Brazilian Journal of Biology®

ISSN 1519-6984 (Print)
ISSN 1678-4375 (Online)

Original Article

Distribution of benthic macroinvertebrate communities in different kind of inland water bodies in northeastern Algeria

Variação na distribuição das comunidades de macroinvertebrados no nordeste da Argélia

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Abstract

Benthic macroinvertebrates are integral parts of inland waters, inhabiting a diversity of aquatic ecosystems where communities are spatially structured. Macroinvertebrates of some Mediterranean regions such as North Africa are still not well studied. Due this reason we proposed study the community structure in water bodies located in Northeastern Algeria. For this objective, we sampled 12 different kind of water bodies, two dams, three rivers, and seven streams during the period from October 2020 to September 2021. To biotic and abiotic data, a redundancy analysis (RDA) was applied with the aim of determine the role of both kind of variables for grouping the sites. Also, two types of Null models were considered: species co-occurrence and niche sharing for study the potential associations between species reported. Redundancy analysis showed that water velocity and conductivity were the main drivers of community structure of macroinvertebrates. The species co-occurrence results reveal that species associations are ramdom, except for two sites: El fadjoudj and Ain ben baida corresponding to Seybouse river. At the same time, there is no niche sharing and in consequence, there is no interspecific competition except in the two sites: Salah Salah Salah stream and Bouhamdane dam. The results revealed similarities with other similar studies for Algerian rivers and dams, and with other similar water bodies with Mediterranean climate.

Keywords: benthic macroinvertebrates, community structure, freshwater, north-est Algeria.

Resumo

Os macroinvertebrados bentônicos são partes integrantes das águas interiores, habitando uma diversidade de ecossistemas aquáticos onde as comunidades estão espacialmente estruturadas. Os macroinvertebrados de algumas regiões mediterrânicas, como o Norte de África, ainda não são bem estudados. Por esta razão propusemos estudar a estrutura comunitária em massas de água localizadas no Nordeste da Argélia. Para tanto, foram amostrados 12 corpos d'água diferentes, duas barragens, três rios e sete córregos durante o período de outubro de 2020 a setembro de 2021. Aos dados bióticos e abióticos foi aplicada uma análise de redundância (RDA) com o objetivo de determinar o papel de ambos os tipos de variáveis para agrupar os sites. Além disso, foram considerados dois tipos de modelos nulos: co-ocorrência de espécies e compartilhamento de nicho para estudar as potenciais associações entre as espécies relatadas. A análise de redundância mostrou que a velocidade e a condutividade da água foram os principais impulsionadores da estrutura da comunidade de macroinvertebrados. Os resultados da co-ocorrência de espécies revelam que as associações de espécies são aleatórias, excepto em dois locais: El fadjoudj e Ain ben baida correspondentes ao rio Seybouse. Ao mesmo tempo, não há partilha de nicho e, consequentemente, não há competição interespecífica, excepto nos dois locais: riacho Salah Salah Salah e barragem de Bouhamdane. Os resultados revelaram semelhanças com outros estudos semelhantes para rios e barragens argelinos, e com outras massas de água semelhantes com clima mediterrânico.

Palavras-chave: macroinvertebrados bentônicos, estrutura comunitária, água doce, nordeste da Argélia.

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Received: April 4, 2023 – Accepted: December 6, 2023

1. Introduction

The inland waterbodies of north-eastern Algeria are characterized by high biodiversity of species, that is conditioned by environmental characteristics (Samraoui and Samraoui, 2008; Khelifa et al., 2016; Bouali et al., 2021). The community structure in water bodies it express in term of species richness and species dominance is variable in function to species interactions. Both intraspecific competition for resources, predation and abiotic parameters are what could determine the type of species composition (Toft, 1985; Bekhouche et al., 2017; Khelifa et al., 2021a, b; Suarez et al., 2022). In this scenario, in term of species diversity and abundance of each species is variable for each site such as was observed for other Algerian rivers determining also the community structure (Baaloudj, 2019; Chaib et al., 2023).

