VARIABILITY OF PHYTOPLANKTON AND ZOOPLANKTON IN RELATION TO THE ENVIRONMENTAL VARIABLES IN TONGA LAKE, ALGERIA (RAMSAR SITE OFTHE SW MEDITERRANEAN)

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Abstract. The purpose of this study was to assess the biological and physicochemical quality of Tonga Lake, a RAMSAR site situated in Algeria, during the Coronavirus pandemic. Phytoplankton and zooplankton, as well as several physicochemical variables (water temperature, pH, dissolved oxygen, total suspended particulate, and nutrients), were analyzed monthly at two stations during 2019–2020. The results showed that the physicochemical variables were within the tolerable ranges, except for phosphate, which slightly exceeded the reference threshold. No phytoplankton blooms were encountered; cyanobacteria were the most abundant during the study period and reached their maximum in winter (137888 cells/l), while dinoflagellates and diatoms reached their maxima in autumn and spring, respectively (23809 and 102083 cells/l). while the maximum of all the identified zooplankton groups was recorded in the spring. Dinoflagellates were strongly affected by pH and total suspended particulate. On the other hand, high significant correlations were reported between protozoa and dissolved oxygen, as well as between rotifers and water temperature. Nonetheless, no-significant correlations were detected between the remaining groups (diatoms, cyanobacteria, cladocerans, and copepods) and the investigated environmental variables.
Keywords:*Tonga Lake, Algeria, PNEK, physicochemical parameters, water quality, monitoring*

Introduction

The distribution of aquatic species in a habitat is determined by biotic factors, environmental variables, and interactions involving species at different levels of the food web (Menge and Sutherland, 1976;Arnott and Vanni, 1993;Harley, 2003;Abdul et al., 2016; Carter et al., 2017).

Phytoplankton represents the dominant principal producer in aquatic ecosystems (Reynolds, 1984). The trophic status is indicated by changes in the structure and distribution patterns of phytoplankton, which also reflect environmental fluctuations

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(Vanni and Temte, 1990; Reynolds et al., 1993; Carrillo et al., 1995; Chen et al., 2003; Wu et al., 2011;Burford and Davis, 2011).

On the other hand, zooplankton, which is an essential component that provides a link between the phytoplankton and higher trophic levels and contributes to regulating microbial productivity (Dejen et al., 2004), reflects the equilibrium of the food chain because they are responsive to variations in their resources and predators, as well as to the changes in environmental conditions (Mills and Schiavone, 1982; Carpenter et al., 1985; Suikkanen et al., 2007;Hansson et al., 2007;Braun et al., 2021).

Indeed, both phytoplankton and zooplankton have been identified as excellent bioindicators (Whitton and Kelly, 1995; Bianchi et al., 2003; Pinto-Coelho and Bezerra-Neto, 2005; Pinto-Coelho et al., 2005;Hoch et al., 2008), which makes them imperative for assessing ecosystem functioning and stability (Medlin and Wilson, 1979; Laskar and Gupta, 2009; Singh et al., 2010; Gökçe and Turhan, 2014; Msiteli-Shumba et al., 2017); especially when it comes to the National Park of El Kala (PNEK), which has been classified as a biosphere reserve by UNESCO in 1990. According to the World Wildlife Fund, the PNEK comprises an important reservoir of biodiversity and a unique ecosystem in the Mediterranean region. It contains several lakes (Tonga and Oubeira lakes, El Mellah Lagoon), and is home to 40,000 plant species, 138 amphibians and reptiles, 193 fish species, 450 bird species, and 305 mammals (Achour, 2011). Consequently, monitoring the basis of its ecosystem remains a necessity in order to contribute to its preservation.

This region has benefited from numerous studies that considered a variety of ecological aspects in various fields (Nasri et al., 2008; Amri et al., 2010; Djabourabi, 2014; Djabourabi et al., 2017; Bensafia et al., 2020).

Nonetheless, our investigation represents a preliminary study that aims first to evaluate the biological and physicochemical quality of Tonga Lake by analyzing phytoplankton, zooplankton, and several physicochemical variables monthly at two sampling sites during 2019–2020 and, second, to understand the interactions between these organisms and environmental parameters at the local scale.

Materials and methods

Study area

Tonga Lake is a brackish water reservoir located in the northeastern part of Algeria (36.991944° N, 8.502778° E). It communicates with the Mediterranean Sea through Messida Wadi (a small river) (*Fig.1*) and represents the most important nesting area in North Africa. It is a wetland of great importance and a strict reserve in the National Park of El Kala (Fishpool and Evans, 2001).

The lake covers an area of 2300 hectares, which corresponds to 12% of the total water surface of the PNEK. It is the recipient of El Hout Wadi, and also receives groundwater from the surrounding land, which contributes to its maintenance and prevents it from drying up.

Based on climatic data (*Fig. 1d*) provided by the national office of meteorology (ONM, 2020) over a period of 11 years (2004–2014), the zone is characterized by a rainy autumn and winter (the monthly maximum precipitation of 407 mm was detected in 2006), and a hot and dry summer, where the monthly maximum temperature (27.4°C) was recorded in 2004.

