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Zooplankton Diversity at Lake Oubeira, a Wetland at the National Park of El Kala NPEK (North-east Algeria)

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ABSTRACT

The zooplankton community in Oubeira Lake, a wetland at the national park of El Kala (north-east Algeria), was addressed for 13 months, from January 2021 to January 2022, at two stations : St1= Demnet Errihane north of the lake, and St2= Oued Messida south of the lake. The results of this study revealed that the zooplankton community at the lake is composed of 34 species pertaining to three classes : the rotifers, copepods and cladocerans. The spatial distribution of the inventoried individuals showed important values of abundance (244108ind/ L) and species richness (31 species) at St1 compared to St2, where they were lower with145502ind/ l and 25 species. Meanwhile the seasonal distribution showed that April has the higher value of species richness (15 species), followed by May (13 species) although May presented a higher value of abundance (171999ind/ l). It is pointed out that St1 seemed to be more diversified than St2, whereas the rotifer species : *Filinia terminalis* was the most abundant at St1 in May (55667ind/ l), followed by *Keratella tropica* at the same station in January (39000ind/ l).

INTRODUCTION

Zooplankton is very important for energy transfer in the aquatic ecosystems **(Altaff, 2004)**. Certain species are sensitive to abiotic factors change **(Primo *et al.*, 2015)**. According to **Dorche *et al*. (2018)**, a zooplankton community can change responding to water quality, therefore, those microorganisms can be used as bioindicators to define the ecological state of a lake.

El Kala is a small town located in the extreme east of Algeria, specifically in El Taref Province. Its national park, NPEK, is one of the most famous wetlands in Algeria and includes three major water reservoirs: Mellah Lagoon, Tonga Lake, and Oubeira Lake, which are the focus of this study. The park's rich and unique biodiversity has earned its international recognition as a Ramsar wetland **(Meddour & Bouderda, 1999)**. However, the park faces risks of degradation due to anthropogenic activities from the surrounding communities, such as wastewater discharges, farming, and aquaculture. Biomonitoring of aquatic ecosystems has become essential. Many studies have examined the structure of zooplankton communities in relation to abiotic factors, including **Meddour and Bouderda (1999)**, **Branco *et al.* (2002)**, **Adeyemi (2012)** and **Balqis *et al.* (2023)** at the international level, and **Gerfi and Tadjine (2018)** and **Sehili *et al.* (2018)** at the national level. These studies have demonstrated that the spatio-temporal distribution of zooplankton communities is closely related to variations in several environmental factors. The continuous monitoring of the zooplanktonic composition of an ecosystem enables the instant detection of problems such as pollution and ecosystem degradation; therefore, this research work was intended to study the zooplankton community at lake Oubeira by identifying the species belonging to the ecosystem and analyzing the biodiversity status.

MATERIALS AND METHODS

Presentation of the study site

Oubeira is a freshwater lake, located at the extreme east of Algeria (36° 50' 695 N – 8° 23' 272 E), as a part of NPEK of El Taref province (Fig. 1); it was naturally created in 1983, covering a surface of 2200ha, presenting 22% of the watershed's whole surface area which is 9730ha, with an altitude of 25m above sea level and a maximal depth of 4m **(Sehili *et al*., 2020)**, which classifies it as pond water body. It has a roughly square shape whose parameter is equal to 19.80km; the surface area is 2257ha, and the volume is 45m^3 **(Djabourabi, 2014)**. Two sampling stations were chosen (Table 1 & Fig. 2) based on the hydrodynamic movement. St1 was located in a stagnated area in the lake, unlike St2 that was located at the outlet of Messida Wadi and receiving tributaries.

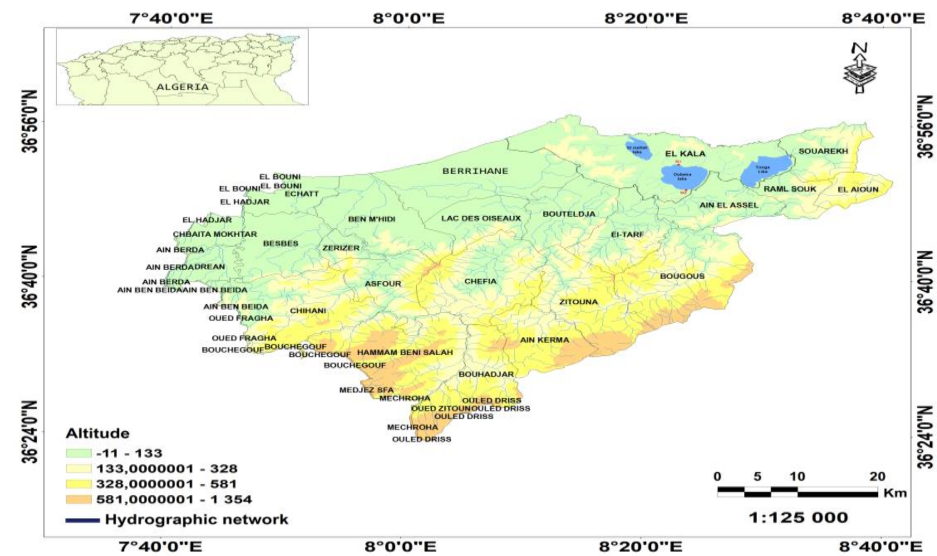

Fig. 1. Geographic map of El Taref province representing the location of NPEK

Table 1. Location and geographic coordinates of the study site

Station	Location	Geographic coordinates	Characteristics
Demnet Errihane	North	36,8632 lat ; 8,3859 lang	Enthropic activity (aquaculture exploitation station)
Oued Messida	South	36,316 lat ; 8,4095 lang	A running river

