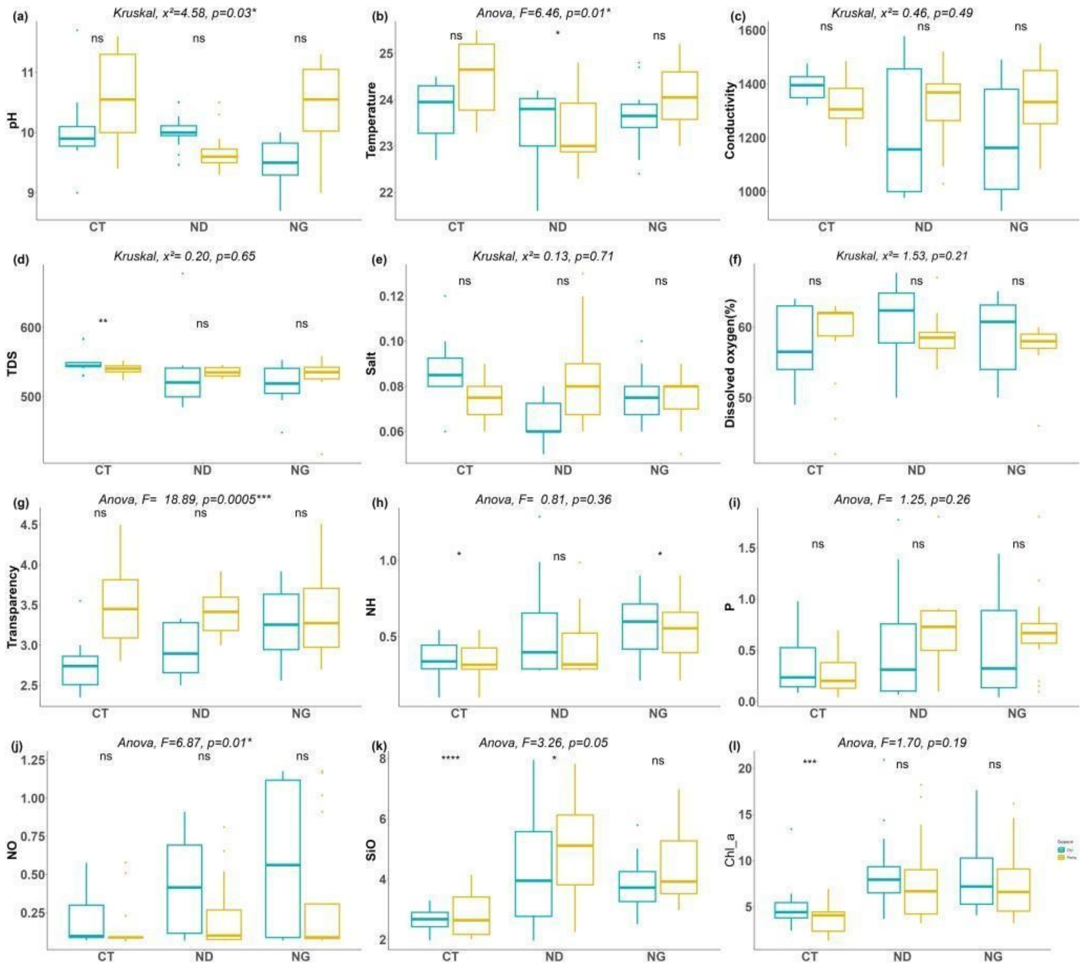

Figure 2. Effect of the season on the water quality parameters in the selected bays. The static analysis results (ANOVA) are also shown in this figure: *** Highly significant (β<0.0001),** Very significant (β<0.001), * Significant (β<0.05), and ns: Not significant (β>0.05). pH=Potential Hydrogen, NH=ammonia (NH_4^+), P=Phosphate (PO_4^{3-}), NO=Nitrite (NO_2^-), SiO=Silicate (SiO_2), Chl-a = Chlorophyll *a*. The code a & b represented the statically difference. CT: Control bay, ND: Ndendere bay and NG: Nguba bay. Blue color =Dry season, and yellow color = Rainy season.