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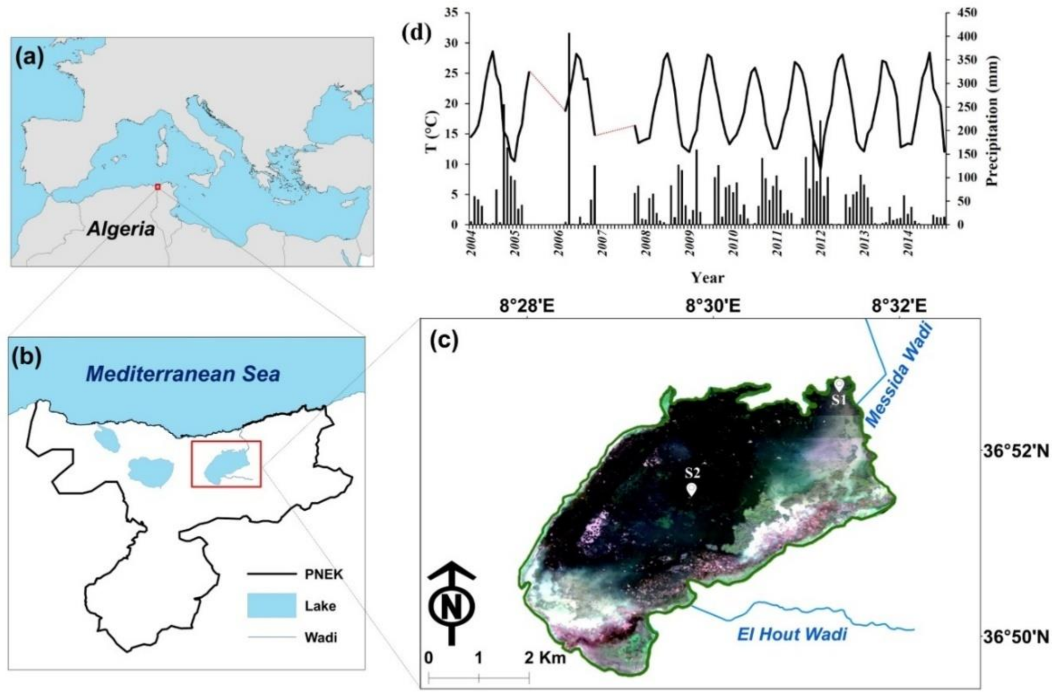

Figure 1. *Geographical position of Tonga Lake and the location of sampling stations (a, b, and c), and the climatic data related to area between 2004-2014 (d)*

Sampling and laboratory analysis

Monthly sampling was carried out between December 2019 and November 2020. Samples were collected from water surface (depth less than 1 m) at two fixed stations following the same procedure (*Fig. 1*). The first station (S1) was located in the north of the lake (36° 52.74' N, 8° 31.53' E), and the second one (S2) in the center of the lake (36° 51.64' N, 8° 29.85' E). Sampling was carried out during the day, between 8:00 and 11:00 am, to ensure consistent results. Weather forecasts were checked before each sampling date, to avoid windy days.

Phytoplankton and zooplankton samples were collected using a plankton net with an opening of 25 cm in diameter, a length of 1 m, and a round mesh of 20 µm.Sampling was performed at the front of the embarkation after stabilization to minimize disturbance. The samples were preserved immediately with formaldehyde solution (10%) and maintained in dark and cool conditions (4°C) until laboratory analysis.

The taxonomic identification was conducted under a light microscope, following the works of Bourrelly(1985) andCouté (1995), while cell counting was done according to Andresen Leitao et al. (1982). Different magnifications (100x, 200x, or 400x) were utilized based on the size and richness of the sample (Muñiz et al., 2017). The density was expressed as number of cellules per liter (cells/l).

The counting and identification of zooplankton was done on a slide under a light microscope, based on the works ofBalcer et al. (1984); Dussart et al. (1984); Pourriot and Francez (1986); Witty (2004), andDoan Dang et al. (2015) at a magnification of Gx4. However, the identification of different species required a higher magnification of Gx10. The zooplankton density in each sample was expressed as the total number of individuals per liter (indiv/l).

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The suspended particulates (TSP) were analyzed according to the protocol described by Aminot and Chaussepied (1983).

Inorganic nutrient analyses (nitrite, ammonia, and phosphate) were performed based on the colorimetric method (Aminot and Chausspied, 1983), while nitrate was measured according to the method described by AOAC (2002).

Water temperature, pH, and dissolved oxygen (DO) were measured using a multi-parameter (Consort 535) with several probes.

Statistical analysis

In addition to descriptive statistics for the entire dataset, an ANOVA test and Fisher's t-test for variance were performed to investigate the variation of the several studied parameters over time and space. The Bravais-Pearson linear correlation coefficient (r) was used to assess the relationships between environmental variables, phytoplankton, and zooplankton densities. The statistical analyses were conducted using R software (version 4.2.3).

