The influence of environmental factors on the seasonal dynamics of the zooplankton community in the MBAK dam, Morocco

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Abstract. The MBAK dam reservoir is situated within the Nekor watershed in northeastern Morocco, characterized by a semi-arid climate. This study aimed to conduct an inventory of zooplankton communities and assess their seasonal distribution concerning environmental factors in the MBAK dam reservoir. Analysis of the frequency and relative abundance of the 16 identified species revealed considerable variations in the temporal dynamics of these organisms. Notably, crustacean taxa exhibited greater significance compared to rotifer taxa. Consequently, several indices including the Shannon-Wiener diversity index (H'), Margalef richness index (D), Pielou evenness index (J'), and density were computed to explore the structure and distribution of zooplankton over a nine-year seasonal average. The Kruskal-Wallis test confirmed the variability in physicochemical parameters (p value < 0.01) across different seasons. Furthermore, Canonical Correspondence Analysis (CCA) and correlation examinations underscored the impact of specific environmental factors - temperature, pH, dissolved oxygen, phosphorus, nitrate, water supply, and chlorophyll-*a* concentration - on shaping the zooplankton community structure.

Key Words: abundance, density, diversity index, MBAK dam reservoir, zooplankton community.

Introduction. The importance of dams lies in their pivotal function of water storage for agricultural purposes, supplying drinking water, and fostering the growth of fisheries and aquaculture (Bacha & Amara 2007; Kara 2012; Elouahli et al 2022; Machrafi et al 2022). However, water reserves in semi-arid bioclimatic regions exhibit distinctive hydrological, physicochemical, and biological traits, as highlighted by several researchers (Loudiki 1990; Cherifi & Loudiki 2002; Cherbi et al 2008).

They are affected by prolonged droughts and significant fluctuations in water inputs, which lead to an imbalance in the ecosystem as a whole (Alfaidy et al 1999; Rojo et al 2000; Sadani et al 2004). Indeed, the zooplankton population is the most sensitive component of the aquatic trophic system (Platt et al 2003; Berger et al 2010; García-Chicote et al 2018), as they are essential due to their trophic role in the functioning and dynamics of aquatic ecosystems, contributing to the transfer of energy fixed by autotrophs to higher trophic levels (Noges et al 2009).

They also serve as the primary protein source for fish and predatory invertebrates (Balvay 1990; Nogrady et al 1995; Piasecki et al 2004; Brassard 2009). Additionally, zooplankton species are recognized as sentinel organisms and pollution indicators, playing a crucial role in monitoring water quality (Ejsmont-Karabin 2012; Haberman & Haldna 2014; Neto et al 2014; Tasevska et al 2017).

Several studies highlight the significant role of crustaceans as important grazers of algae and detritus (Balayla & Moss 2004) actively contributing to nutrient recycling in aquatic ecosystems (Hudson et al 1999; Urabe et al 2002). The correlation between cladoceran composition, abundance, and the trophic status of lakes has been extensively investigated globally (Neves et al 2003; Hart 2004; De Bie et al 2008; Ganie et al 2015).

Rotifers, integral to these pelagic communities and a vital component of freshwater zooplankton, serve as an essential structural and functional element (Tasevska et al 2012). Their specific composition can effectively indicate the trophic status of reservoirs (Mäemets 1983; Bērziņš & Pejler 1989; Duggan et al 2001; Wen et al 2011).

In North Africa, research has investigated zooplankton populations in dam lakes situated in subhumid regions (Cherbi et al 2008; Brahim Errahmani et al 2015) and arid areas (Hamil et al 2021), and study by Hamaidi et al (2010) focused on zooplankton in five dam lakes. Similarly, another study conducted by Smaoune et al (2021) focuses on the trophic status of three dams in the north west of Algeria. On the other hand, Bidi-Akli et al (2014) delved into examining the temporal dynamics of zooplankton, analyzing the impacts of both biotic and abiotic factors on their populations. In Morocco, despite limited available research data, a few hydrological investigations have explored zooplankton in reservoir lakes, including the Yacoub El Mansour reservoir (Chakir & Saadi 2018), Lalla Takerkoust Reservoir (Pourriot et al 1994), Hassan I Reservoir (Benzekri 1992), El Kansra Reservoir (Fqih Berrada et al 2000; Elouahli et al 2022), Mansour Eddahbi Reservoir (Sadani et al 2004), as well as Zima and Sedd-El-Messjoun (Saadi 1985; Saadi & Champeau 1987, 1994).

This study represents the first comprehensive examination of zooplankton's temporal dynamics over a significant period from 2006 to 2015 in the MBAK dam. It involves an analysis of diverse ecological indices related to this community. The aim is to identify trends in species abundance and assess the sequential seasonal influence of environmental factors on the structure and temporal distribution of the zooplankton community in the MBAK dam.

Material and Method

Study area. The MBAK dam was commissioned in 1981, covering an area of 3.86 km^2 with a storage capacity of 43.3 Mm^3. It lies within the Nekor watershed in northeastern Morocco, specifically in the eastern region of the Rif Mountains (35°05’06’’N, 3°36’04’’ W). This reservoir serves as the exclusive water source for the city of Al Hoceima and adjacent urban areas such as Imzouren and Beni Bouayach (Figure 1). The climate in this area typically exhibits Mediterranean characteristics with a semi-arid tendency, marked by cold and wet winter and hot, dry summer. The average annual rainfall within the basin is approximately 340 mm (Machrafi et al 2022). The water flow pattern of the primary tributary (Oued Nekor) is intermittent, experiencing fewer than ten floods per year (Dimane et al 2017).