Effect of Tilapia cage culture on the variation of Nutrients and primary productivity along Water Depth in sampling bays

The inter-bays variation of nutrients and Chl-*a* water use function to depth sampled. Chl-*a* concentration was significantly higher in the bays with cages than in the control bay ($p < 0.0001$). Silicate concentration was higher in bays with cages than in the control bay ($p < 0.05$). Phosphate, ammonia, and nitrite concentrations were both higher in the bays with cages compared to the control bay was illustrated (Figure 3). From the surface down to 20 meters of water depth, the mean values of these 3 nutrients grew more in the two bays with cages than in the control bay. However, there were no appreciable variations between the bays. Tilapia cage culture have accelerated the concentrations of nutrients and Chl-*a* in the water depth of bays with cages (figure 3).

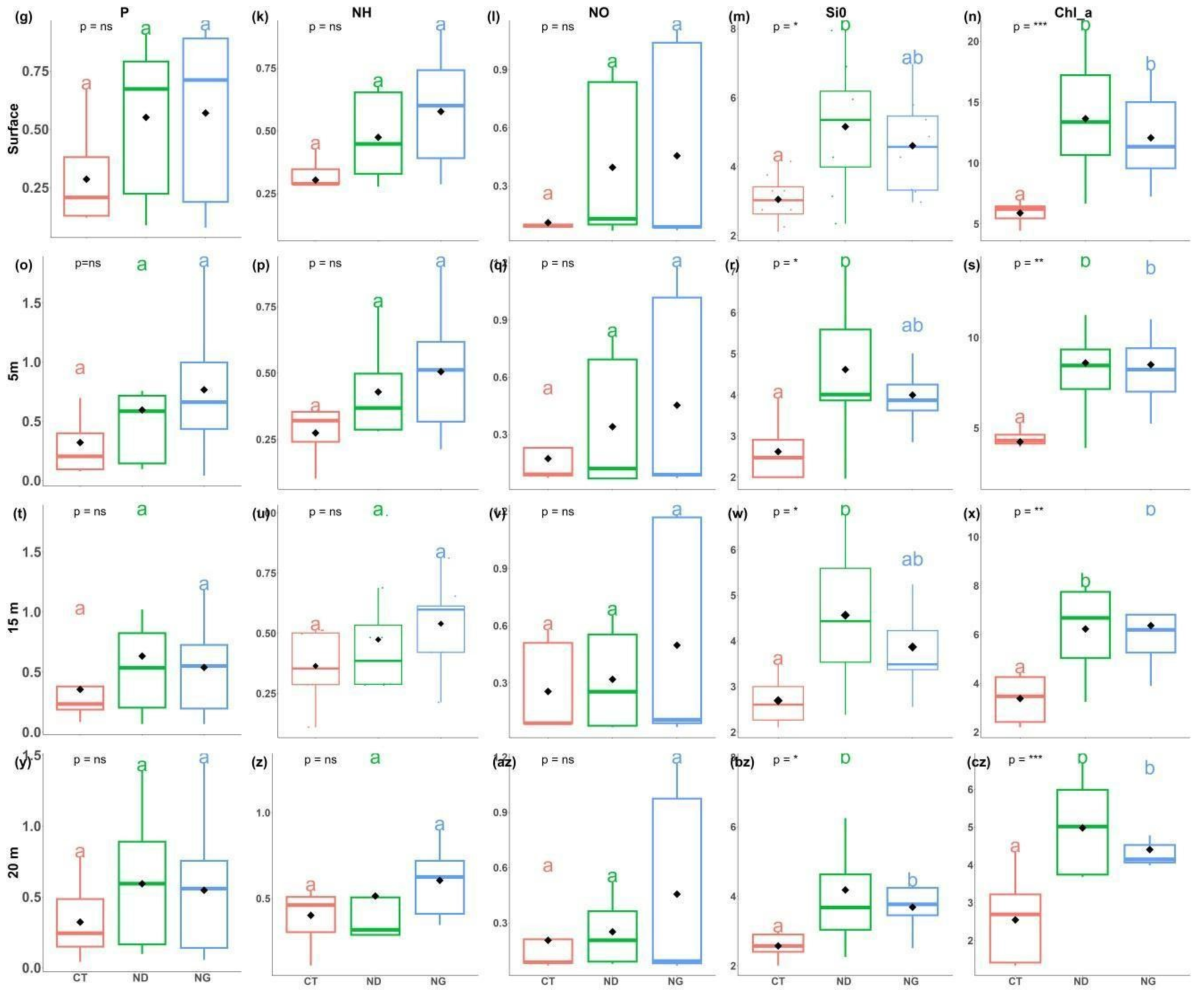

Figure 3. Inter-site variability of nutrients and primary productivity by water column sampled. The static analysis results (ANOVA) are also shown in this figure: *** Highly significant (β <0.0001),** Very significant (β <0.001), * Significant (β <0.05), and ns: Not significant (β>0.05). NH=ammonia (NH_4^+), P=Phosphate (PO_4^{3-}), NO=Nitrite (NO_2^-), SiO=Silicate (SiO_2), Chl-a = Chlorophyll a. The code a & b represented the statically difference. CT: Control bay (red color), ND: Ndendere bay (green color), and NG: Nguba bay (blue color).

DISCUSSION

Effect of Tilapia cage culture on the water physicochemical parameters in the selected bays of Bukavu basin

The results of this study revealed that physicochemical parameters including temperature, pH, DO, salt, transparency, and EC of the surface water varied between the bays. Although the water temperature at the control bay was much warmer than in the two bays with cages, the absolute temperature difference is negligible because the bays with cages were much larger than the control bay (Macuiane *et al.,* 2016). Lake Kivu is classified as a meromictic