Results

Environmental parameters of the water

Table 1 shows the range and the mean of the environmental parameters in each season for the studied period 2019–2020. Similarly, *Figure 2* illustrates their monthly variability in each station.

Table 1. *Seasonal data for physicochemical parameters in the surface water of Tonga Lake*

		Water temperature (°C)	**Dissolved oxygen (mg/l)**	**pH**	**Nitrite (µmol/l)**	**Nitrate (µmol/l)**	**Ammonium (µmol/l)**	**Phosphate (µmol/l)**	**TSP (mg/l)**
winter	Range	12.2–15.4	3.78–12.55	6.7–7.92	0–2.98	0–0.43	0	0–1.91	10–76
	mean	13.6	7.67	6.79	0.58	0.12	0	0.7	27.67
Spring	Range	14.6–22.7	2.27–6.5	6.64–7.18	0.02–0.39	0–1.28	0–0.11	0.79–2.22	5–45
	mean	19.85	3.86	6.95	0.2	0.21	0.08	1.19	18.67
Summer	Range	23.2–26.9	3.43–7.9	6.35–8.1	0.005–0.37	0–1.07	0–9.92	0.08–9.92	6–40
	mean	24.86	5.18	7.12	0.19	0.19	3.07	2.12	17.33
Autumn	Range	13.2–24.8	7.97–7.3	6.44–6.98	0.09–0.34	0–0.59	0–0.73	0–0.94	1–31
	mean	19.2	5.95	6.67	0.19	0.09	0.14	0.23	13
Overall	Range	12.45–26.15	2.56–11.53	6.51–8.05	0–1.49	0–0.64	0–8.1	0–5.74	3.5–47.5
	mean	19.38	5.67	6.89	0.29	0.16	0.83	1.06	19.17

While *Table 2* depicts the results of the ANOVA test and Fisher's t-test employed to assess the effect of seasons and sampled stations on the variability the physicochemical parameters, respectively.

The mean water surface temperature displays a seasonal pattern and ranged from 12.45 ºC in winter (December) to 26.15 ºC in summer (August), significant variation is observed between the two stations ($p = 0.033$), as well as a significant variance is detected between seasons, as indicated by a p-value of less than 0.05 (*Table. 2*).