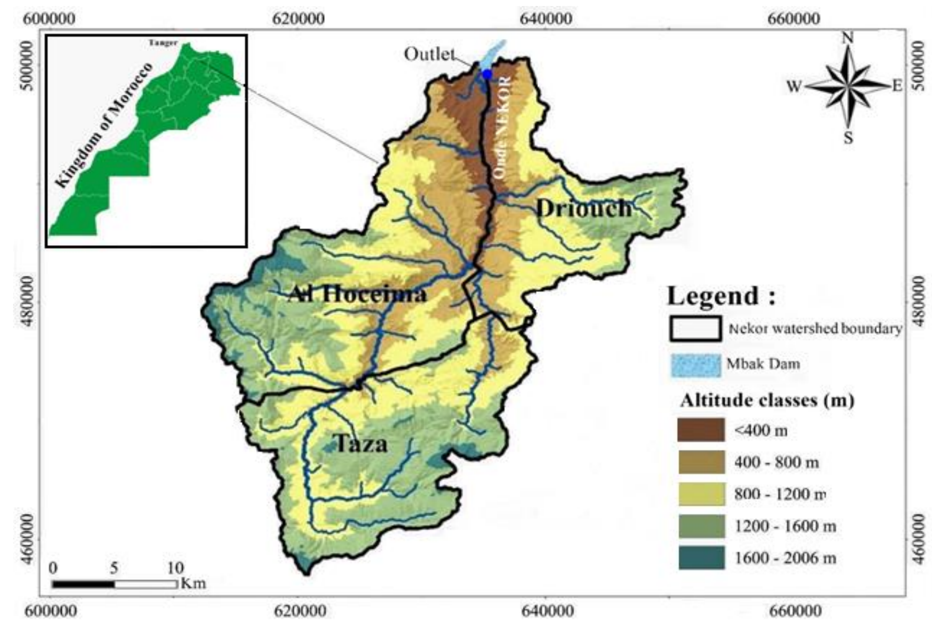

Figure 1. Geographical location of the Mohamed Ben Abdelkrim Al Khattabi (MBAK) dam.

Sampling*.* The study's temporal sampling extends from March 2006 to September 2015. Within the water column, samples were obtained both horizontally at the dam outlet (Figure 1), covering the water surface, and vertically at a depth of 15 meters. Zooplankton samples were specifically gathered from the water's surface at the same location. Consequently, the sample size comprises approximately 82 observations.

At the specified sites, water samples were collected using clean 1-liter polyethylene bottles. These samples were then transported to the ONEP laboratory at a temperature of 4°C for analysis of chemical components (such as dissolved oxygen, phosphorus and nitrate) and biological parameters (including chlorophyll-*a* extraction), as detailed by Rodier et al (2009). Conversely, physical parameters such as temperature (T°C), pH, electrical conductivity (EC) and water transparency were measured directly on site (Table 1).

Table 1

Methods and technique used in the physical-chemical parameters

Measurements	*Parameter*	*Method or technique*
In situ	Temperature (°C)	Thermometer
	pH	pH Philips 4014
	EC	EC Philips 4025 counter
	Trans	Secchi disk
Laboratory	DO)	Nitrogen method in modification of the Winkler method
	TP	Colorimetric (after mineralization of persulfate in an acid environment)
	Nitrate (NO^{3-})	Colorimetry
	Chl-*a* extraction	Using 80% acetone extraction procedure, which was determined at 663 and 645 nm
	TSM	ASTM D3977
	Turb	Turbidimeter HACH 2100 AN ORCHIDIS

Notes: EC = electrical conductivity; Trans = transparency; DO – dissolved oxygen; TP = total phosphate; TSM = total suspended matter; Turb = turbidity.

For the zooplankton study, surface samples (horizontal sampling) were taken with a planktonic vacuum net with a mesh size of 100 μm. Each sample was preserved in 4% formalin, then observed for identification (specific composition) and counting. microscopic analyses were carried out using an inverted microscope using keys developed by Elliott & Ruttner-Kolisko (1976), Koste & Voigt (1978), Segers (1995) for Rotifera; Flößner (1972), Negrea (1983) for Cladocera; Einsle (1996), Dussart & Defaye (1995) for Copepoda. The quantitative samples of zooplankton are added to the filtered freshwater suspension to a volume of 10 mL. A random 1 mL portion of the concentrated sample was extracted after thorough mixing and subjected to analysis in a Sedgewick-Rafter chamber using an inverted microscope (Zeiss-Winkel).

Relative abundance, species richness, occurrence frequencies, and diversity indices such as Shannon-Weaver (H'), Pielou (J'), density, and Margalef (D) were computed following the methodologies outlined in the works of Barbault (1992), Ramade (2003), Boulinier et al (1998) and Margalef (1961). The percentage of relative frequency and relative abundance was calculated following the methodology outlined by Willen (2008). The Shannon index H' reaches its minimum value when it equals zero, indicating a scenario with only one species present in the sampling, and attains its maximum (theoretically incomplete) value when all individuals belong to different species.

Zooplankton diversity can be indicated by the Shannon-Wiener index (H’):

$$H' = -\sum_{i=1}^{S} p_i \ln p_i$$

where: S is the number of zooplankton species and pi is the ratio of the density of species i to the total density (Lam et al 2014).

Absolute abundance represents the number of individuals of a species harvested from a given collection or population present per unit area or volume (Ramade 2003). Relative abundance, also called dominance, represents the abundance of a species in relation to the total abundance of individuals of all species caught; it is calculated by the following formula:

$$pi = (ni/N) * 100$$

where: pi is the dominance of species i, ni is the number of individuals of species i, and N is the total number of individuals of all species.

The relative frequency is the total number of samples where the species is present, in relation to the total number of samples taken. Frequency is expressed as a percentage:

$$F (\%) = (pi/p) * 100$$

where: pi is the number of samples where species "i" exists, and p is the total number of samples taken.

The Pielou equitability index is represented by the ratio of H' to the theoretical maximum index in the stand (Hmax), it is quoted by Çinar et al (2012) and given by the following formula:

$$J' = H' / Hmax = H'/log2 (S)$$

where: H' is the observed specific diversity (the Shannon-Weaver index) and Hmax is the logarithm of the total number of species (S) in the sample.