lake and its characteristics could be affecting the change of water temperature in the protected bays where waves are weak (Zadereev *et al.,* 2017). The water temperature studied in the bays of Bukavu basin was significantly different than the water temperature in cage systems in Lake Malawi (Gondwe *et al.,* 2010) and in Ghana's Lake Volta (Karikari *et al.,* 2021). These differences could be attributed to origin and altitudinal distribution, inputs of catchment tributaries, and stratification conditions in Tilapia culture sites in these three lakes. The pH values varied within bays, indicating the water's generally alkaline nature. The deviations observed were not substantial enough to suggest significant pH-related impacts from cage culture activities.

The decrease in pH values observed in bays with cages compared to the control bay is significant was probably due to anthropogenic activities around the bays such as waste food, agriculture activities, disposal of rubbish, and organic waste including cage culture which could contribute to the variation of pH. The fact that the two bays with cages do has not significant differences reflects the water's ionic composition, chemical equilibrium, and alkalinity (Mwamburi *et al.,* 2020) may be from the aquaculture activities. The present results differ from those of Kashindye *et al*. (2015) and Karikari *et al*. (2013) in Lakes Victoria and Volta, where the bays with cages had recorded an acidic pH of about 5.23 after comparing to the control bays with a pH value of about 8.81.

These results show that the impact of cage culture may be felt differently from one ecosystem to another. The level of the water electrical conductivity from the bays with cages was not significantly different from the control bay indicating that the water quality parameters may be affected by anthropogenic activities (Bisimwa *et al.,* 2022) The low electrical conductivity recorded in the bays may be explained by the chemical equilibrium between the water inside and outside cages (Mwamburi *et al.,* 2020).