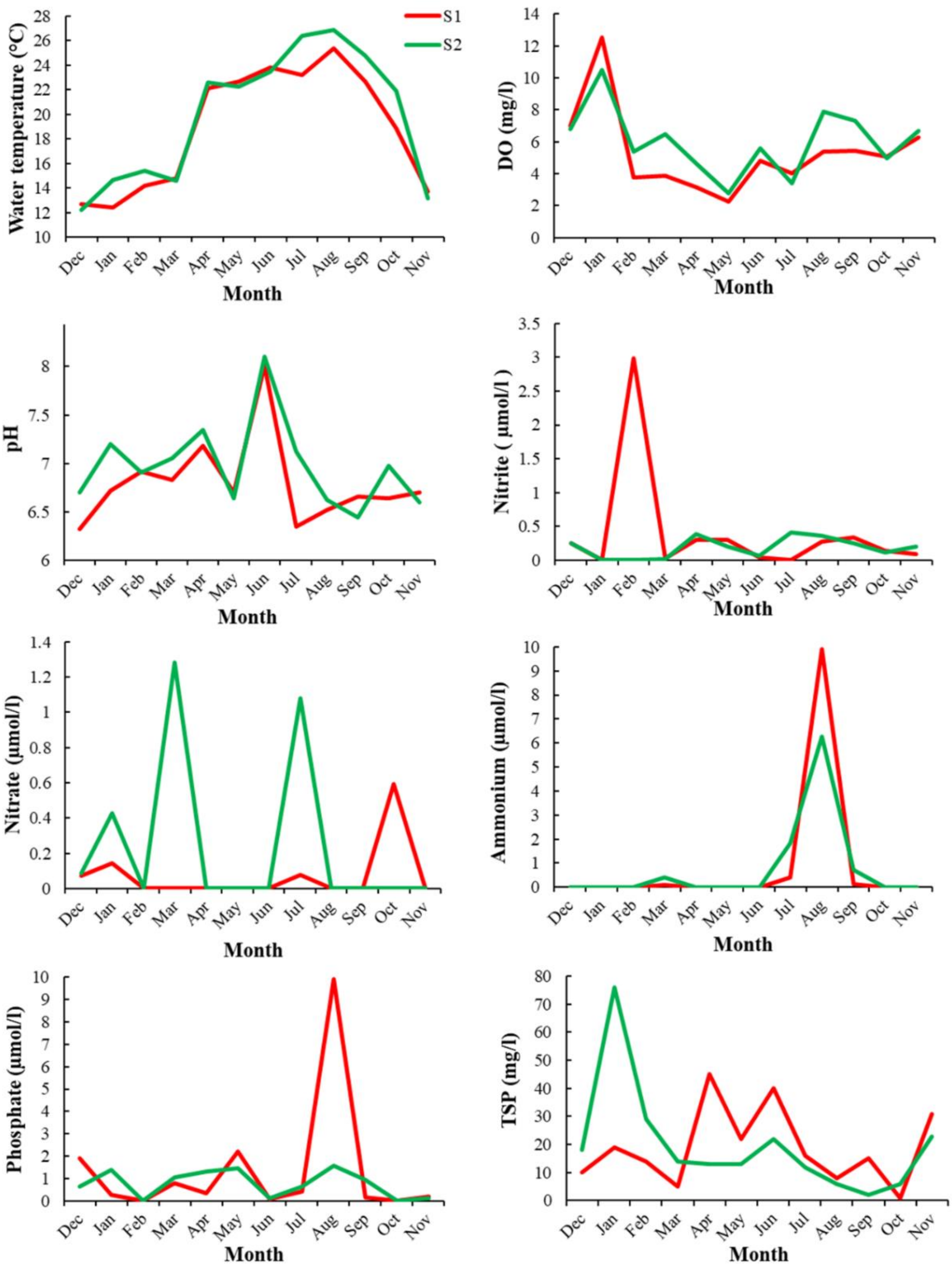

Figure 2. *Monthly variability of the measured physicochemical variables in Tonga Lake*

The average concentration of the dissolved oxygen in the water of Tonga Lake attains its maximum in January (11.53 mg/l), and the minimum is detected in May (2.53 mg/l). DO content varies significantly across seasons ($p = 0.052$), but there is no statistically significant variance between sites ($p = 0,085$).

For the remaining environmental parameters, both ANOVA test and Fisher's t-test indicated a non–significant effect for the seasons and the sampled sites ($P > 0.05$).

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Table 2. *Summary of ANOVA two-way and Fisher's t-test analyses investigating the effects of seasons and sites on the fluctuation of phytoplankton, zooplankton, and the environmental variables in Tonga Lake*

Variable	Fisher's t-test for sites variance		ANOVA test for monthly variance	
	T-value	P value	F	P value
Water temperature	-2.44	0.033	9.699	0.001
DO	-1.89	0.085	3.189	0.052
Ph	-2.24	0.047	1.008	0.415
Nitrite	0.81	0.438	0.611	0.618
Nitrate	-1.15	0.274	0.131	0.940
Ammonium	0.32	0.753	2.560	0.091
Phosphate	0.80	0.443	0.900	0.463
TSP	-0.11	0.918	0.471	3.239
Cyanobacteria	0.37	0.717	0.922	0.453
Diatoms	-0.43	0.679	6.433	0.005
Dinoflagellates	0.30	0.773	4.569	0.017
Copepods	-0.71	0.492	4.839	0.014
Cladocerans	-1.39	0.191	3.045	0.059
Rotifers	0.48	0.640	5.693	0.008
Protozoa	0.03	0.980	2.288	0.118

Regarding the mean pH of the water in Tonga Lake, the recorded values are slightly acidic for the whole study period (between 6.51 and 6.92); except for April and June, where the average values were 7.27 and 8.06, respectively.

The mean concentration of TSP ranges between 3.5 and 47.5 mg/l, with the highest concentration occurring in winter (January) and the lowest in autumn (October).

The monthly levels of nitrite do not exceed 2 µmol/l, and are generally below 0.4 µmol/l, except for in winter when a value of 1.49 µmol/l is recorded (in February).

The concentration of nitrate remains consistently low, ranging between 0.07 and 0.64 µmol/l throughout most of the study period. Similarly, ammonium concentrations remained below 2 µmol/l, except for an important concentration of 8.09 µmol/l recorded in August.

The amount of phosphate in the water surface is more important and ranges from 0.01 to 5.74 µmol/l, reaching the maxima in summer and the minima in winter, while the stock of phosphate is depleted in February, reaching 0 µmol/l.

Seasonal variability of phytoplankton and zooplankton

Figures 3 and 4 illustrate the monthly variability of phytoplankton and zooplankton, while *Table 3* depicts the seasonal average and the most frequent species for the studied groups.

According to the ANOVA test (*Table 2*), there is a seasonal effect on all phytoplankton and zooplankton groups, as indicated by the significant p-value, except for cyanobacteria and protozoa ($p = 0.453$ and 0.118, respectively). In contrast, no significant site effect was found for any of the groups studied.

During the entire study, a total of 43 phytoplankton species were recorded: 24 belonging to diatoms, 12 to cyanobacteria, and 7 to dinoflagellates. Regarding the zooplankton community, a total of 35 species were identified: 15 belonging to rotifers, 12 to cladocerans, 5 to copepods, and 3 to Protozoa.