Despite all that, the study of macroinvertebrates in the streams of Algeria has only been undertaken in recent decades in order to put an inventory as exhaustive as possible and to have knowledge of their systematics, their ecology, and their biogeography (Rouibi et al., 2021). The reports for Algerian rivers mentioned marked heterogeneity at spatial scale along river course and the differences of the kinds of water bodies in term of community structure, specifically in species diversity and dominant species (Rouibi et al., 2021; Ferguani and Arab, 2013), that would be explained also due marked geographical isolation and environmental heterogeneity (Bekhouche et al., 2017; Ferguani and Arab, 2013; Rouibi et al., 2021).

For that, the main goals of our study were do a first exploratory analysis for study the benthic invertebrate communities in rivers, dams and streams in Northeastern Algeria using exploratory multivariate analysis, specifically redundance analysis for determine the role of biotic and abiotic variables for as potential grouping variables, and in second instance using null models (species co-occurrence and niche sharing) for determine the potential role of species interactions.

2. Material and Methods

Study area: The basin of Seybouse is located in northeastern Algeria. It covers a total surface of approximately 6471 km^2. It consists of 42 rivers (Baaloudj et al., 2020), including our 12 sites (Figure 1, Table 1). Among the 12 sampling sites (Table 1), we chose 2 dams: Bouhamdane II, whose area extends over 13,000 ha with a capacity of 2.8 million m^3, and Medjez el bgare, with a capacity of 2,86 million m^3 and three sites in Seybouse river (El fadjoudj, Bouchegouf and Ain Ben Baida) and seven streams (Zimba, Bou Sora, Hellia, Charef, Bouhamdane I, Salah salah salah and Echham). The regional climate is typically Mediterranean, with a long hot and dry season (8 months) and a short-wet season (4 months) (Rouibi et al., 2021). Also, the vegetation cover is extensive but mainly includes: *Juncus* sp, *Typha* sp, *Phragmites australis*, *Tamarix sp*, *Nerium oleander*, and *Lemna minor* (Baaloudj et al., 2020, 2022).