Total dissolved solids (TDS) level was higher in bays with cages than in the control bay due to the bays with cages receiving waste food and fish fecal from the Tilapia cage culture. The level of TDS from the bays with cages was significantly different from the control bay reflecting the existence of dissolved and suspended organic and inorganic materials and also plankton and other microorganisms (Osei *et al.,* 2019). Increased TDS in the bays with cages can affect the penetration of light thereby impeding photosynthesis by phytoplankton in the water column (Harrison *et al.,* 2005). The high TDS recorded in the control bay was probably a result of the sediment accumulation from the catchment of Murhundu River which increased the level of turbidity in the area as observed by Feuerstein *et al*. (2022).

Regarding the dissolved oxygen, no significant variations were detected between the sampling bays. The small variability observed in the bays with cages was not attributed to Tilapia cage culture. The slow wave velocity in bays does not favor large-scale water exchange (Gondwe *et al.,* 2010). The bays with cages may fall into Delaney & Klesius's (2004) explanations where many intensive fish culture systems are subjected to a lack of dissolved oxygen in the water due to high fish density and feeding practices, algal blooms, and elevated temperatures which reduce the availability of oxygen. In addition, during the day, DO was higher than at night at the sites where cages are operated (Musa *et al.,* 2022).

This would explain the low significant difference between the studied bays. On the other hand, water was more transparent in the control bay than in the two bays with cages probably due to an abundance of food waste from an area that may explain the high concentration of nutrients in fish cages (Gondwe *et al.,* 2010; Musa *et al.,* 2022). In contrast, the control bay is less affected by human activities than the two bays with cages.

However, this control bay was not significantly different from Ndendere Bay, where cages are installed. This similarity may be due to the control bay's connection to the Murhundu River, which is believed to be a major source of sediment for Lake Kivu (Feuerstein *et al.,* 2022). It was noted that no relationship was found between the physicochemical parameters of bays with caged fish and the seasons The fact that the Bukavu basin is threatened by erosions (Bisimwa *et al.,* 2022) which would lead to the accumulation of waste in the bays, could explain the little fluctuation in of some water parameters in the bays with cages during the rainy than the dry season.

Effect of fish cages on nutrients in the selected bays of Bukavu basin

The present results revealed that Tilapia cage culture has triggered a significant increase in concentrations of nutrients in the water at the bay with cages compared to the control bay. In Nguba Bay, the observed higher level of nutrients such as nitrite, phosphate, and ammonia than in Ndendere Bay maybe since one cage from Nguba Bay daily rejects into water 43.2 kg compared to 12.74 kg from Ndendere Bay (unpublished). Also, fish farms in Nguba Bay used a more important stock of feed than other bays. This indicates that the Tilapia cage culture affects the water column in the bays where cages are installed.

Many studies related to this, indicated that waste from fish and feed is the main source of higher concentrations of nutrients (Mente *et al.,* 2006; Gondwe *et al.,* 2010; Nyanti *et al.,* 2012; Macuiane *et al.,* 2016). The high phosphate levels recorded in the bays with fish cages can be attributed to the use of commercial feeds, fishmeal, and soybean meal intended to enhance growth rates (Macuiane *et al.,* 2016). The bays with cages were more strongly charged by silica than the control bay. These results may be attributed to Tilapia cage culture activities, anthropogenic activities, diatom productivity, and volcanic waters (UNEP & WHO 1996; Aura *et al.,* 2017; Bashar *et al.,* 2021). The nutrients studied varied from the surface to 20 m. They warned that the intensification of farming activities has the potential to increase the nutrients and occurrence of eutrophication in the bays of Bukavu basin, Lake Kivu. These trends were observed in Lake Malawi (Gondwe *et al.,* 2010) Lake Victoria (Musa *et al.,* 2022), and Lake Volta (Karikari *et al.,* 2021).

The present study showed that there were no significant seasonal differences between the three bays for the four parameters of nutrients, although nutrients increased significantly in the dry season. The bays with cages had high nutrients in the two seasons may be due to the supplementary feed in the water and by anthropogenic activities (Montanhini & Ostrensky, 2015; Musa *et al.,* 2023). In addition, Nguba Bay was less impacted by anthropogenic activities and had fewer cages than Ndendere which was highly impacted by anthropogenic activities and by high cages (Baguma *et al.,* 2023). The control bay showed significant differences between the dry and the rainy seasons due to the accumulation of inorganic and organic matter inputs by the Murhundu River (Feuerstein *et al.,* 2022).