The Margalef index is used to estimate absolute specific wealth regardless of sample size (Margalef 1961);

$$D = S -1/ \ln (N)$$

where: N is the number of individuals and S is the total number of species.

Statistical analyses. Statistical tests were applied on the datasets of physicochemical and biological parameters obtained during the study period from the dam impoundment grouped by season and presented as mean values. Spearman's bivariate correlation test was used to describe the relationship between abiotic and biotic factors. Differences in water physicochemical parameters between seasons were investigated using the Kruskal-Wallis test at a 5% significance level.

A canonical correspondence analysis (CCA) was performed to explain the relationship between the identified species and physicochemical parameters. The analyses were performed using XLSTAT (version 2020). CCA was used to explore relationships between abundance of taxonomic groups and physical and chemical variables (ter Braak & Šmilauer 2002).

Results and Discussion

Physicochemical parameters. The physicochemical data measured during the study period reflect a temporal variation of all parameters, as confirmed by the Kruskal-Wallis test (p value < 0.05) between seasons.

A thermal difference is observed, the water temperature varied from 13.30°C in winter to 31.6°C in summer with a temperature close to 20°C during the other seasons. Dissolved oxygen levels ranged from 1.5 mg L^{-1} in spring to 12 mg L^{-1} in winter, with intermediate values (near 7.2 mg L^{-1}) noted in summer and autumn. The water was alkaline and pH values ranged from 7.88 (in winter) to 8.46 also in winter, and were close to 8.27 and 8.02 respectively during summer and autumn (Table 2).

The electrical conductivity (EC) values ranged from 21 to 226.11 µS cm^{-1}, except high values of the order of 1233 µS cm^{-1} recorded in spring. The seasonal average levels of chlorophyll-*a* were high during winter, and decreased from the mean value of 3.73 µg L^{-1} in winter to the mean value of 1.90 µg L^{-1} in autumn, and the averages did not show much difference between summer and spring.

Table 2

Distribution of water physicochemical parameter values for the MBAK dam reservoir by season over the period 2006-2015

Parameters	*Spring*				*Summer*				*Autumn*				*Winter*			
	Min	*Max*	*Mean*	*σ*	*Min*	*Max*	*Mean*	*σ*	*Min*	*Max*	*Mean*	*σ*	*Min*	*Max*	*Mean*	*σ*
Temp (°C)	13.30	25.00	19.80	3.40	25.00	31.60	26.99	1.91	14.90	25.80	20.35	5.45	14.10	28.90	18.59	4.85
EC (μs cm^{-1})	21.00	1233.00	266.11	353.92	23.00	271.00	133.78	101.64	137.00	237.00	187.00	50.00	29.00	267.00	187.89	71.54
pH	8.10	8.35	8.26	0.09	7.99	8.70	8.27	0.19	7.95	8.10	8.02	0.075	7.88	8.46	8.22	0.17
DO (mg L^{-1})	1.50	11.00	7.53	2.44	5.00	8.40	7.04	1.20	7.20	7.70	7.45	0.250	5.00	12.00	7.97	1.85
TSM	3.40	31.00	10.99	7.84	4.00	20.00	11.44	5.07	4.30	25.00	14.65	10.35	6.00	27.00	13.83	5.73
TP (mg L^{-1})	0.12	2.70	0.89	0.87	0.18	0.68	0.42	0.21	0.32	0.52	0.42	0.10	0.14	0.90	0.47	0.25
NO^{3-} (mg L^{-1})	0.83	5.24	2.53	1.39	0.25	5.36	2.35	1.84	2.74	5.00	3.87	1.13	0.53	7.24	2.57	2.34
Turb (NTU)	5.00	31.00	14.47	7.16	1.00	17.00	8.86	4.28	3.30	11.00	7.15	3.85	13.00	45.00	23.11	11.08
Chl-*a* (mg L^{-1})	1.00	3.50	2.44	0.81	0.95	3.30	2.24	0.72	0.90	2.90	1.90	1.00	1.40	7.00	3.73	1.86
FR (%)	32.38	98.47	63.74	27.08	18.90	89.30	53.33	24.01	40.00	94.85	69.25	17.62	36.50	100.00	73.81	25.18

Note: Temp = water temperature; EC = electrical conductivity; DO = dissolved oxygen; TSM = total suspended matter; TP = total phosphorus; NO^{3-}= nitrates; Turb = turbidity; Chl-*a* = chlorophyll-*a*; FR = filling rate; σ = standard deviation.

Nitrate concentrations vary from 0.25 µm L^{-1} in summer to 7.24 µm L^{-1} in autumn, with lower values in spring and intermediate values in winter. The minimum concentration of total phosphorus is 0.12 in spring. Also, the high concentration was recorded in the same season in the order of 2.7 µm L^{-1}.

The average variation of turbidity is marked by the value 23.1 NTU in winter which can reach a maximum value of 45 NTU, otherwise a large difference is recorded between autumn (7.15 NTU) and spring (14.47 NTU). The seasonal variation of turbidity is similar to that of chlorophyll-*a*.

The extreme levels of suspended matter were recorded during spring (3.40 µm L^{-1}), although its seasonal average is the lowest, however the important values were measured in autumn (14.65 µm L^{-1}) and winter (13.83 µm L^{-1}).

The seasonal variations of physicochemical parameters observed during this study indicate the existence of particular characteristics in the dam's reservoir in the distribution of the zooplankton community with a dominant contribution of abiotic factors (Cherbi et al 2008).

The evolution of temperature is variable with time, which was influenced by the difference in water inputs, and air temperature, especially by radiative transfers received from the sun and the atmosphere (Westhoff et al 2007; Rodier et al 2009). The high temperatures resulted in a sharp decrease in dissolved oxygen and a decrease in pH.

The dissolved oxygen levels recorded are above the lower limit of survival and protection of all living organisms (Lapointe & Ryther 1978). Nevertheless, levels of 11 and 12 mg L^{-1} have been observed and particularized by times in which sedimentation and deposition of organic matter are probably favored (Djezzar et al 2021).