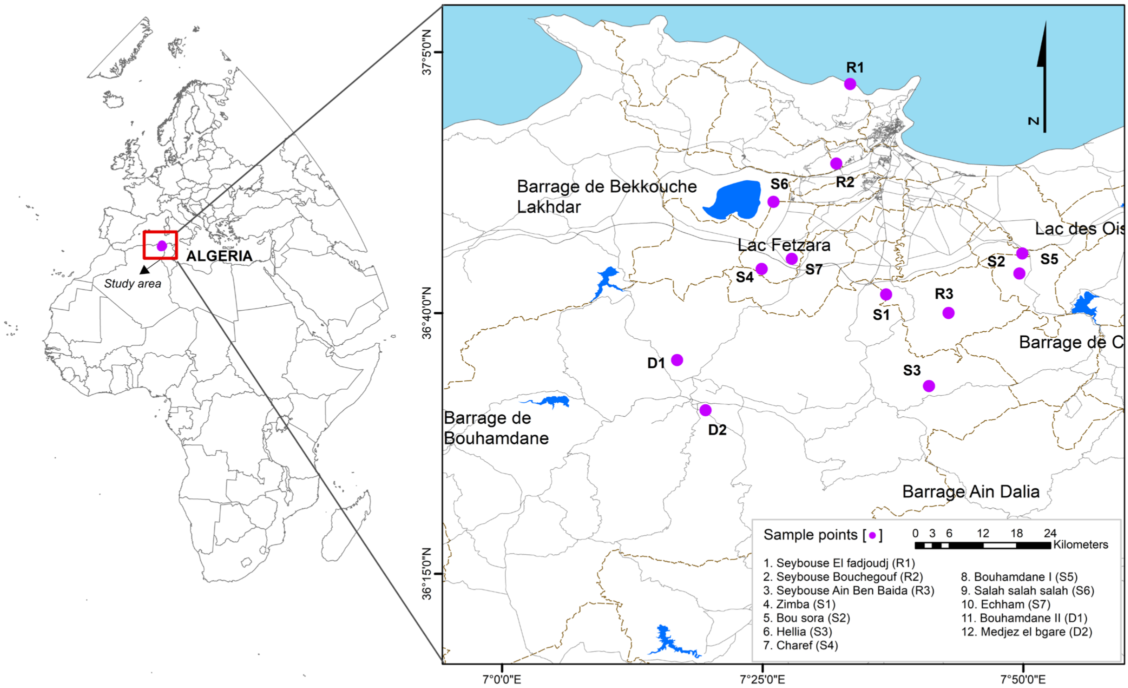

Figure 1. Geographic distribution of the study sites in Northeast Algeria. The map was generated from the leaflet R package (Code site see Table 1).

Sampling protocol: To assess and monitor changes in the physicochemical and biological quality of freshwater, we sampled the macroinvertebrates and nine physicochemical parameters (depth of water body, water speed, conductivity, dissolved oxygen [O_2], pH, nitrate, nitrite, salinity, and water temperature) in each site monthly from October 2020 to September 2021. We used multi-parameter Multi 3620 IDS WTW to estimate the physicochemical parameters. The measurements were taken near the bank in lentic sites and in the middle of the watercourse in lotic sites. The probe was submerged in the water at a depth of about 10 cm. All measurements were taken between 08:00 and 16:00 hrs. We made sure to take physicochemical measurements before sampling the macroinvertebrates to avoid biased data due to habitat perturbation. The collection of macroinvertebrates was done by using a large landing net with a mesh opening of 1 mm. The collected specimens were fixed with ethanol 96%. The sorting and the identification of the different organisms (by family) were carried out in the laboratory under a binocular loupe type (Olympus S236206) according to several identifying keys (Tachet et al., 2012; Greenhlg and Ovenden, 2009); they were counted and stored separately in different ethanol vials labelled with identification, a number of individuals and collection date.

Exploratory data analysis: To determine the relationship between the abiotic factors and the composition of benthic communities (based on abundance), we used redundancy analysis (RDA) model (Legendre and Legendre, 1998). Prior to this analysis, we removed collinearities among explanatory variables (six abiotic factors) using the vif.cca function (variance inflation factor) and applying a threshold of < 2 to retain variables. We retained only five explanatory variables after removing dissolved oxygen because of high correlation with salinity (Spearman's correlation: $r = 0.85$, $P=0.0004$). We also standardized all environmental variables and Hellinger-transformed the community data. We determined whether the full RDA model was significant using the ANOVA function of the package *vegan* (Oksanen et al., 2019) and *ggplot2* (Wickham, 2009) R software packages. We then used a forward selection procedure to reveal the most influential abiotic factors on the benthic community composition using the ordiR2step function. We reported both R2 and adjusted R2 (corrected for the number of explanatory variables) estimated using the RSquareAdj function. Values are mean ± SD.

Null model in ecology: As a first step, a species presence/absence matrix was constructed, with the species in rows and the pools in columns. From this matrix we calculated a Checkerboard score ("C-score"), which is a quantitative index of occurrence that measures the extent to which species co-occur less frequently than expected by chance (Gotelli, 2000). A community is structured by competition when the C-score is significantly larger than expected (Gotelli, 2000; Tondoh, 2006; Gotelli and Entsminger, 2007; Tiho and Josens, 2007). It is used simulation to compare co-occurrence patterns to null expectations. Gotelli and Ellison (2013) suggested the statistical null models Fixed- Fixed, in this model, the row and column sums of the matrix are retained. As a result, each random community has the same number of species as the original community (fixed column), and each species occurs at the same frequency (fixed row). The null model analyses were conducted using the EcosimR R-package (Gotelli and Ellison, 2013; Carvajal-Quintero et al., 2015) and software R (R Development Core Team, 2021).