Effect of fish cages on primary productivity in the selected bays of Bukavu basin

A significant increase in Chl-*a* concentration in the bays with cages than in the control bay was observed probably due to food availability and nutrient-rich feed quantity given to the fish within cages (Tibúrcio *et al.,* 2021; Pergent *et al.,* 1998). These are often the causes of planktonic bloom (Borges *et al.,* 2010) and of the increase of the primary productivity (Karikari *et al.,* 2013; Simões *et al.,* 2015). In the bays with cages, the increase of Chl-*a* suggests an excessive primary productivity related to the prevailing conditions such as high levels of nutrients (organic load). The current results are similar to those earlier reported by Tibúrcio *et al.* (2021) who found the same results in the Rosana Reservoir (Brazil).

Tilapia cage culture would contribute to the eutrophication of the bays where cages are installed. The primary productivity was higher from the surface to the bottom in the bays with cages than at the control bay. This may be due to the feces released in the water column which contains ammonia and phosphate (Mwamburi *et al.,* 2020). Those are essential elements for algae biomass (Gondwe *et al.,* 2010) sources of high productivity. The fact that bays with cages had a higher concentration of Chl_*a* during the dry season than at the control bay may be attributed to the weak movement of the water which doesn't facilitate the water mixing. These results are similar to those of Mwandu *et al*. (2022) and Aura *et al*. (2017) regarding Tilapia cage culture.

CONCLUSION

In conclusion, the study found that water quality parameters such as pH, temperature, dissolved oxygen, salinity, total dissolved solids, conductivity, and transparency varied slightly in the bays with Tilapia cages compared to the control bay. This variation was likely influenced by reduced water movement, proximity to the cages, and higher fish density inside them. Nutrient concentrations including phosphate, ammonia, nitrite, and silicate were significantly higher in the bays with cages due to supplementary and manufactured feeds, as well as fish feces. Primary productivity was also elevated in these bays, indicating increased nutrient availability from Tilapia cage culture. The study suggests that Tilapia cage farming and anthropogenic inputs from the watershed are major factors contributing to eutrophication in these bays. It recommends relocating the cages to less impacted areas and implementing controlled feeding practices to manage nutrient levels effectively.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the assistance of Toussaint Mushamalirwa (Lecture and Researcher at UOB) in accessing the data and locating the map of the sampling sites. We thank the International Society of Limnology (SIL) for the Tonolli Memorial Award 2021 which facilitated us in the realization of a part of this research.

CONFLICT OF INTEREST

The authors declare that there is no conflict.

REFERENCES

American Public Health Association. (2005). Standard methods for the examination of water and waste water (Vol. 6). 21st edition. (Centennial edition.) A. Eaton, L.S. Clesceri, E. W. Rice and A.E.Grenberg (Eds.). American Public Health Association. APHA.Washington DC, USA.

Akonkwa, B. D., Ahouansou, M. S., Nshombo, M.V. & Lalèyè P. (2017). Description de la pêche au lac Kivu. European Scientific Journal*,* 13(21), 1857-7881.

Aura, C. M., Roegner, A., Owiti, H., Birungi, D., Fiorella, K. J., Corman, J., Kayanda, R., Mbullo, P., Nyamweya, C.S., & Mchau, G. (2022). Mind the gaps for the best practices: Enhancing the management of Lake Victoria fisheries resources. Lakes & Reservoirs: Research & Management, 27(3), e12411.

Baguma, B. G., Cocquyt, C., Cubaka, K.A., Irenge, B.A., Nakangu, F. N., Akonkwa, B. D., & Mbalassa, M. (2023). Physical characterization of the cage culture of *Oreochromis niloticus* (L. 1758), in the Bukavu sub-basin on Lake Kivu, Democratic Republic of the Congo. Annales des Sciences et des Sciences Appliquées*,* 5(1), 130-147.