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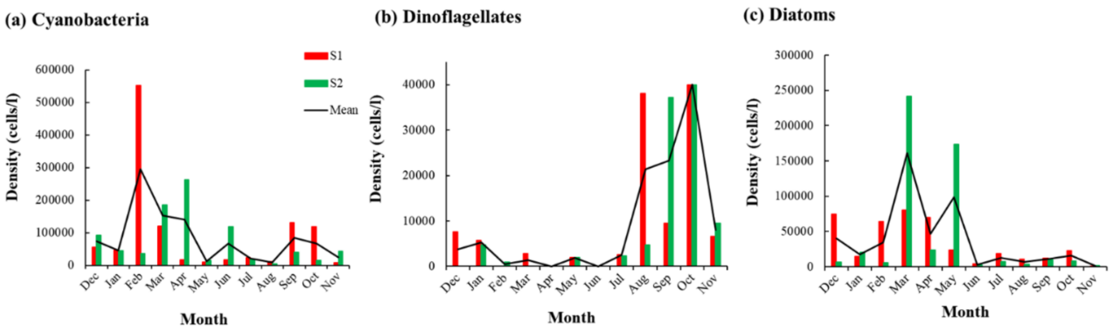

Figure 3. *Monthly variability of the phytoplankton groups in Tonga Lake*

Table 3. *Seasonal variability of phytoplankton and zooplankton densities in Tonga Lake*

Mean abundance	Winter	Spring	Summer	Autumn
Cyanobacteria(cells/l)	137888	101796	32203	59037
Most frequent taxa	*Microcystis sp.* and *Oscillatoria sp.*			
Dinoflagellates(cells/l)	3174	1111	7976	23809
Most frequent taxa	*Prorocentrum sp.*			
Diatoms(cells/l)	30787	102083	7638	9212
Most frequent taxa	*Syndrasp. Nitzschiasp. Navicula sp. Cyclotella sp.*			
Copepods (indiv/l)	1653	12246	100	348
Most frequent taxa	*Nauplii sp. Diacyclopsbicuspidatus*			
Cladocerans(indiv/l)	213	2106	125	26
Most frequent taxa	*Daphnia s. and Simocephalusvetulus*			
Rotifers (indiv/l)	820	806	25	93
Most frequent taxa	*Keratellacochlearis, Keratella quadrata, Polyarthra sp.*			
Protozoa(indiv/l)	0	100	8	0
Most frequent taxa	*Phacodinium sp.*			

Cyanobacteria are present throughout the year with high densities ranging between 8333 and 294055 cells/l; they reach their maximum at the end of winter (February), and the minimum is observed at the end of summer (August).

The dinoflagellates show minimal and convergent densities between February and June (density between 0 and 1900 cells/l) and then increase until reaching their peak in full autumn (40000 cells/l in October).

For diatoms, it is rather the opposite: the lowest densities are observed in summer and autumn (between June and November), while the maximum is observed during spring (161111 cells/l in March).

As depicted in *Figure 4*, copepods are the most abundant through the study period, and their mean density ranges from 25 to 25240 indiv/l, except for August and October, where they are absent in the samples (*Fig. 4a*). Followed by cladocerans (*Fig. 4b*) and rotiferes (*Fig. 4c*), with less important densities ranging from 80 to 4700 indiv/l and 75 to 1120 indiv/l, respectively; their minima are noticed in summer. Then come the protozoa (*Fig. 4d*), with the lowest densities that do not exceed 160 indiv/l; they are absent in June and from August to December. All the groups reach their maxima in the spring (April for the majority).

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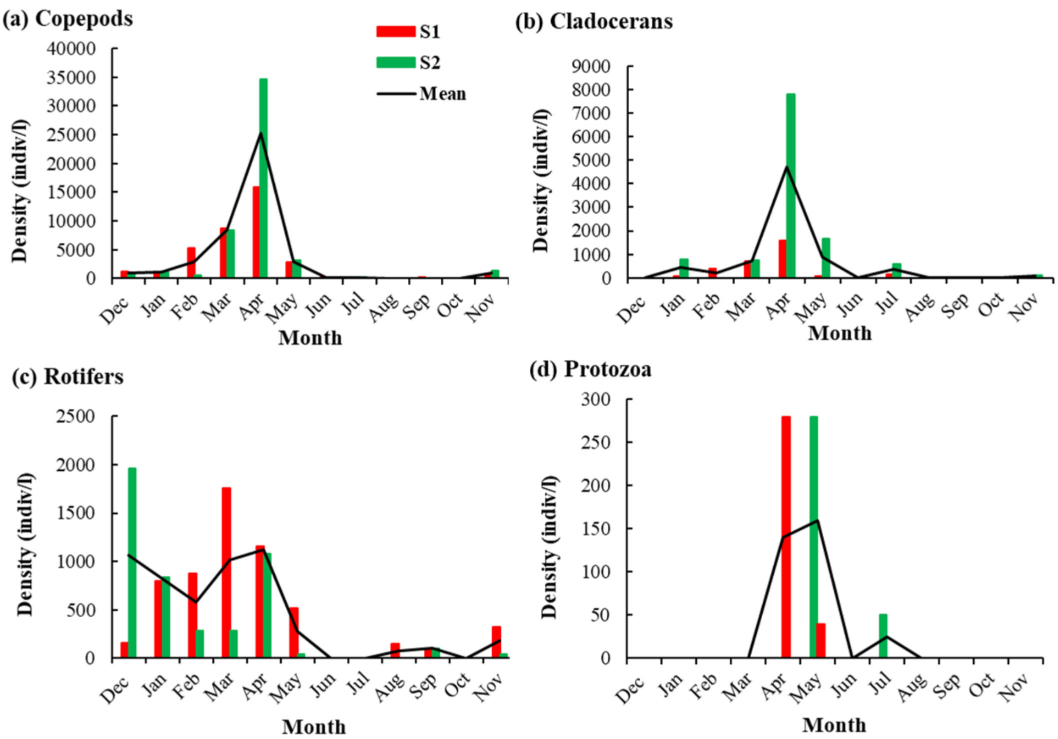

Figure 4. *Monthly variability of the zooplankton groups in Tonga Lake*

Correlation analysis between phytoplankton, zooplankton, and environmental variables

Table 4 shows the correlation between the phytoplankton, the zooplankton, and the several studied parameters.