It was investigated if niche overlap significantly differed from the comparable value under the null hypothesis (for example, random assemblage) using data from the second niche period. The Pianka index was used for determining niche overlap. This model is based on a median table that shows the probability of niche sharing when compared to the simulated community niche overlap (Gotelli and Entsminger, 2007; Carvajal-Quintero et al., 2015). The niche amplitude can be maintained or reshuffled; when retained, it preserves each species; specialty; when is reshuffled, it often uses a wider usage gradient, resulting in a large niche overlap in the simulated community when compared to the real population. In addition, the zero states are retained or simulated in each simulated matrix, with 0 involvements in the observed matrix being maintained or not. The RA3 algorithm was employed in this investigation (Gotelli and Ellison, 2013; Carvajal-Quintero et al., 2015).

Table 1. Geographical location of study sites.

Sites	Code site	Kind of site	Geographical location
Seybouse El fadjoudj	R1	River	36º 48.12' N; 07º 41.56' E
Seybouse Bouchegouf	R2	River	36º 49.56' N; 07º 72.29' E
Seybouse Ain Ben Baida	R3	River	36º 56.44' N; 07º 74.19' E
Zimba	S1	Stream	36º 26.02' N; 07º 28.47' E
Bou sora	S2	Stream	36º 39.22' N; 07º 52.40' E
Hellia	S3	Stream	36º 20.47' N; 07º 31.23' E
Charef	S4	Stream	36º 42.31' N; 07º 31.32' E
Bouhamdane I	S5	Stream	36º 27.45' N; 07º14.38' E
Salah salah salah	S6	Stream	36º 47.17' N; 07º 34.11' E
Echham	S7	Stream	36º 37.21' N; 07º 63.06' E
Bouhamdane II	D1	Dam	36º 27.48' N; 07º 13.56' E
Medjez el bgare	D2	Dam	36º 22.03' N; 07º 29.04' E

The RA3 model keeps the amplitude while rearranging the zero conditions (Gotelli and Entsminger, 2007). The R-package EcosimR was used to conduct this null model study (Gotelli and Ellison, 2013; Carvajal-Quintero et al., 2015) and software R (R Development Core Team, 2021).

3. Results

The results of abiotic factors revealed that the measured parameters had relatively moderated values of all studied variables (depth of water body, water speed, conductivity, dissolved oxygen [O_2], pH, nitrate, nitrite, salinity, and water temperature) for ten sites (three sites along Seybouse river, five streams and two dams), nevertheless two sites have marked differences, first Boudhame I stream that had high depth of water body, high pH level and high dissolved oxygen [O_2], whereas the second site Salah Salah Salah stream, has high conductivity, high water speed and high nitrate levels (Table 2). The results of taxa composition revealed that site El fadjoudj of river Seybouse has high taxa number with 18 taxa reported (Table 3), whereas the site Zimba stream has the lower taxa number with 5 taxa reported (Table 3). The most abundant taxa for all sites are Corixidae and Gammaridae, and the most abundances were reported mainly between February to June (Table 3).

Table 2. Results of physico-chemical parameters for sites included in the present study.