Bashar, A., Hasan, N. A., Haque, M. M., Rohani, Md. F., & Hossain, Md.S. (2021). Effects of Dietary Silica Nanoparticle on Growth Performance, Protein Digestibility, Hematology, Digestive, Morphology, and Muscle Composition of Nile Tilapia, *Oreochromis niloticus*. Frontiers in Marine Science, *8*, 706179.

Bisimwa, M. A., Amisi, M. F., Bamawa, M. C., Muhaya, B. B., & Kankonda, B. A. (2022). Water quality assessment and pollution source analysis in Bukavu urban rivers of the Lake Kivu basin (Eastern Democratic Republic of Congo). Environmental and Sustainability Indicators, 14, 100183.

Borges, P., Trans, S., Dias, J. D., & Bonecker, C. C. (2010). Effects of fish farming on plankton structure in a Brazilian tropical reservoir. Hydrobiologia, 649, 279-291.

Boyd, C.E. (1982). Water Quality Management for Pond Fish Culture. Elsevier. Amsterdam.

Darchambeau, F., Sarmento, H., & Descy, J-P. (2014). Primary production in a tropical large lake: The role of phytoplankton composition. Science of the Total Environment, 473–474, 178–188.

Delaney, A. M., Klesius, P. H. (2004). Hypoxic conditions induce Hsp70 production in blood, brain and head kidney of juvenile Nile tilapia *Oreochromis niloticus* (L.). Aquaculture, 236, 1-4, 633-644.

Dinno, A. (2022). Dunn's Test of Multiple Comparisons Using Rank Sums (Package 'dunn.test'). CRAN p7.

El-Gayar, O. F., & Leung, P. S. (2000). ADDSS: A tool for regional aquaculture development. Aquacultural Engineering, 23(1-3), 181-202.

Food Agriculture Organization. (2021). Global aquaculture production 1950–2019. Food and Agriculture Organization. FAO.

Food Agriculture Organization. (2023). Fishery and Aquaculture Statistics. Global aquaculture production 1950-2021 (FishStatJ). In: FAO Fisheries and Aquaculture Division. Food and Agriculture Organization. Rome.

Feuerstein, S., Wang, Z., & Bachofer, F. (2022). Evaluation et Surveillance des paramètres d'érosion des sols dans le bassin transfrontalier du lac Kivu et de la rivière Ruzizi. OT4LAC KIVU. Centre aérospatial allemand-Centre de données de télédétection allemande (DLR-DFD), Münchener Str. 20, 81241.

Gondwe, M. J. S., Guildford, S. J., & Hecky, R. E. (2010). Physical-chemical measurements in the water column along a transect through a tilapia cage fish farm in Lake Malawi, Africa. Journal of Great Lakes Research, 37, 102-11.

Harrison, W. G., Perry, T., & Li, W. K. W. (2005). Ecosystem indicators of water quality, Part I. Plankton biomass, primary production and nutrient demand. In: Hargrave, B.T. (ed) Environmental effects of marine finfish aquaculture. Handbook of Environmental Chemistry. Vol 5M. Springer-Verlag, Berlin.

Hyangya, B. L., Riziki, J. W., Masilya, P. M., Zabene, F. Z., Alunga, G. L., Kaningini, B. M., & Kankonda, A. B. (2021). Physico-chemical characterization of littoral water of Lake Kivu (southern basin, Central Africa) and use of water quality index to assess their anthropogenic disturbances. World Water Policy, 7(2), 166-193.

Karikari, A. Y., Amisah, R., Anku, W. W., Amisah, S., Trevor, T., & Lindsay, R. (2021). Assessment of cage fish farm impacts on physicochemical parameters of the Volta Lake in Ghana. J. Fish. Coast. Mgt., 3(1), 22-35.