The statistical relationships between the fluctuations in phytoplankton and zooplankton and the physicochemical environmental variables at the different sites were analyzed.

The single group of phytoplankton that shows significant correlations with the environmental variables is dinoflagellates, exhibiting a strong and negative correlation with pH ($r = -0.648$, $p < 0.05$), followed by the TSP ($r = -0.611$, $p < 0.05$).

Regarding the zooplankton community, the protozoa density displays a high negative correlation with DO ($r = -0.753$, $p < 0.05$), whereas the rotifers are found to be inversely correlated with the water temperature ($r = -0.613$, $p < 0.05$).

While none of the other correlations between cyanobacteria, diatoms, cladocerans, and environmental variables were statistically significant ($p > 0.05$).

Some groups show an association with others in different divisions. For example, diatoms show a tendency towards association with cladocerans ($r = 0.66$, $p < 0.05$), copepods ($r = 0.71$, $p < 0.05$), and Rotifers ($r = 0.70$, $p < 0.05$). The dinoflagellates in their turn are inversely correlated with copepods ($r = -0.69$, $p < 0.05$).

Other positive associations are noticed between copepods and cladocerans ($r = 0.87$, $p < 0.001$), cladocerans and Protozoa ($r = 0.69$, $p < 0.05$), and also between copepods and rotifers ($r = 0.79$, $p < 0.05$).

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Table 4. *Pearson's correlation coefficients of biological and physicochemical variables of Tonga Lake*

	Phosphate	Nitrite	Nitrate	Ammonium	DO	pH	Water temperature	TSP	Cyanobacteria	Diatoms	Dinoflagellates	Cladadocerans	Copepods	Protozoa
Phosphate	1.00													
Nitrite	0.05	1.00												
Nitrate	0.03	-0.61	1.00											
Ammonium	0.33	0.14	0.20	1.00										
DO	0.24	-0.29	0.01	0.03	1.00									
pH	-0.36	-0.34	0.12	-0.36	-0.27	1.00								
Water Temperature	0.08	0.32	-0.24	0.65	-0.38	-0.02	1.00							
TSP	-0.17	-0.18	-0.29	-0.59	0.06	0.58	-0.32	1.00						
Cyanobacteria	-0.38	0.16	0.05	-0.25	-0.07	0.33	-0.36	0.11	1.00					
Diatoms	0.37	0.08	0.34	-0.21	-0.38	0.18	-0.31	-0.01	0.41	1.00				
Dinoflagellates	0.08	-0.11	0.15	0.30	0.44	**-0.65***	0.04	**-0.61***	-0.42	-0.41	1.00			
Cladadocera	0.22	-0.01	0.13	-0.17	-0.51	0.46	-0.14	0.43	0.11	**0.66***	-0.54	1.00		
Copepods	0.13	0.07	0.01	-0.39	-0.34	0.42	-0.45	0.54	0.45	0.71	**-0.69***	**0.87****	1.00	
Protozoa	0.25	0.29	-0.10	-0.04	**-0.75****	0.13	0.33	0.18	-0.26	0.41	-0.40	0.69	0.43	1.00
Rotifers	0.39	0.18	0.00	-0.34	0.13	0.08	**-0.61***	0.33	0.50	0.70	-0.37	0.55	**0.79***	0.13

Correlation is significant (*) at the 0.05 level, and ** highly significant (**) at the 0.001 level

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Discussion

The investigated environmental parameters of Tonga Lake were analyzed and compared to the specific water quality standards for lakes, considering the permissible range devoted to category C, in which our study area is classified (Sharip and Suratman, 2017).

On the other hand, the results of the present study were compared to the investigation led in the same area by Loucif et al. (2020). It should be noted that the average considered for our study involves the whole year (2019–2020), whereas the results reported by Loucif et al. (2020). It should be noted that the average considered for our study involves the data set of the whole year (2019, 2020), while the results reported by Loucif et al. (2020), refer to a six-month survey (from January to June 2018).

With the exception of the water temperature and DO, the spatiotemporal trends of all physicochemical variables measured in Tonga Lake demonstrated non-significant variations, whether for seasonal or site factors.

The average water temperature of Tonga Lake was 19.38°C, and the mean summer temperature was above 26°C; this level of temperature usually favors the growth of phytoplankton (Dao and Bui, 2016), while causing a decline in the quantity of dissolved oxygen in the water (Akiya and Savage, 2002; Bhateriaand Jain, 2016).