Fig. 2. Satellite location of the two sampling stations (ArcGIS version 10.5)

Field sampling

The sampling was carried out monthly between 09:00 am and 11:00 am from January 2021 to January 2022. Zooplankton was collected by filtering 50L of raw water vertically through a 50mµ mesh net. By the end of this process, we got a volume of 50 to 120ml of fully filtered water that we poured into a shaded bottle already containing 5ml of diluted formalin at 1/9 and tagged it as follows : the researcher's first name and family name, date and station, then a simple agitation was applied to ensure homogenization of the solution and species fixation. According to **Bouzidi *et al*. (2008)** using this method increases the chances of getting samples more enriched with zooplankton, which helps eventually with the recognition of the species and the estimation of the indicative values of each subsample. Overall, 26 samples were collected (2 sampling sites * 1 sample *13 months).

Zooplankton identification

When the field sampling was conducted, the samples were transferred as soon as possible to the laboratory to start the identification process; 3ml subsamples were prepared and sedimented for 24h, and then observed under an optical microscope at three replicates; the species identifications were accomplished using identification keys provided by **Dussart (1967)**, **Rey and Saint-Jean (1980)**, **Pourriot (1986)**, **Sandercock,**

Vancouver and Scudder (1994), **Shiel (1995)**, **Mouelhi *et al*. (2000)**, **Alberti *et al*. (2003)**, **Witty (2004)**, **Balvay (2014)** and **Glime (2017)**.

Quantitative study

Individuals counting : The number of species individuals was calculated in each sample according to the following formula**:** $N_t = V*N/3$.

Where,
N_t : total number of individuals in a sample
N : individuals number at 3ml subsample
V : sample volume
3 : replicates mean

Qualititative study

Data processing : The data processing was carried out under software R (version 4.2.2), following the calculation of the number of individuals of the species inventoried; for each station and each month, we calculated the frequency of occurrence (FO) or the species constancy (c) which represents the ratio of the number of samples containing the species under study (Pi) to the total number of samples (P) in percentage **(Dajoz, 1985)**, according to the formula: [FO (%) = Pi/P*100], of which: Pi is the total number of samples containing the species i and P is the total number of samples taken**.** The frequencies of the occurrence of species are grouped into classes according to the value of FO(%). The species is considered ubiquitous when FO = 100%, and infrequent when FO = 75%, common when 75% > FO 50%, occasional when 50% > FO 25%, rare when 25% > FO 10% and accidental when FO < 10%. In addition to the indices of ecological diversity, the abundance (1) representing the number of individuals of a given species per unit of space: ind/ L; the specific richness (2), which is the total number of species encountered at a given station **(Jaulin, 2009)**. It aims to determine the most relevant habitat type, (H') **(Shannon weiver diversity index, 1948)** (3) corresponding to the biodiversity monitoring of a habitat according to the formula: [H' = - Σ (Pi log 2 Pi) Pi = N i/N], where Ni is the number of individuals of a given species; i is the total number of species, and N is the total number of individuals. If the value of (H') is minimum, all individuals in the stand belong to a single species, and each species is represented by a single individual **(Frontier, 1998)**. If (H') is at a maximum value, all individuals are equally distributed over all species, therefore this index is more sensitive to rare species **(Krebs, 1972)**. Simpson's index (4) measures the probability that two randomly selected individuals could belong to the same species: [D = 1-Σni(ni-1) / N (N-1)], of which: ni is the number of individuals of a species in the sample, and **N** is the total number of individuals. This index also considers the most abundant species and measures intraspecific competition at the trophic level according to **Washington (1984)**, and equitability (5), which measures the degree of balance and complexity of a stand by the ratio of the diversity (H') observed to the maximum diversity (Hmax) **(Benyacoub 1993)**, in addition to Venne diagram (6) of species in common between the two stations, PERMANOVA test (7) of the effect of seasons on the spatial distribution of species and NMDS (8) of the distribution of species according to seasons.

RESULTS

1. Quantitative study

- ***Abundance***

During the 13 months of sampling from January 2021 to January 2022, a total of 244108ind/ l at St1 and 145832ind/ l at St2 were calculated. Samples belong to 34 species and 3 zooplankton classes: 15 rotifers, 13 copepods, and 6 cladocerans with densities of 221494ind/ l (67%), 39614ind/ l (17%), 39900ind/ l (16%), respectively, at St1 and 90278ind/ l (61%), 43967ind/ l (30%) , 11578ind/ l (8%), respectively, at St2 in Oubeira Lake. Among the taxa inventoried, the species *Filinia terminalis* showed a high abundance during the month of May at St1 (A = 55667ind), followed by the species *Keratella tropica* during January at the same station (A = 39000ind). However, January, April and May were very rich in zooplankton, while October did not host any species (A = 0 ind) (Fig. 3).