The presence in excess of nitrates and phosphorus can result in a significant development of phytoplankton, inducing eutrophication of the environment (Gómez et al 2014). Moreover, the recorded maximum nitrate levels can be explained, on one hand, by nitrification because the environment is well-oxygenated, and on the other hand, by an exogenous allochthonous contribution from runoff in the watershed and agricultural activities practiced around in mediterranean-climate lakes (Cherbi et al 2008).

However, the availability of phosphorus is mainly determined by the internal sediment load of this element and that its mobility depends on the redox potential. In addition, the elevated turbidity observed can be attributed to substantial algal growth, particularly at semi-arid bioclimate (Fqih Berrada et al 2000).

Structure of the zooplankton population. The analysis of the zooplankton populations of the MBAK dam allows us to describe the specific composition and distribution of the zooplankton community. Over a nine-year sampling period, 16 zooplankton taxa were identified, comprising eight crustacean species groups and eight rotifer species. The distribution of zooplankton exhibits temporal variations, with peak specific richness observed in summer (SR = 14), consisting of eight crustacean species and seven rotifer species, and lower richness in fall (SR = 5), involving four crustacean species and a solitary rotifer species (Table 3).

Generally, crustaceans are consistently present throughout the year, except for a few taxa absent in autumn and winter. In contrast, rotifers are less abundant in spring and summer and exhibit reduced presence in autumn and winter. Overall, crustaceans emerge as the predominant group within this dam's zooplankton community.

On the number of individuals, the dominant rotifer taxa are *Asplancha* sp. in spring and winter, *Keratella cochlearis* in summer and a total dominance of *Polyarthra* sp. in autumn. Otherwise, the dominant crustacean taxa are *Bosmina* sp. and *Acanthocyclops* sp. in spring; *Ceriodaphnia* sp., copepods and *Daphnia* sp. in autumn; *Ceriodaphnia* sp. and copepods in winter with a significant dominance of *Ceriodaphnia* sp. in summer.

The dominance of the taxa *Bosmina* sp. and *Acanthocyclops* sp. in the spring period could be explained by its temperature preferences (Aoujdad et al 2014). In addition, these species are thermophobic and their frequency of presence decreases in winter due to low temperatures (Balkhi & Yousuf 1996; Karuthapandi & Rao 2016).

Contrary to our results, in the semi-arid zone, Feniova et al (2019) reported the predominance of *Bosmina* sp. and *Diaphanosoma* sp.

The level of abundance of the observed taxa is related to their level of constancy. Ubiquitous taxa are most abundant when secondary taxa are less abundant (Table 3) (Cherbi et al 2008).

Table 3

List of zooplankton species collected from MBAK dam

Crustaceans	*Spring*		*Summer*		*Autumn*		*Winter*	
	RF	*RA*	*RF*	*RA*	*RF*	*RA*	*RF*	*RA*
Acanthocyclops sp.	C	+++	C	++	A	+++	F	+
Bosmina sp.	F	+++	O	+	--	--	R	+
Calanoides sp.	R	++	O	++	--	--	--	--
Ceriodaphnia sp.	C	++	F	+++	A	+++	F	+++
Copepod, nauplius	A	+	C	+	A	+++	C	+++
Daphnia sp.	A	+	F	+	F	+++	F	++
Diaphanosoma sp.	O	+	R	+	--	--	--	--
Neolovenula alluaudi	--	--	R	+	--	--	R	+
	SR (07)		SR (08)		SR (04)		SR (06)	
Rotifers	*Spring*		*Summer*		*Autumn*		*Winter*	
	RF	*RA*	*RF*	*RA*	*RF*	*RA*	*RF*	*RA*
Asplanchna sp.	R	+++	--	--	--	--	O	+++
Brachionus sp.	O	++	O	+++	--	--	--	--
Conochilus sp.	--	--	R	--	--	--	--	--
Hexarthra sp.	O	++	R	++	--	--	--	--
Keratella cochlearis	O	+	O	+++	--	--	--	--
Keratella quadrata	R	++	R	+	--	--	--	--
Keratella valga	O	++	R	+	--	--	O	+++
Polyarthra sp.	--	--	R	++	F	+++	O	+++
	SR (06)		SR (06)		SR (01)		SR (03)	

RF = relative frequency: A - abundant with RF = 81-100%, C - common with RF = 61-80%, F - frequent with RF = 41-60%, O - occasional with RF = 21-40%, R - rare with RF = 0-20%; RA = relative abundance: +++ with RA > 21%, ++ with RA = 11-20%, + with RA = 1-10%; SR = species richness.

Temporal variation in specific richness can be explained by nutritional and reproductive variability and variability in abiotic environmental parameters. The rotifer species are concentrated in different areas and thus present variations in their horizontal and vertical distribution (Pouriot et al 1997). The simultaneous presence of the genus *Brachionus* with a high abundance is a good indication of the eutrophic nature of an aquatic system (Hamil et al 2021). Another study found high species diversity in areas with high levels of eutrophication (Hamil et al 2021). This corroborates the results of our study.

The results of the diversity (Shannon-Wiener H'), richness (Margalef D), evenness (Pielou J) and biomass indices of four seasons of the MBAK Dam reservoir are presented in Figure 2.

The total mean values of the H' index for rotifers (1.78, 1.43, 1.20, and 0) and crustaceans (1.78, 1.47, 1.63, and 1.38) correspond to spring, summer, winter, and autumn, respectively However, the total values of Margalef richness (D) for rotifers (1.17, 0.95, 0.72, and 0) and crustaceans (0.79, 0.90, 0.89, and 0.53) were specified for each season. The mean Pielou's evenness (J') values for rotifers (0.91, 0.73, 0.61, and 0) and crustaceans (0.85, 0.70, 0.78, and 0.66) correspond to spring, summer, winter, and autumn, respectively. The average total biomasses of rotifers on the same order are 205, 2654, 289 and 522 ind L^{-1} and of crustaceans are 3334, 11007, 1608 and 2438 ind L^{-1} (Figure 2).