In the current study, the dissolved oxygen levels were over 2 mg/l, indicating that the water is adequately oxygenated, and the ecosystem is well maintained (Hach et al., 1997). However, the average concentration observed in spring (3 mg/l) is below the range (4.5-10.3 mg/l) set by Sharip and Suratman (2017). According to Egemen (2011) the minimum DO level in continental waters must not be below 5 mg/l. Although several factors affect the amount of DO In the water (Bhat et al., 2013), the main cause of low amounts of dissolved oxygen (DO) in water could be attributed to a lack of water-atmosphere interaction, which is a common situation in poorly replenished ecosystems such as lakes (Tampo et al., 2014). Low DO concentrations are mainly the result of decomposition processes and an oxygen demand situation in the ecosystem, which can be likened to important algal activities, elevated ammonia and phosphate concentrations, or a large quantity of untreated wastewater (Blume et al., 2010; Sharifinia et al., 2013; Ngodhe et al., 2014; Ouma et al., 2016).

Nevertheless, the measured concentration is far from indicating an anaerobic state (less than 1 mg/l) (De Villers et al., 2005), and the annual average (5.67 mg/l), which slightly exceeded the minimum requirement (5 mg/l) for aquatic life (Egemen, 2011), remained more important than the amount (0.69 mg/l) reported by Loucif et al. (2020).

The oligotrophic water bodies are characterized by an acidic pH, while the eutrophic and mesotrophic waters have neutral and alkaline pH levels, respectively (Kumar et al., 2008; Soni et al., 2013). According to JORA (2011), the pH of the majority of surface waters typically ranges from 6.5 to 9 (Rodier et al., 2005). The average pH recorded in the present study is 6.98, which falls within the range (6–9) outlined by SharipandSuratman (2017) and indicates an environment that is neutral to slightly alkaline, which represents an optimum condition for fish life (Rodier et al., 2009; MutluandUncumusaoğlu, 2016). This average is convergent to the value (7.2) recorded by Loucif et al. (2000).

The turbid aspect of the water is mainly due to TSP, which had an average value of 19.17 mg/L and remains far from the limit (200 mg/L) considered by SharipandSuratman (2017). The previous study conducted in the region also conveyed a low convergent level of TSP (11.79 mg/l by Loucif et al. (2020)). These low levels of TSP could be partly

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attributed to limited phytoplankton activity and the low amount of wastewater charged by organic and inorganic particles (Sinha et al., 2002; Mariappan and Vasudevan, 2002; Ougrad et al., 2022).

Regarding nutrient concentration, the average nitrate was (0.16 µmol/L) which is insignificant compared to the threshold (112.90 µmol/l) established by SharipandSuratman (2017). The amount of nitrate remains significantly lower in comparison with the concentration (232.24 µmol/l) reported by Loucif et al. (2020).

Nitrite reached even a lower level of 0.29 µmol/l, the concentrations measured are below the limits established by SharipandSuratman (2017) and JORA (2011) (8.69 and 2.17 µmol/l, respectively). Furthermore, the amount of nitrite remained very low compared to an average of 17.82 µmol/l measured by Loucif et al. (2020).

The ammonium concentration detected is within ideal range (55.44 µmol/l) according to Sharip and Suratman (2017), with an average of 0.83 µmol/l. A higher concentration (145.24 µmol/l) was noticed by Loucif et al. (2020). This low amount of ammonium may not cause unevenness in the nitrogen cycle, increase the stock of DO, or add a significant nitrate or nitrate charge (Bousseboua, 2002; Derwich et al., 2008; Kumar et al., 2018).

In contrast to the other inorganic element, the phosphate content, with an average of 1.06 µmol/l exceeded the threshold of 0.37 µmol/l established by SharipandSuratman (2017). Nevertheless, this level is not alarming and still within the range (52.65 µmol/l) suggested by Rodier et al. (2005). On the other hand, the occurrence of eutrophication is not expected, as this low amount is insufficient to generate a massive algae proliferation (Vyas et al., 2006; Bhateria and Jain, 2016). The concentration detected remained much lower than the one (61.17 µmol/l) reported by Loucif et al. (2020).

In comparison with the results reported by Loucif et al. (2020), Tonga lake water during 2019-2020, remains more oxygenated, and presents slightly higher amount of TSP, with a convergent pH, and is characterized by lower concentrations of nutrients, those disparities could be related to the Corona virus pandemic which appears in Algeria from March 2020, consequently most of activities have been suspended, particularly the agriculture activities which is very intensified in this region that add an important supply of nutrient and organic maters coming from the pesticides and fertilizers then driven to the lake (Saadali et al., 2015). We can assume that with this break the lake found an equilibrium.