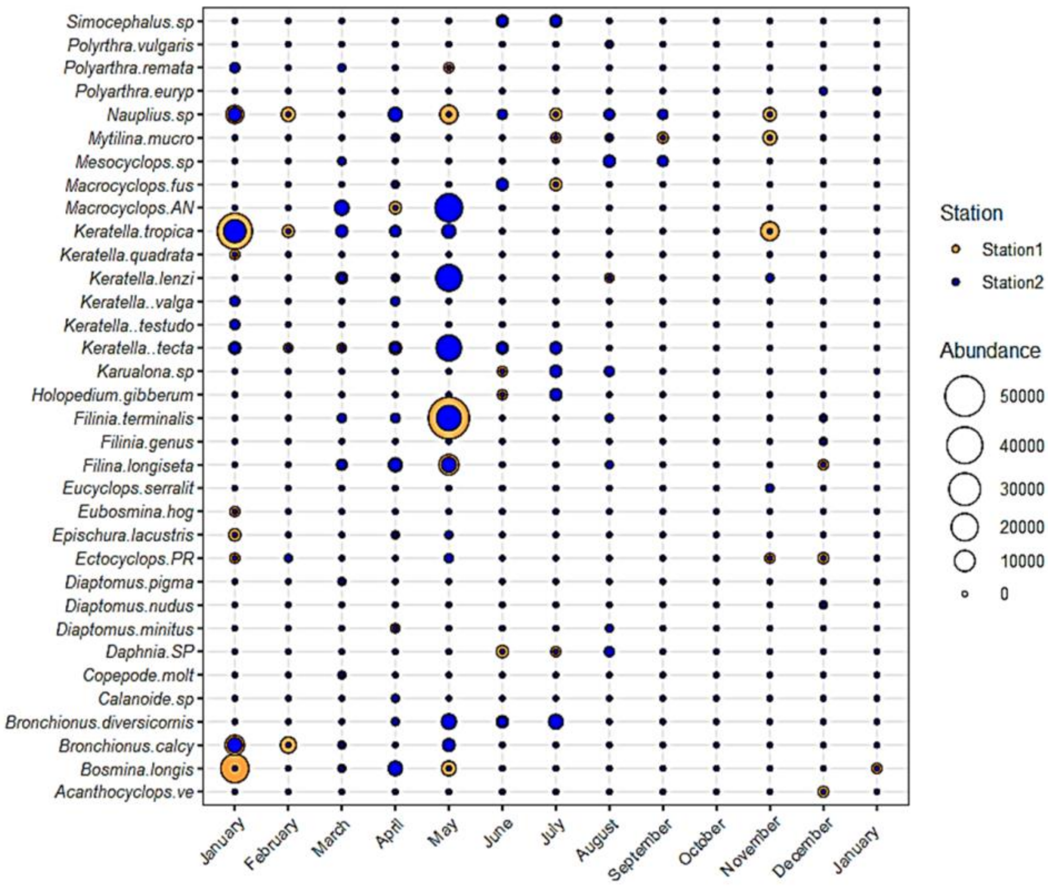

Fig. 3. Species abundance according to months

2. Qualitative study

2.1. Inventory of zooplankton species

The zooplankton community consisted of 34 species and three classes: the rotifers, copepods and cladocerans (Table 2).

Table 2. Inventoried zooplankton species at lake Oubeira

Taxa			Months : Station 1													Months : Station 2												
class	species		J	F	M	A	M	J	JU	AU	S	O	N	D	J*	J	F	M	A	M	J	JU	AO	S	O	N	D	J*
Rotifers	*Keratella*	*tropica*	+	+	+	+	-	-	-	-	-	-	+	-	-	+	-	+	+	+	-	-	-	-	-	-	-	-
	Keratella	*quadrata*	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Keratella	*lenzi*	-	-	+	+	-	-	-	+	-	-	+	-	-	-	-	+	-	+	-	-	-	-	-	+	-	-
	Keratella	*testudo*	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-
	Keratella	*tecta*	+	+	+	+	+	+	+	-	-	-	-	-	-	+	-	-	+	+	+	+	-	-	-	-	-	-
	Keratella	*valga*	-	-	-	-	-	-	-	-	-	--	-	-	-	+	-		+	-	-	-	-	-	-	-	-	-
	Bronchionus	*calcyfloris*	+	+	+	-	-	-	-	-	-	-	-	-	-	+	-	-	-	+	-	-	-	-	-	-	-	-
	Bronchionus	*diversicornis*	-	-	-	-	+	+	+	-	-	-	-	-	-	-	-	-	+	+	+	+	-	-	-	-	-	-
	Polyarthra	*remata*	-	-	-	-	+	-	-	-	-	-	-	-	-	+	-	+	-	-	-	-	-	-	-	-	-	-
	Polyarthra	*vulgaris*	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Polyarthra	*euryptera*	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	+	-
	Filinia	*longiseta*	-	-	+	+	+	-	-		-	-	-	+	-	-	-	+	+	+	-	-	+	-	-	-	-	-
	Filinia	*terminalis*	-	-	+	+	+	-	-	-	-	-	-	+	-	-	-	+	+	+	-	-	+	-	-	-	-	-