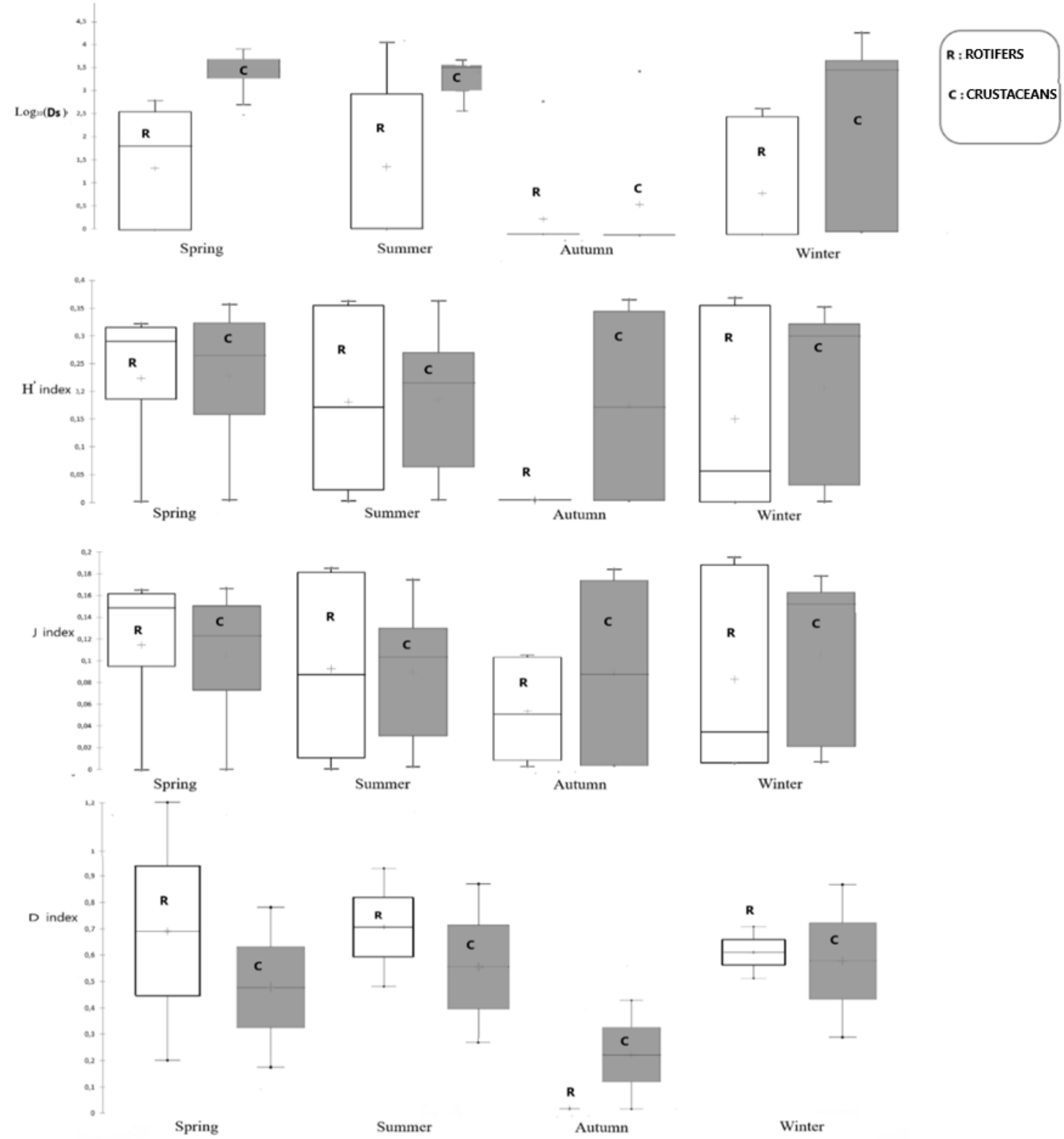

Figure 2. Box plots of seasonal variations of calculated diversity indices and zooplankton density.

Throughout the study period, the Shannon index and Pielou equitability revealed significant seasonal fluctuations in rotifers and crustaceans. These results highlight a pronounced instability in community structure.

The rotifer's diversity index peaks during spring and summer indicate a well-distributed population among various species. Conversely, the recorded value in winter proves a temporary absence of specific taxa (*Brachionus* sp., *Conochilus* sp., *Hexarthra* sp., *K. cochlearis* and *K. quadrata*). Notably, during autumn, the index hits a null value, signifying a lack of population diversity in this study period. This observation aligns with the equitability index (J’), revealing an environmental imbalance and uneven distribution of taxa throughout the year.

The low regularity value of rotifers recorded in winter is due to the high relative abundance of *Asplanchna* sp. and *Polyarthra* sp., as previously reported by Brahimm Errahmani et al (2015). On the other hand, crustaceans are recorded in autumn, which is explained by a codominance of the collected taxa (*Acanthocyclops* sp., *Ceriodaphnia* sp., copepod and *Daphnia* sp.) which agree with the results of previous studies such as the one carried out at Lake Oubeira (Sehili et al 2020).

A difference in the Shannon index between the sampling periods (spring and winter) is observed in the order of 0.58 for rotifers and 0.15 for crustaceans, which indicates that the community structure is not affected by the quality of the environment but varies according to the change in physicochemical parameters between seasons, knowing that the dynamics of crustaceans is more sensitive than that of rotifers to this change (Milan et al 2017; Tran et al 2023).

However, the low values of the diversity indices during autumn and winter were explained by a small number of species collected from rotifers. We note that the Pielou index oscillates with the temporary evolution. In spring, the crustacean and rotifer population are in equilibrium (J' > 0.8), however in summer and winter, the crustacean index is between 0.65 and 0.8, which shows that the population is in slight disequilibrium, contrary to rotifers which are in disequilibrium in winter. Indeed, high values were recorded in spring and summer, reflecting an equitable distribution of taxa. Conversely, in autumn and winter, the observed patterns are explained by the presence of certain predominant taxa that thrive under the prevailing environmental conditions, which favor the development of these zooplankton and lead to their high relative abundance (Devaraju 2015). Our results are consistent with those of Tasevska et al (2017).