Conductivity (mS/cm)												
Sites	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**
Seybouse El fadjoudj	1509	854	601	966	841	875	733	795	950	980	1601	1245
Seybouse Bouchegouf	899	908	1032	1209	965	827	1400	1309	1503	991	726	845
Seybouse Ain Ben Baida	954	1635	1965	1430	1235	1087	934	504	935	974	1090	1268
Zimba	1453	1542	1968	1845	985	963	734	822	845	985	913	1008
Bou sora	1236	1054	1624	865	954	751	789	966	1502	1325	752	865
Hellia	864	681	968	864	587	785	834	913	997	1025	1324	975
Charef	989	1715	1753	1798	1465	1547	1400	963	801	965	873	921
Bouhamdane I	1103	1398	1365	1712	945	847	599	865	931	1603	1235	993
Salah Salah Salah	1301	1832	1711	1839	1853	1515	1294	985	951	894	975	1120
Echham	1420	1536	1605	1207	950	536	684	604	799	825	801	967
Bouhamdane II	1542	968	1522	968	547	565	854	758	940	1230	1435	1702
Medjez el bgare	832	918	865	964	597	752	731	966	814	1094	922	632
Salinity (g/L)												
Seybouse El fadjoudj	0.5	0.7	0.8	0.5	0.7	0.6	0.4	0.8	0.1	0.3	0.6	0.8
Seybouse Bouchegouf	0.3	0.2	0.2	0.3	0.2	0.5	0.4	0.7	0.5	0.4	0.6	0.4
Seybouse Ain Ben Baida	0.6	0.3	0.1	0.3	0.2	0.4	0.4	0.6	0.4	0.5	0.7	0.5
Zimba	0.6	0.7	0.7	0.8	0.6	0.4	0.7	0.5	0.7	0.5	0.7	0.4
Bou sora	0.4	0.2	0.6	0.7	0.5	0.2	0.4	0.5	0.7	0.8	0.6	0.7
Hellia	0.5	0.3	0.3	0.2	0.4	0.6	0.5	0.4	0.6	0.7	0.6	0.4
Charef	0.2	0.4	0.5	0.6	0.2	0.4	0.5	0.3	0.1	0.2	0.6	0.5
Bouhamdane I	0.3	0.5	0.1	0.5	0.3	0.4	0.2	0.6	0.4	0.7	0.6	0.8
Salah Salah Salah	0.6	0.4	0.6	0.7	0.6	0.8	0.5	0.4	0.5	0.1	0.3	0.2
Echham	0.4	0.3	0.1	0.3	0.2	0.4	0.6	0.7	0.6	0.5	0.5	0.6
Bouhamdane II	0.4	0.2	0.2	0.1	0.3	0.5	0.6	0.5	0.3	0.6	0.4	0.7
Medjez el bgare	0.6	0.7	0.2	0.1	0.5	0.6	0.2	0.4	0.7	0.5	0.8	0.4
pH												
Seybouse El fadjoudj	0.5	0.7	0.8	0.5	0.7	0.6	0.4	0.8	0.1	0.3	0.6	0.8
Seybouse Bouchegouf	0.3	0.2	0.2	0.3	0.2	0.5	0.4	0.7	0.5	0.4	0.6	0.4
Seybouse Ain Ben Baida	0.6	0.3	0.1	0.3	0.2	0.4	0.4	0.6	0.4	0.5	0.7	0.5
Zimba	0.6	0.7	0.7	0.8	0.6	0.4	0.7	0.5	0.7	0.5	0.7	0.4
Bou sora	0.4	0.2	0.6	0.7	0.5	0.2	0.4	0.5	0.7	0.8	0.6	0.7
Hellia	0.5	0.3	0.3	0.2	0.4	0.6	0.5	0.4	0.6	0.7	0.6	0.4
Charef	0.2	0.4	0.5	0.6	0.2	0.4	0.5	0.3	0.1	0.2	0.6	0.5
Bouhamdane I	0.3	0.5	0.1	0.5	0.3	0.4	0.2	0.6	0.4	0.7	0.6	0.8
Salah Salah Salah	0.6	0.4	0.6	0.7	0.6	0.8	0.5	0.4	0.5	0.1	0.3	0.2
Echham	0.4	0.3	0.1	0.3	0.2	0.4	0.6	0.7	0.6	0.5	0.5	0.6
Bouhamdane II	0.4	0.2	0.2	0.1	0.3	0.5	0.6	0.5	0.3	0.6	0.4	0.7
Medjez el bgare	0.6	0.7	0.2	0.1	0.5	0.6	0.2	0.4	0.7	0.5	0.8	0.4

Table 2. Continued...