	Filinia	*genus*	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Mytilina	*mucronafa*	-	-	-	+	-	-	+	+	+	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Copepods	*Ectocyclops*	*phalerat us-rubescens*	+	-	-	-	-	-	-	-	-	-	+	+	-	-	+	-	-	+	-	-	-	-	-	-	-	-
	Epischura	*lacustris*	+	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-
	Nauplius	sp.	+	+	-	-	+	+	+	+	+	-	+	-	-	+	-	-	+	-	-	-	+	+	-	-	-	-
	Mesocyclops	sp.	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	+	+	-	-	-	-
	Macrocyclop	*albidus*	-	-	+	+	-	-	-	-	-	-	-	-	-	-	-	+	-	+	-	-	-	-	-	-	-	-
	Macrocyclop	*fuscus*	-	-	-	+	-	+	+	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-
	Diaptomus	*pigmaeus*	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Diaptomus	*minitus*	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-
	Diaptomus	*nudus*	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Copepod	*molt*	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Eucyclops	*serralitus*	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-
	Acanthocyclops	*vernalis*	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-

	Calanoide	sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-
Cladocerans	*Bosmina*	*longosrostris*	+	-	+	+	+	-	-	-	-	-	-	-		+	-	-	+	+	-	-	-	-	-	-	-	+
	Eubosmina	*hogamani*	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Simocephalus	sp.	-	-	-	-	-	+	+	-	-	-	-	-	-	-	-	-	-	-	+	+	-	-	-	-	-	-
	Holopedium	*gibberum*	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-
	Karualona	sp.	-	-	-	-	-	+	+	-	-	-	-	-	-	-	-	-	-	-	+	+	-	-	-	-	-	-
	Daphnia	sp.	-	-	-	-	-	+	+	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-

2.2. Frequency of occurrence

Table 3. Frequency of occurrence of the inventoried species

	Station				Month																									
Species	St1	Ind	St2	Ind	Jan	Ind	Feb	Ind	Mar	Ind	Apr	Ind	May	Ind	Jun	Ind	Jul	Ind	Aug	Ind	Sep	Ind	Oct	Ind	Nov	Ind	Dec	Ind	Jan	Ind
Ectocyclops phaleratus rubenscens	23	Ra	15.4	Ra	50	Co	50	Co	0	Ac	0	Ac	50	Co	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	50	Co	50	Co	0	Ac
Epischura lacustris	15.4	Ra	7.7	Ac	50	Co	50	Co	0	Ac	0	Ac	50	Co	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac
***Nauplii* sp.**	53.9	Co	38.5	Oc	100	Fr	50	Co	0	Ac	50	Co	50	Co	50	Co	50	Co	100	Fr	100	Fr	0	Ac	0	Ac	0	Ac	0	Ac
***Mesocyclops* sp.**	7.7	Ac	23	Ra	0	Ac	0	Ac	100	Fr	0	Ac	0	Ac	0	Ac	0	Ac	50	Co	50	Co	0	Ac	0	Ac	0	Ac	0	Ac
Macrocyclops albidus	15.4	Ra	15.4	Ra	0	Ac	0	Ac	100	Fr	50	Co	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac
Diaptomus pigmaeus	7.7	Ac	0	Ac	0	Ac	0	Ac	50	Co	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac
Copépode molt	7.7	Ac	0		0	Ac	0	Ac	50	Co	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac
Diaptomus minitus	7.7	Ac	7.7	Ac	0	Ac	0	Ac	0	Ac	50	Co	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac
Diaptomus nudus	7.7	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0		0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	50	Co	0	Ac
Macrocyclops fuscus	23	Ra	7.7	Ac	0	Ac	0	Ac	0	Ac	50	Co	0	Ac	100	Fr	50	Co	0		0	Ac	0	Ac	0	Ac	0	Ac	0	Ac