The statistical data treatment indicated that there was none significant correlation between phytoplankton groups (diatoms and cyanobacteria) and physicochemical variables, expect for dinoflagellates group, which was in significantly negative correlation with pH, which is considered the main variable influencing their abundance according to Yoo (1991). Nevertheless, those abiotic factors are complexly interconnected, and the pH requirements of phytoplankton differ from one trophic state to another (Moss, 1972). The dinoflagellates were also inversely correlated with the TSP, this result substantiates the statement of Sahu et al. (2014), indicating that increased turbidity reduces dinoflagellate abundance. In addition, suspended matters concentration is considered as one of the major parameters influencing dinoflagellate proliferation (Ge et al., 2020; Hilaluddin et al., 2020).

Significant changes in phytoplankton density have occurred during the year, notably the peak of cyanobacteria in S1 in February, associated with the highest amount of nitrite and the second lowest level of DO observed during the year (*Fig.2*).

The high concentration of nitrites suggests a substantial input of nitrogen, probably from domestic wastewater conveyed by Messida Wadi. The effect of this enrichment has

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also been observed by Abdallah et al. (2024) on the coastal part, which represents the other outlet of the same Wadi. As an intermediate in the nitrogen cycle, nitrite can be rapidly used by cyanobacteria as a source of nitrogen. Indeed, some species of cyanobacteria display particularly efficient nitrite uptake, which gives them a competitive advantage in these conditions (Flores and Herrero, 2005). On the other hand, the low concentration of dissolved oxygen implies conditions that may be favorable to certain species of cyanobacteria. Given that many cyanobacteria are able to exist in low-oxygen environments, either due to their autotrophic mode or their ability to fix atmospheric nitrogen for some species (Paerl and Otten, 2013), This combination of factors provides an environment suitable for cyanobacteria dominance, which are often more competitive than other groups under conditions of high nutrient enrichment and low oxygenation, since they can efficiently exploit these resources while tolerating oxidative stress (O'Neil et al., 2012).

Another trend in S1 was the peak in dinoflagellates in August, coinciding with high ammonium and phosphate concentrations (*Fig.2*). These high concentrations indicate a nutrient-rich environment, typical of dinoflagellates, which have the ability to proliferate, particularly when the N:P ratio is balanced (Anderson et al., 2002; Glibert et al., 2012). This high density can also be explained by higher water temperatures and a more pronounced stratification of the water column, creating optimal conditions for dinoflagellate proliferation (Hallegraeff, 2010). In addition, certain dinoflagellate species are able to migrate vertically in the water column, enabling them to access deeper, nutrient-rich layers (Smayda, 1997).

The peaks of dinoflagellates observed in both stations in September and October, could be explained by the phenomena of selective grazing, as high dinoflagellate densities are associated with low diatom densities (*Fig.3b and 3c*). While the difference in densities between the two stations in September could be attributed to the highest amount of ammonium and phosphate in S2 compared to S1 (*Fig.2*).

Regarding zooplankton groups, the protozoa depicted strong negative correlation with DO, this in concordance with previous studies that highlighted the high sensitivity of protozoa to the amount of DO in the water (Fenchel and Finlay, 2008; Fenchel, 2012).

Rotifer’s density was negatively correlated with the water temperature, the effect of water heating on seasonal changes in rotifer abundance was investigated in Gosawskie Lake, and it was demonstrated that elevated temperatures generated a minor seasonal change in rotifer abundance which was moderately slight compared to non-warming lakes (Ejsmont-Karabin and Weglenska, 1988), this can explain the significate negative correlation encountered in the present study.

While the remaining groups (cladocerans and copepods) did not exhibit any significant correlation with the environmental parameters.

Nevertheless, it should be noted that zooplankton response to changes in water quality depend on ecosystems and species diversity, and it differs between and within lakes (Ravera, 1996).

The absence of significant correlation between cyanobacteria and the zooplankton groups, could be explained by the fact that they are slightly grazed, due to their large form that make them difficult to consumed (Lampert, 1981; Infante and Abella, 1985), their low nutritional value as they are limited in nutrients (Lampert, 1981), in addition to their toxic propensity (Arnold, 1971).

The same is true for diatoms, our results do not reflect any statistically relevant relationship with zooplankton. Even though this group is considered the most grazed,

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especially the small non-colonial diatoms (Porter, 1977; Sommer et al., 1986). Similar results were reported by Elser and Goldman (1991).

Although dinoflagellates were reported as potentially inedible (Porter, 1977; Sommer et al., 1986), our results depicting a strong negative correlation with copepods are consistent with the findings of Elser (1992) and Proulx et al. (1996), who reported high grazing rates on this group, especially when it comes to relatively small species.

Conclusion

This research evaluated the biological (phytoplankton and zooplankton) and physicochemical variables in Tonga Lake during the coronavirus pandemic. The assessed parameters were within the preference standards established for lakes, with the exception of the phosphate amount, which slightly exceeded the threshold. Considering the low nutrient concentrations and the detected OD levels, the trophic status is far from eutrophication in comparison to the previously reported results. The groups that demonstrated significant correlation with the physicochemical parameters were dinoflagellates, rotifers, and protozoa. Although the results revealed a good physicochemical quality of the lake water, this ecosystem should be continually monitored in order to maintain it, preserve the associated flora and fauna, and preserve this important part of PNEK, which is labeled Ramsar.

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