Conductivity (mS/cm)												
Sites	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**
Oxygen (mg/L)												
Sites	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept
Seybouse El fadjoudj	0.20	0.19	0.17	0.28	0.33	0.07	0.4	0.20	0.32	0.24	0.28	0.34
Seybouse Bouchegouf	0.29	0.10	0.05	0.09	0.14	0.08	0.19	0.20	0.24	0.15	0.20	0.24
Seybouse Ain Ben Baida	0.07	0.10	0.05	0.08	0.10	0.09	0.18	0.15	0.20	0.24	0.28	0.09
Zimba	0.12	0.29	0.70	0.50	0.15	0.31	0.11	0.80	0.25	0.40	0.10	0.08
Bou sora	0.09	0.14	0.15	0.08	0.29	0.09	0.05	0.17	0.24	0.08	0.34	0.17
Hellia	0.21	0.17	0.25	0.29	0.20	0.35	0.32	0.35	0.28	0.19	0.18	0.24
Charef	0.14	0.17	0.29	0.19	0.12	0.08	0.07	0.06	0.15	0.2º	0.07	0.09
Bouhamdane I	0.53	0.40	0.70	0.54	0.49	0.20	0.40	0.60	0.80	0.85	0.90	0.92
Salah Salah Salah	0.10	0.08	0.30	0.04	0.17	0.10	0.04	0.06	0.12	0.09	0.10	0.15
Echham	0.30	0.34	0.20	0.25	0.19	0.30	0.33	0.20	0.40	0.35	0.24	0.29
Bouhamdane II	0.40	0.30	0.30	0.50	0.20	0.40	0.50	0.30	0.20	0.40	0.50	0.70
Medjez el bgare	0.45	0.30	0.90	0.89	0.65	0.80	0.70	1.20	2.03	0.90	0.81	0.60
Depth (cm)												
Seybouse El fadjoudj	19.4	23.5	25.2	29.6	34.2	40.3	42.32	46.8	60.0	56.1	41.8	31.9
Seybouse Bouchegouf	29.5	28.3	26.2	30.4	32.5	34.5	42.6	45.0	49.2	45.9	39.0	37.2
Seybouse Ain Ben Baida	29.0	30.4	32.5	38.1	39.8	40.2	49.0	51.2	45.0	37.2	28.0	25.9
Zimba	31.0	25.6	23.0	21.0	40.9	39.0	50.6	61.6	71.9	60.0	55.9	32.2
Bou sora	7.0	10.3	16.1	20.6	32.4	34.9	22.1	16.1	11.9	9.6	8.2	7.5
Hellia	22.5	24.9	28.0	30.1	34.5	35.9	37.0	36.9	31.2	28.3	23.2	24.0
Charef	41.3	36.2	50.2	79.5	82.3	60.0	86.0	98.7	98.1	72.1	49.8	45.3
Bouhamdane I	49.2	48.0	50.0	52.0	54.5	59.0	68.2	76.3	71.2	66.0	54.3	50.5
Salah Salah Salah	25.0	21.1	30.5	35.1	37.0	4.2	40.6	76.6	64.21	57.3	31.2	29.9
Echham	20.3	21.5	20.5	22.0	25.5	27.4	30.1	46.0	32.0	25.3	21.5	19.6
Bouhamdane II	75.0	87.6	82.8	94.2	100.8	101.2	112.0	92.6	86.5	84.8	81.0	79.9
Medjez el bgare	45.3	47.0	52.0	54.0	59.1	59.8	68.3	70.5	64.0	56.2	51.2	49.9
Turbidity (NTU)												
Seybouse El fadjoudj	88.0	978.0	547.2	235.0	30.5	118.0	1035.0	86.0	245.0	652.2	21.3	120.0
Seybouse Bouchegouf	70.6	19.2	13.9	355.0	10.9	67.6	598.2	155.0	401.0	213.6	1003.0	365.0
Seybouse Ain Ben Baida	1036.0	15.6	18.3	258.1	19.4	9.6	366.0	478.0	78.3	45.2	563.9	354.0
Zimba	971.0	64.5	40.8	19.5	354.0	103.0	565.2	64.3	854.0	244.0	19.4	150.0
Bou sora	296.0	71.5	80.0	98.2	1324.0	247.0	1097.0	503.0	950.0	621.3	98.4	67.9