Eucyclops serralitus	7.7	Ac	7.7	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	100	Fr	0	Ac	0	Ac
Acanthocyclops vernalis	7.7	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	50	Co	0	Ac
***Calanoide* sp.**	0	Ac	7.7	Ac	0	Ac	0	Ac	0	Ac	50	Co	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac
Bosmina longirostris	38.5	Oc	7.7	Ac	50	Co	0	Ac	50	Co	100	Fr	50	Co	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	50	Co
Eubosmina hogzmznni	7.7	Ac	0	Ac	50	Co	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac
Mytilina mucronafa	38.5	Oc	0	Ac	0	Ac	0	Ac	0	Ac	50	Co	0	Ac	0	Ac	50	Co	50	Co	50	Co	0	Ac	50	Co	0	Ac	0	Ac
***Simocaphalus* sp.**	15.4	Ra	15.4	Ra	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	100	Fr	100	Fr	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac
Holopedium giberus	7.7	Ac	7.7	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	50	Co	50	Co	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac
***Karualona* sp.**	15.4	Ra	15.4	Ra	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	50	Co	100	Fr	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac
***Daphnia* sp.**	15.4	Ra	7.7	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	50	Co	50	Co	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac
Keratella tropica	38.5	Oc	30.8	Oc	100	Fr	50	Co	100	Fr	100	Fr	50	Co	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	50	Co	0	Ac	0	Ac
Keratella quadrata	7.7	Ac	0	Ac	50	Co	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac
Keratella lenzi	30.8	Oc	23	Ra	0	Ac	0	Ac	50	Co	50	Co	50	Co	0	Ac	0	Ac	50	Co	0	Ac	0	Ac	100	Fr	0	Ac	0	Ac
Keratella testudo	0	Ac	7.	Ac	50	Co	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac

			7																											
Keratella cochlearis forme tecta	38.5	Oc	38.5	Oc	100	Fr	50	Co	50	Co	100	Fr	50	Co	100	Fr	50	Co	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac
Keratella valga	0	Ac	15.4	Ra	50	Co	0	Ac	0	Ac	50	Co	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac
Bronchionus calcyflorus	23	Ra	15.4	Ra	100	Fr	50	Co	50	Co	0	Ac	50	Co	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac
Bronchionus diversicornis	23	Ra	30.8	Oc	0	Ac	0	Ac	0	Ac	50	Co	100	Fr	100	Fr	100	Fr	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac
Polyarthra remata	7.7	Ac	15.4	Ra	50	Co	0	Ac	50	Co	0	Ac	50	Co	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac
Polyarthra vulgaris	7.7	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	50	Co	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac
Polyarthra eureptera	7.7	Ac	7.7	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	50	Co	50	Co
Filinia terminalis	30.8	Oc	30.8	Oc	0	Ac	0	Ac	100	Fr	100	Fr	100	Fr	0	Ac	0	Ac	50	Co	0	Ac	0	Ac	0	Ac	50	Co	0	Ac
Filinia longiseta	30.8	Oc	30.8	Oc	0	Ac	0	Ac	100	Fr	100	Fr	100	Fr	0	Ac	0	Ac	50	Co	0	Ac	0	Ac	0	Ac	50	Co	0	Ac
Filinia genus	7.7	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	0	Ac	50	Co	0	Ac

Table (3) shows that the presence of each species varies by month at both stations; the species *Keratella tropica*, *Filinia terminalis* and *Filinia longiseta* were occasionally present at the two stations and more frequent in January, April and May, while in June *keratella cochlearis* was more frequent. *Copepod nauplius* was also occasionally present at both stations and omnipresent almost throughout the sampling period. On the other hand, the rarest species at the two stations were: *Ectocyclops phaleratus-rubescens* with a more or less common presence throughout the collection period, *Macrocyclops nudus* frequented in March, *karualona* sp. frequented in July, and *bronchionus calcyflorus* in January.

2.3. Spatial diversity

- **Diversity indices**: The spatial study of the specific richness (S) of zooplankton species inventoried at the two study stations showed that St1 is the richest in species (31 species) compared to St2 which hosted only 25 species. The values of the Shannon diversity index and the Simpson index were almost similar for both stations (H' 2.500, SRI 1.100); the Piélou equitability index (s) varied between 0.7 and 0.8, and the maximum diversity varied between 3 and 3.4 (Fig. 4).

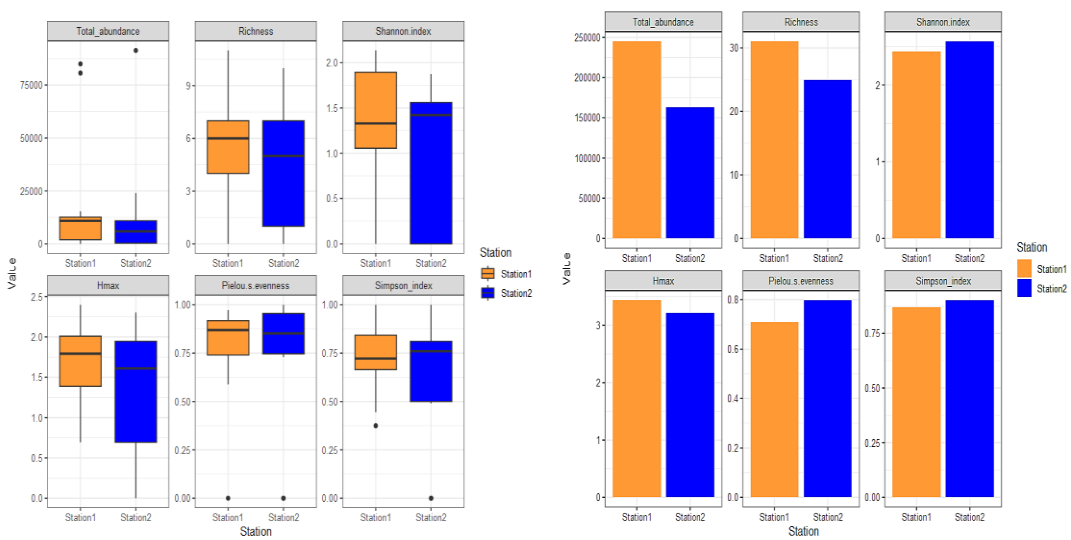

Fig. 4. Boxplot and bar diagram of zooplankton spatial diversity indices inventoried at the two study stations (January 2021-January 2022)

- **Venne diagram**: Have shown that 26.5% of the species (9 species) belonged specifically to st1 and 8.8% of species (3 species) belonged specifically to st2 and the rest were species in common between the two stations.