Karikari, A. Y., Akpabey, F., & Abban, E. K. (2013). Assessment of water quality and primary productivity characteristics of Volta Lake in Ghana. Academia Journal of Environmental Sciences, 1(5), 88 - 103.

Kashindye, B. B., Nsinda, P., Kayanda, R., Ngupula, G. W., Mashafi, C. A., & Ezekiel, C. N. (2015). Environmental impacts of cage culture in Lake Victoria: the case of Shirati Bay-Sota, Tanzania. Springer Plus, 4, 475.

Kassambara, A. (2020). Package 'ggpubr': 'ggplot2' Based Publication Ready Plots. 155 P.

Kneubühler, M., Toni, F., Kellenberger, T. W., Pasche, N., & Schmid, M. (2007). Mapping Chlorophyll-a in Lake Kivu with remote sensing methods. In: Envisat Symposium Montreux (CH), Uropean Space Agency, Communication Production Office, 23-27 April 2007.

Kundu, R., Aura, C. M., Nyamweya, C., Agembe, S., Sitoki, L., Lung'ayia, H. B., Ongore, C. O., Ogari, Z., & Werimo, K. (2017). Changes in pollution indicators in Lake Victoria, Kenya and their implications for lake and catchment management. Lakes & Reservoirs: Research & Management, 22, 199–214.

Macuiane, M. A., Hecky, R. E., & Guildford, S.J . (2016). Temporal and Spatial Changes in Water Quality in Lake Malawi/Niassa, Africa: Implications For Cage Aquaculture Management. Oceanography & Fisheries, 1(1), 555552.

Mawundu, S., Jacques, R. W., Liti, D. M., Ouko, J., Alfred, A., Evans, A., & Kaunda-Arara, B. (2023). Influence of net cages on water quality and trophic status of Lake Victoria, Kenya: The case of Kadimu Bay. Lakes & Reservoirs: Research & Management, 28, e012432.

Mente, E., Graham, J. P., Santos, B. M., & Neofitou, C. (2006). Effect of feed and feeding in the culture of salmonids on the marine aquatic environment: a synthesis for European aquaculture. Aquaculture International, 14(5), 499–522.

Millot, G. (2009). Comprendre et réaliser les tests statistiques à l'aide de R. Manuel pour les débutants. De Boeck, Belgium.

Montanhini, N. R. & Ostrensky A. (2015). Nutrient load estimation in the waste of Nile tilapia *Oreochromis niloticus* (L.) reared in cages in tropical climate conditions. Aquaculture Research, 46, 1309–1322.

Musa, S., Aura, C. M., Tomasson, T., Sigurgeirsson, Ó., & Thorarensen, H. (2022). Impacts of Nile tilapia cage culture on water and bottom sediment quality: The ability of a eutrophic lake to absorb and dilute perturbations. Lakes & Reservoirs: Research & Management, 27, e12413.

Musa, S., Aura, C. M., Tomasson, T., Sigurgeirsson, Ó., & Thorarensen, H. (2023). Nutrient Budget of Cage Fish Culture in a Lacustrine Environment: Towards Model Development for the Sustainable Development of Nile Tilapia (*Oreochromis niloticus*) Culture. Emerging Sustainable Aquaculture Innovations in Africa, 365-381.

Gabriel N. N., Omoregie E. & Abasubong K. P. (Eds) Emerging Sustainable Aquaculture Innovations in Africa, Sustainability Sciences in Asia and Africa. Springer, 365–381.

Mwamburi, J., Basweti, G., Owili, M., Babu, J., & Wawiye, P. (2020). Spatio-temporal trends of nutrients and physico-chemical parameters on Lake Ecosystem and fisheries prior to onset of cage farming and re-opening of the Mbita passage in the Nyanza Gulf of Lake Victoria. Lakes & Reservoirs: Research & Management, 3(25), 292-313.