The very high density of crustaceans in spring explains the low value of the Margalef D index, which is in agreement with the study of Smaoune et al (2021) and contrary to what has been observed in Asia (Qian et al 2007; Chen et al 2012 ; Wen et al 2017), which showed that eutrophication can reduce species diversity and evenness. According to García-Chicote et al (2019), the composition of zooplankton in reservoirs with high trophic status can be best explained by the presence of a few species adapted to stressful environments.

The seasonal proportions of the other rotifer taxa vary in the following order: autumn < winter < spring < summer. Simple linear correlations between abiotic and biotic variables are presented in Table 4. *Acanthocyclops* sp. correlated positively with nitrate and electrical conductivity ($p < 0.05$), and negatively with pH, dissolved oxygen and turbidity ($p < 0.0001$). Conversely, *Bosmina* sp. shows a negative correlation with dissolved oxygen, electrical conductivity and temperature ($p < 0.0001$), but positively with turbidity. *Calanoides* sp. shows a negative correlation with pH, dissolved oxygen and total phosphate ($p < 0.0001$) and positively correlated with *Bosmina* sp. ($p < 0.05$). Copepods correlated negatively with temperature, suspended matter and chlorophyll-*a* ($p < 0.0001$). The taxon *Diaphanosoma* sp. was positively correlated with pH, nitrate and turbidity ($p < 0.05$) and negatively correlated with suspended matter and *Calanoides* sp. and *Ceriodaphnia* sp. ($p < 0.0001$).

N. alluaudi was strongly negatively correlated with total phosphorus, chlorophyll-*a*, and particularly with the taxa *K. cochlearis* and *K. valga*. Thus, *Asplanchna* sp. was negatively correlated with pH, dissolved oxygen and mainly total phosphorus ($p < 0.0001$), while it was positively correlated with the taxa *Bosmina* sp., *Ceriodaphnia* sp. and *Daphnia* sp. ($p < 0.05$). *Brachionus* sp. was negatively correlated with electrical conductivity and *Daphnia* sp.. Otherwise, Hexarthra sp. was negatively correlated with *Ceriodaphnia* sp. and *Daphnia* sp. , unlike *Acanthocyclops* sp. ($p < 0.05$). The behavior of species of the genus *Keratella* is different in the MBAK dam, we find that *K. cochlearis* was negatively correlated with nitrate, chlorophyll-*a* and with two taxa, namely *Ceriodaphnia* sp. and *Daphnia* sp.. In addition, *K. quadrata* was negatively correlated with nitrate, total phosphorus, *Daphnia* sp. and *Hexarthra* sp.. Then, *K. valga* was negatively related with temperature, electrical conductivity, dissolved oxygen, suspended matter and *K. quadrata* ($p < 0.0001$). Polyarthra sp. was positively correlated with chlorophyll-*a* and with *K. cochlearis* ($p < 0.05$) and negatively with temperature and with *Bosmina* sp. ($p < 0.0001$).

We can say that some ecological parameters are responsible for the distribution of the zooplankton community, namely temperature, pH, water supply, dissolved oxygen, phosphorus and nitrate. Most taxa show a preference for mineralized waters rich in organic matter and eutrophic.

The results obtained (Figure 3A) allow a first typological approach of the different variables according to their affinities on the first three axes, comprising 36.55% of the total information (16.03% for axis 1, 12.59% for axis 2 and 7.92% for axis 3). In the canonical correspondence analysis CCA, three axes were selected (axis 1, axis 2 and axis 3). A large part (72.26%) of the total variation of the zooplankton community is explained by abiotic and biotic factors, and which showed a strong relationship between the community and environmental variables (Figure 3B).

The first factorial axis (F1) explained (32.44%) of the species-environment variance and represents a gradient of eutrophication, this axis was strongly associated with the taxa *Bosmina* sp., *Diaphanosoma* sp. and *Hexarthra* sp., phosphorus concentration and temperature which are negatively correlated, in contrast to electrical conductivity which is positively associated with this axis. Bosmina sp. was considered as an indicator of the eutrophication process (García-Chicote et al 2019), and this reinforces the existence of a strong correlation of this taxon with high trophic status in our analysis, contrary to what was shown that *Diaphanosoma* sp. is able to survive in lakes with high cyanobacteria density (Kerfoot & Kirk 1991) and in environments with high solids content (Dejen et al 2004). It is also noted that phosphorus is negatively correlated with oxygen, nitrate, conductivity and pH, but positively correlated with water temperature. The taxa *Bosmina* sp., *Diaphanosoma* sp. and *Hexarthra* sp. were associated with high phosphorus concentration, while the taxa *Ceriodaphnia* sp., *Polyarthra* sp., *Daphnia* sp. and *N. alluaudi* were associated with high dissolved oxygen, nitrate and high turbidity.

The second axis presents 21.87% of the total variance which mainly represents a gradient of seasonality with an enrichment of nitrogenous element during the wet period. The taxa *Ceriodaphnia* sp., *Polyarthra* sp., *Daphnia* sp. and *N. alluaudi* show a preference for the wet season that are positively correlated to this axis. Their distribution is due to the high value of nitrate, high oxygen content and high turbidity during winter accompanied by a high-water supply. Indeed, in winter, the abundance of aquatic invertebrates is linked to the rise in water level of dams, which leads to the submergence of littoral zones favoring the distribution of nutrients and the hatching of eggs at rest (Dejen et al 2004; Mergeay et al 2007), and that this hydrological regime and water dynamics are known by their actions in the ventilation and oxygen dissolution processes (Sadani et al 2004; Rossetti et al 2009). The taxa *K. quadrata*, *Asplanchna* sp. and *Calanoides* sp. require an alkaline environment, rich in suspended matter and medium conductivity that oppose with the copepod taxa; in addition, of these common taxa *K. cochlearis* and *Brachionus* sp. have a wide tolerance for the interaction of these environmental parameters. Otherwise, the taxa *Brachionus* sp., *K. cochlearis*, *K. valga* and copepods prefer high temperatures and high chlorophyll-*a* values.