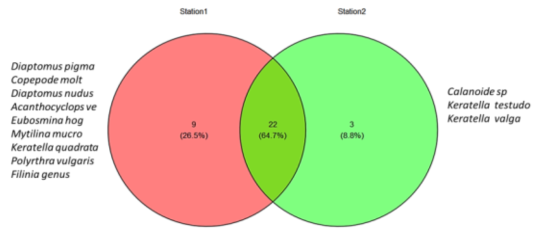

Fig. 5. Venne diagram of the presentation of species in common between the two stations

2.4. Seasonal diversity

- **Diversity indices**: The seasonal study of the species richness (S) of inventoried zooplankton species showed that the spring season is the richest with species (28 species) followed by the winter season (24 species). Shannon diversity index values ranged from 2.6 in the spring season to 0.5 in the winter season and zero in the fall season, whereas Simpson index values ranged from 1 to 0.30, and equitability from 1 to 0.65, the maximum diversity ranged from 2.8 in the spring season to 0.5 in the winter season, with a zero value in the fall season (Fig. 6)

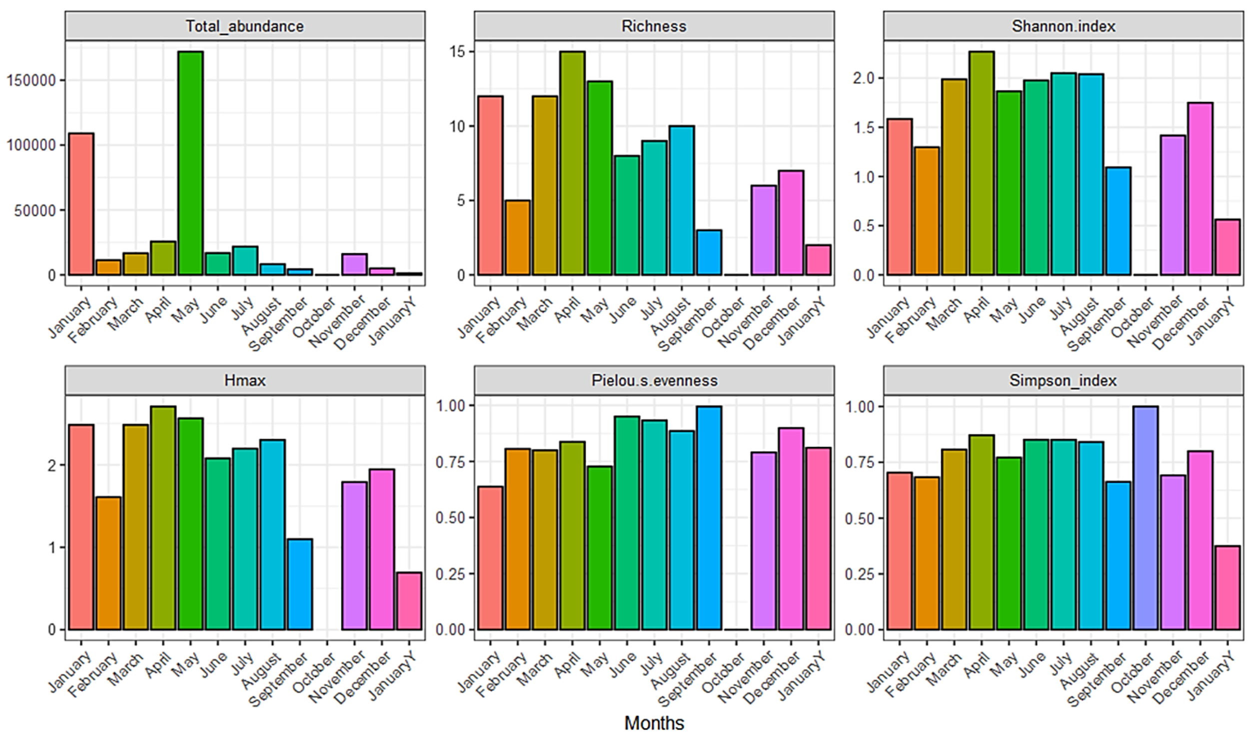

Fig. 6. Indices of the seasonal diversity of zooplankton inventoried at the two study stations (January 2021-January 2022)