Mwebaza-Ndawula, L., Kiggundu, V., Magezi, G., Naluwayiro, J., Gandhi-Pabire, W., & Ocaya, H. (2013). Effects of cage fish culture on water quality and selected biological communities in northern Lake Victoria, Uganda. Uganda Journal of Agricultural Sciences, 14(2), 61–75, 1026-0919.

Nabirye, H., Mwebaza-Ndawula, L., Bugenyi, F. W. B., & Muyodi, F. J. (2016). The evaluation of cage fish farming effects on water quality using selected benthic macro-invertebrate community parameters in the Napoleon Gulf, northern Lake Victoria. International Journal of Fisheries and Aquatic Studies, 4(1), 42-50.

Nyanti, L., Hii, K.M., Sow, A., Norhadi, I., & Ling, T. Y. (2012). Impacts of aquaculture different depths and distances from cage culture sites in Batang Ai Hydroelectric Dam Reservoir, Sarawak, Malaysia. World Applied Science Journal, 19(4), 451–156.

Osei, L. K., Asmah, R., Aikins, S., & Karikari, A. Y. (2019). Effects of Fish Cage Culture on Water and Sediment Quality in the Gorge Area of Lake Volta in Ghana: A Case Study of Lee Fish Cage Farm. Ghana Journal of Science, 60(1), 1-16.

Programme Alimentaire Mondial. (2019). Analyse de la Sécurité Alimentaire en Situation d'Urgence au Sud Kivu. Rapport final du sous bureau de Bukavu du Programme Alimentaire Mondial. PAM.

Pergent, G., Mendez, S., Pergent-Martini, C., & Pasqualini, V. (1998). Preliminary data on the impact of fish farming facilities on *Posidonia oceanica* meadows in the Mediterranean. Oceanologica Acta, 22(1).

Sarmento, H., Isumbisho, M., & Descy, J-P. (2006). Phytoplankton ecology of Lake Kivu (eastern Africa). J. Plankton Res., 28, 815-829.

Simões, N. R., Nunes, A. H., Dias, J. D., Lansac-tôha, F. A., Velho, L. F. M., Bonecker, C. C. (2015). Impact of reservoirs on zooplankton diversity and implications for the conservation of natural aquatic environments. Hydrobiologia, 758, 3-17.

Stainton, P. M., Capel, M. J., & Armstrong, F. A. (1977). The chemical analysis of fresh water. Fish Mar. Serv. Misc.Spec. Publ, 25.

Tassi, F., Vaselli, O., Tedesco, D., Montegrossi, G., Darrah, T., Cuoco, E., Mapendano, M.Y., Poreda, R., & Huertas, A.D. (2009). Water and gas chemistry at Lake Kivu (DRC): Geochemical evidence of vertical and horizontal heterogeneities in a multibasin structure. Geochem, Geophys. Geosyst, 10, Q02005.

Tibúrcio, V. G., Mantovano, T., Da Silva, J. V. F., & Bonecker, C.C. (2021). Influence of the chlorophyll-*a* gradient on the community structure of plankton microcrustaceans (Cladocera and Copepoda) in a Neotropical reservoir. An. Acad. Bras. Cienc., 93(2), e20190379.

United Nations Environment Programme & World Health Organization. (1996). Water Quality Monitoring: A practical guide to the design and implementation of freshwater quality studies and monitoring programmes. Taylor and Francis, Abingdon.

Wickham, H., Chang, W., Henry, L., Pedersen, L. T., Takahashi, K., Wilke, C., Woo, K., Yutani, H., & Dunnington, D. (2022). Package 'ggplot2': Create Elegant Data Visualisations Using the Grammar of Graphics.

World Bank. (2013). Fish to 2030 Prospects for fisheries and Aquaculture, World Bank report number 83177-GLB, Agriculture and environmental services discussion paper 03. December 2013.

Zadereev, E. S., Boehrer, B., & Gulati, R. D. (2017). Ecology of Meromictic Lakes. Springer Cham.