According to Sehili et al (2020), *Brachionus* sp. is a summer species and prefers alkaline waters and warm temperatures. Indeed, temperature is considered a limiting factor for the development of these taxa (Romanovsky & Ghilarov 1996). *K. quadrata* has a wide geographic distribution in eutrophic and thermophilic areas (Balvay 1989). Reynolds (2000) considered this species to be tolerant to a wide range of temperature and mineralization conditions.

In the CCA ordination diagram, the rotifer *Conochilus* sp. has a purely summer distribution with an alkaline environment, high temperature and low nitrate. The third axis shows that the taxa *Acanthocyclops* sp., *Daphnia* sp. and *Polyarthra* sp. are negatively correlated, and positively for *Neolovenula alluvium*, indicating a wide tolerance to suspended matter, turbidity, chlorophyll-*a*, which condition the distribution of these taxa. García-Chicote et al (2018) consider *Polyarthra* sp. as an indicator of mesotrophic system and Lodi et al (2011) consider it as an indicator for oligotrophic and eutrophic systems.

Table 4

Multiple correlation matrix of physicochemical parameters and zooplankton species

Variables	*Temp*	*EC*	*pH*	*Water (FR)*	*DO*	*SM*	*TP*	*Nitrate*	*Turb*	*Chl (a)*	*Aca*	*Bos*	*Cal*	*Cer*	*Cop*	*Dap*	*Dia*	*Neo*	*Asp*	*Bra*	*Con*	*Hex*	*Ker coc*	*Ker qua*	*Ker val*	*Pol*
Temp	1																									
EC	<.00	1																								
pH	<.00	<.00	1																							
Water	-	0.30	<.00	1																						
DO	-	<.00	-	0.305	1																					
SM	<.00	0.35	<.00	0.165	<.00	1																				
TP	<.00	<.00	0.322	<.0001	<.00	-	1																			
Nitrate	0.017	0.05	-	0.538	0.28	<.00	<.00	1																		
Turb	<.00	0.09	0.022	0.172	0.13	0.05	0.05	<.00	1																	
Chl(a)	-	0.03	0.255	<.0001	0.00	0.29	<.00	<.00	0.05	1																
Aca	0.287	0.04	<.00	<.0001	<.00	<.00	-	0.02	<.00	<.00	1															
Bos	0.054	<.00	<.00	<.0001	<.00	<.00	0.21	<.00	0.28	0.13	-	1														
Cal	<.00	0.05	<.00	<.0001	<.00	-	<.00	<.00	-	<.00	<.00	0.03	1													
Cer	<.00	0.29	<.00	0.408	0.36	0.07	<.00	0.51	<.00	<.00	0.111	<.00	<.00	1												
Cop	-	0.19	0.003	0.089	0.10	<.00	0.30	0.13	0.07	-	0.257	0.06	0.02	0.14	1											
Dap	<.00	<.00	-	0.168	0.11	<.00	<.00	0.48	-	0.05	0.402	-	-	0.45	0.20	1										
Dia	0.104	<.00	0.020	<.0001	<.00	<.00	0.44	0.00	0.04	-	0.234	0.34	-	<.00	0.48	0.04	1									
Neo	0.035	<.00	<.00	0.296	0.33	<.00	<.00	0.34	0.12	<.00	<.00	<.00	<.00	0.36	<.00	0.08	<.00	1								
Asp	<.00	0.38	<.00	0.017	<.00	0.24	<.00	<.00	0.28	0.14	-	0.05	<.00	0.02	<.00	0.03	<.00	<.00	1							
Bra	0.134	<.00	0.110	<.0001	<.00	<.00	0.48	<.00	0.15	<.00	<.00	0.24	<.00	<.00	0.19	<.00	0.48	<.00	<.00	1						
Con	0.249	<.00	0.000	<.0001	0.20	<.00	0.16	<.00	0.01	<.00	0.092	<.00	<.00	<.00	0.27	<.00	0.51	<.00	<.00	0.4	1					
Hex	0.103	<.00	-	<.0001	<.00	<.00	0.30	0.20	<.00	<.00	0.049	0.33	0.23	<.00	0.37	0.14	0.65	<.00	<.00	0.1	<.00	1				
Ker coc	0.217	<.0001	0.093	<.0001	<.0001	<.0001	0.244	<.0001	0.175	<.0001	0.019	0.320	<.0001	<.0001	0.054	<.0001	0.327	<.0001	0.086	0.813	0.303	0.086	1			
Ker qua	0.033	0.065	<.0001	<.0001	0.204	<.0001	<.0001	<.0001	<.0001	0.041	<.0001	<.0001	<.0001	<.0001	0.188	<.0001	0.323	<.0001	0.354	0.258	0.694	<.0001	0.149	1		
Ker val	0.031	<.0001	0.227	0.022	<.0001	<.0001	0.058	0.209	0.215	0.060	0.101	0.459	<.0001	<.0001	0.187	0.079	0.440	<.0001	0.077	0.068	<.0001	0.420	0.318	<.0001	1	
Pol	<.0001	<.0001	<.0001	0.010	0.333	<.0001	0.089	0.123	<.0001	0.022	0.143	<.0001	<.0001	0.193	0.275	0.263	0.158	<.0001	<.0001	0.100	0.452	<.0001	0.001	0.271	0.094	1

Note: Temp = water temperature; DO = dissolved oxygen; TSM = total suspended matter; Chl(*a*) - chlorophyll-*a*; EC = electrical conductivity; N = nitrate; TP = total phosphorus; Turb = turbidity; Aca = *Acanthocyclops* sp.; Bos = *Bosmina* sp.; Cal = *Calanoides* sp.; Cer = *Ceriodaphnia* sp.; Cop = copepodes; Dap = *Daphnia* sp.; Dia = *Diaphanosoma* sp.; Neo = *Neolovenula alluaudi*; Asp = *Asplanchna* sp.; Bra = *Brachionus* sp.; Con = *Conochilus* sp.; Hex = *Hexarthra* sp.; Ker coc = *Keratella cochlearis*; Ker qua = *Keratella quadrata*; Ker val = *Keratella valga*; Pol = *Polyarthra* sp.