- **PERMANOVA test**: Fig. (7) shows that the season factor has a very highly significant effect on the distribution of species (*P* > 0.001), but the station factor has no significant effect.

```
Permutation test for adonis under reduced model
Terms added sequentially (first to last)
Permutation: free
Number of permutations: 999

adonis2(formula = df_data[1:34] ~ Seasons + Station, data = df_data, permutations = 999, method = "bray")


             Df   SumOfSqs    R2        F      Pr(>F)
Seasons       3    2.5289    0.27759   2.3828   0.001 ***
Station       1    0.2134    0.02343   0.6033   0.922
Residual     18    6.3678    0.69898
Total        22    9.1101    1.00000
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Fig. 7. PERMANOVA test of the effect of seasons on the species spatial distribution

- **NMDS (no metric dimensional scaling)** : Fig. (8) shows that copepods were much more abundant in the hot season, but in the cold season rotifers and cladocerans were more prevalent. Other species may be present across more than one season.

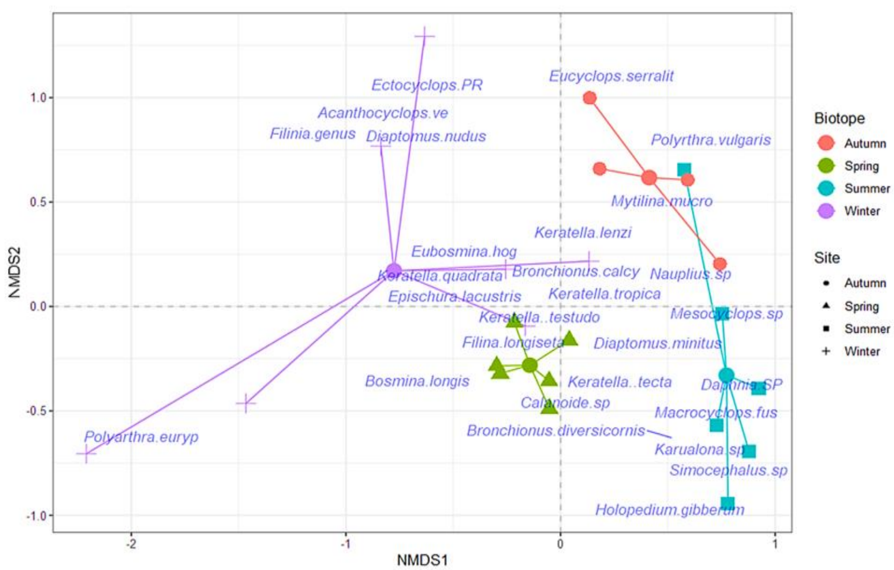

Fig. 8. NMDS (no metric dimensional scaling) of the distribution of species according to the seasons

2.5. Rarefaction Curve for the zooplankton community

According to Fig. (9B), the spatial analysis of the richness curves according to the number of individuals observed shows that St1 is more diversified than St2, which provided less species and fewer individuals. The monthly analysis of the richness curves based on the number of observed individuals (Fig. 9-A) indicates that zooplankton diversity was at its highest in May, followed by January. In contrast, diversity was lower in April, despite the high number of individuals observed during that month. Additionally, diversity was consistently low and convergent for the remaining months.

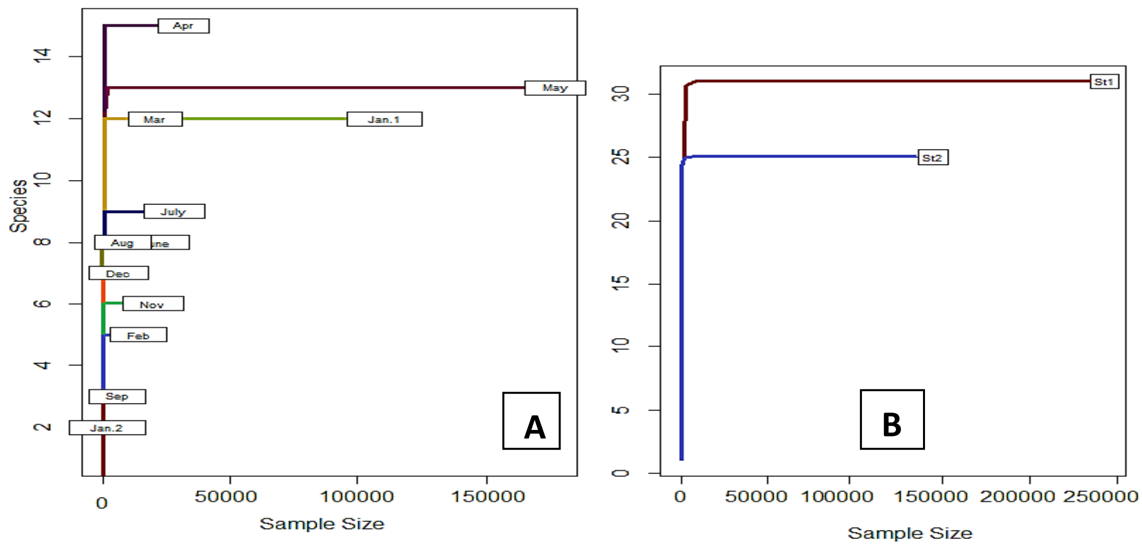

Fig. 9. (A) Seasonal and **(B)** Spatial rarefaction curves for the zooplankton community based on the order of diversity q = 0 (species richness)

DISCUSSION

Diversity study

Both stations showed a minimal diversity but were characterized by the maximum density during May. The results from NMDS and PERMANOVA tests confirm that zooplankton species distribution is directly affected by seasonal factors. The abundance distribution was strongly hierarchical, with the rotifers dominating at both stations. **Ismael and Amalina (2016)** observed similar results in their study of zooplankton diversity in two small lakes in Malaysia, attributing the abundance of the rotifers to eutrophication. Their small size makes them less visible to predators in low-visibility conditions, unlike cladocerans and copepods. Additionally, **Karus (2014)** noted that the larger size of the cladocerans and copepods often leads to decreased abundance due to fish predation.

Sehili (2022) indicated that Lake Oubeira is polymictic. **Sługocki and Czerniawski (2018)** linked increased rotifer biodiversity to the higher species richness typical of polymictic lakes. Conversely, **Badsi *et al.* (2010)** found that the rotifers serve as bioindicators of eutrophic environments. This is despite their low relative fertility due to their high reproduction rate **(Sarma & Nandini, 2001; Hamaidi *et al.*, 2008**) and ability to ingest organic matter.

Rotifers

The genus *Filinia* constituted 44% of the total density of the rotifers at Station 1, followed by *Keratella* at 40%. At Station 2, *Keratella* represented 57% of the total rotifer density, followed by *Filinia* at 27%. **Ayoagui and Bonecker (2004)** noted that these species are generally abundant, regardless of the season. This finding was later supported by **Adeyemi (2012)**, who reported that the rotifers have a wide tolerance to extreme temperatures.

The genus *Brachionus* had a maximum density of 14,333ind/ l, accounting for 9% of the total rotifer density at Station 1. **Branco *et al.* (2002)** established a relationship between high *Brachionus* abundance and a high trophic level in ecosystems. This genus was also proposed by **Attayde and Bozelli (1998)** as a target taxon for biomonitoring aquatic ecosystems.

Cladocerans

Bosmina longirostris reached a maximum density of 23,000ind/ l, making up 62% of the total cladoceran density at Station 1 in January and was also present in March and April. **Hart (2004)** classified this species as tolerant due to its presence throughout the year. Its adaptability to herbivorous feeding behavior with phytoplankton availability **(Korovchinsky & Smirnov, 1995)** and its thermophobic nature explains its high density in January. **Balkhi and Yousuf (1996)**, **Azan *et al.* (2015)** and **Varodi *et al.* (2017)** agreed that high temperatures reduce the longevity and fecundity of *Bosmina longirostris*. In many European eutrophic lakes, *Bosmina longirostris* was reported as dominant **(Jensen *et al.*, 2013; Nevalainen *et al.*, 2019)** and was proposed by **Saler and Aliş (2016)** as an indicator of eutrophication.

In contrast, the genus *Daphnia* had a low density of 990ind/ l at Station 2. **Jensen *et al.* (2013)** attributed its low presence to a preference for less organic matter-laden ecosystems although predation by fish could also be a factor.

Copepods

The copepod group was dominated by *Macrocyclops albidus*, with a density of 26,333ind/ l, accounting for 59% of the total copepod density at Station 2 in May. The seasonal abundance of copepods in Lake Oubeira showed strong presence in the dry season. Studies of zooplankton in Lake Boukourdane **(Errahmani *et al.*, 2015)** and Lake Oubeira **(Sehili, 2022)** also reported high copepod numbers in spring and summer but much lower in fall and winter.

Copepod nauplii were the most common, occurring throughout most of the sampling period at both stations. At Station 1, the highest density was in May at 7,333 ind/l. **Devreker *et al.* (2004)** and **Souissi *et al.* (2008)** confirmed that nauplii are more dependent on hydrodynamics than older stages. **Tieligounon *et al.* (2020)** found nauplii to be more abundant in the dry season, with their abundance significantly influenced by the number of adult copepods and water transparency.

CONCLUSION

This study allowed us to inventory 34 species with a total density of 389940ind/ L distributed at the two study sites; at St1: Demnet Errihane north of Lake oubeira, and at

St2: Oued Messida south of the same lake. These species belong to three zooplankton classes, the most dominant are the rotifers (64%), followed by copepods (23.5%) then cladocerans (12%). The values of the Shannon diversity indices and the Simpson index were almost the same at both stations (H’ 2.500) and (D 1.100), therefore they indicate a minimum diversity of the zooplankton community. Moreover, the study of the spatial and seasonal distribution of the lake showed that St1 is the most diverse, and that it is in spring that the diversity remains maximum.

The zooplankton diversity of Lake Oubeira has a structure that varies in response to environmental changes, which makes of zooplankton communities a true biological indicator of the health status of this aquatic ecosystem. This study reveals the dominance of previously proven bioindicator species, such as *Macrocyclops albidus, Bosmina longirostris, Filinia longiseta* and *Keratella tropica*, which confers the eutrophic state of the lake.

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