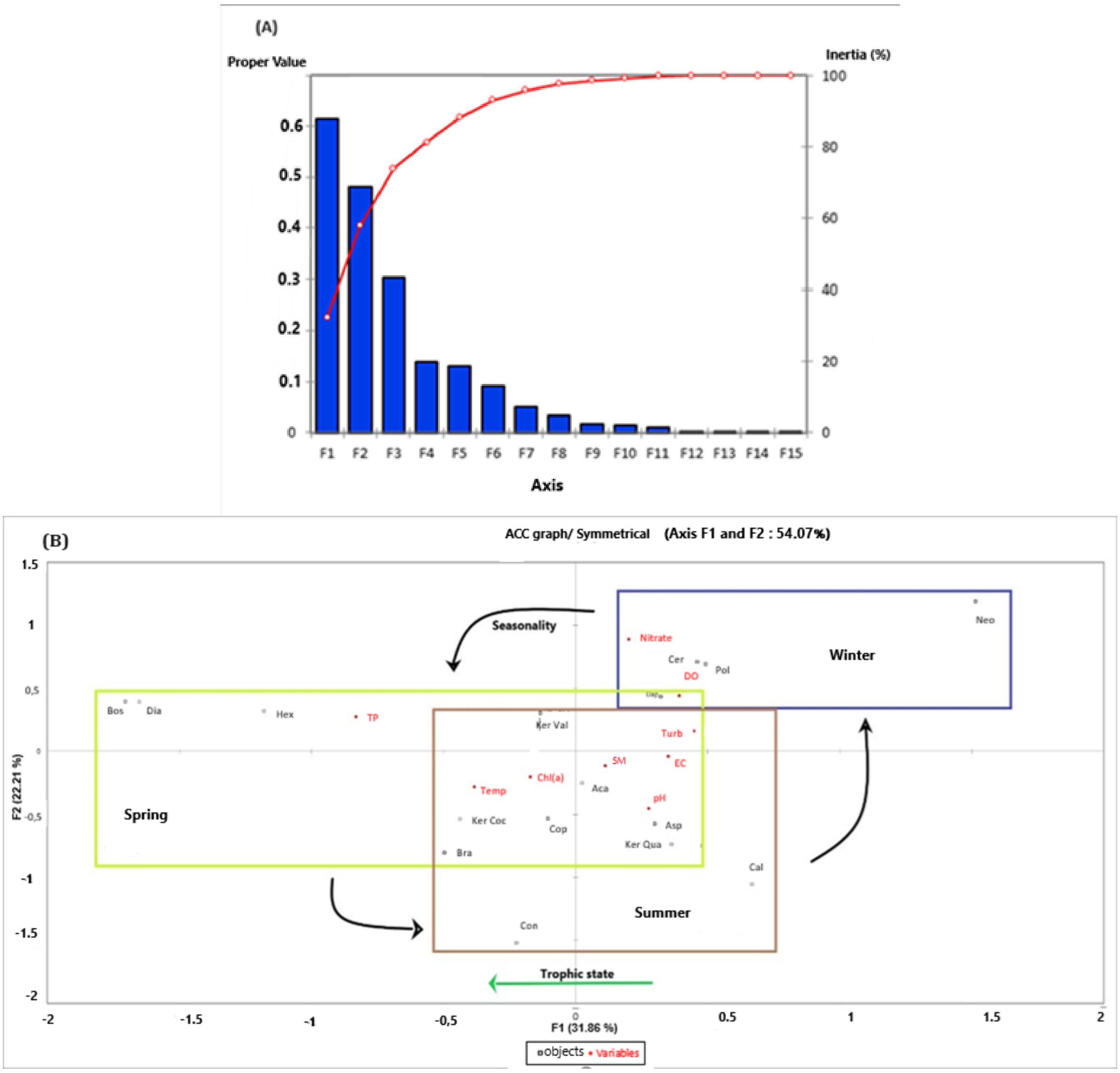

Figure 3. (A) : distribution of the inertia between the axess; (B): Canonical correspondence analysis (CCA) of zooplankton species and physicochemical parameters.

Conclusions. The study of the distribution of the taxa revealed a seasonal temporal variation. The zooplankton community structure was influenced by local environmental factors. Some species indicated a preference for extreme conditions. The use of water physicochemical parameter analyses and the determination of indices were sufficient to characterize the distribution of zooplankton taxa in the MBAK dam.

Seasonal dynamics were characterized by (i) maxima and minima in total densities generally during spring and summer; (ii) individual species reaching maximum and minimum densities during different seasons; (iii) the importance of seasonal variation in taxon diversity; (iv) the hydrological regime of the dam impoundment maintains zooplankton population abundance while the diversity of the latter is influenced.

The use of indices based on the zooplankton community remains an effective tool for monitoring and assessing reservoir eutrophication, especially since this method is inexpensive.

The use of canonical correlation analysis (CCA) has shown that zooplankton structure is influenced by local environmental factors. Some species such as *Neolovenula alluaudi* and those of genera *Bosmina*, *Diaphanosoma* and *Calanoides* showed preference for extreme conditions. The use of biotic indices is strongly recommended for the evaluation of the trophic status of reservoirs for a better management of water resources.

Biodiversity is one of the important characteristics for monitoring ecosystems. The measurement of diversity indices provides important information on the structure of the zooplankton ecosystem.

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