Hellia	160.0	730.0	40.3	89.0	12.9	954.0	658.2	988.7	1079.0	55.8	604.0	90.0
Charef	30.4	11.5	16.5	9.5	399.0	18.9	116.0	364.0	401.0	308.0	115.0	17.5
Bouhamdane I	67.0	647.0	10.32	34.2	614.0	47.6	21.3	437.0	632.1	365.0	41.2	16.4
Salah Salah Salah	29.5	87.1	20.9	15.4	29.6	41.2	179.0	265.0	369.0	45.3	16.8	130.0
Echham	146.2	945.0	60.2	45.2	13.4	203.0	80.1	703.0	588.9	365.0	685.1	544.2
Bouhamdane II	968.2	20.4	921.0	119.5	546.3	804.3	736.0	143.2	19.2	15.8	203.0	658.0
Medjez el bgare	485.0	109.0	645.0	49.5	985.0	1024.0	896.0	1268.0	795.0	856.0	265.0	694.0
Suspended matter (mg/L)												
Sites	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept
Seybouse El fadjoudj	61.0	109.0	36.0	84.5	106.0	1023.0	965.5	601.9	45.3	210.5	235.6	75.0
Seybouse Bouchegouf	36.2	50.5	530.5	803.2	654.0	321.0	132.5	231.8	485.0	95.0	78.1	230.0
Seybouse Ain Ben Baida	70.1	136.0	987.0	1032.0	456.0	658.7	466.0	758.0	456.2	64.0	96.0	40.0
Zimba	280.5	205.0	132.5	231.0	1811.0	756.0	2013.0	651.5	1079	936.5	320.0	136.0
Bou sora	70.0	29.0	56.0	130.2	65.0	145.0	241.5	96.0	452.5	325.1	105.0	214.0
Hellia	60.0	132.0	254.3	152.0	80.1	104.0	352.0	654.0	486.0	912.5	1036.0	74.2
Charef	45.0	42.0	64.0	60.0	362.5	51.0	352.0	846.0	632.0	436.0	321.0	102.5
Bouhamdane I	63.1	145.9	168.5	213.0	98.4	236.4	654.0	988.5	421.0	206.9	104.0	94.0
Salah Salah Salah	102.5	65.0	43.5	33.0	40.0	122.5	265.0	620.0	806.0	431.5	439.9	198.0
Echham	845.3	765.0	32.1	46.0	98.5	103.0	436.1	521.9	869.0	1079.0	1985.0	965.5
Bouhamdane II	325.5	365.0	985.3	519.0	465.0	646.0	64.6	256.7	364.0	40.0	98.1	65.1
Medjez el bgare	106.4	436.0	41.0	845.0	103.5	364.2	620.0	400.5	50.2.	91.0	63.2	230.0
Depth (cm)	61.0	109.0	36.0	84.5	106.0	1023.0	965.5	601.9	45.3	210.5	235.6	75.0

Table 2. Continued...

Conductivity (mS/cm)												
Sites	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**
Nitrite (mg/L)												
Seybouse El fadjoudj	0.12	0.05	0.40	0.60	0.02	0.10	0.30	0.08	0.15	0.70	0.30	0.09
Seybouse Bouchegouf	0.50	0.13	0.30	0.12	0.60	0.09	0.70	0.11	0.20	0.05	0.30	0.19
Seybouse Ain Ben Baida	0.05	0.60	0.40	0.10	0.16	0.04	0.12	0.30	0.09	0.50	0.40	0.18
Zimba	0.30	0.14	0.30	0.09	0.15	0.08	0.10	0.07	0.16	0.50	0.18	0.11
Bou sora	0.10	0.40	0.06	0.08	0.10	0.14	0.60	0.20	0.13	0.08	0.15	0.06
Hellia	0.30	0.10	0.12	0.70	0.06	0.30	0.50	0.09	0.01	0.30	0.40	0.19
Charef	0.14	0.12	0.16	0.60	0.16	0.70	0.15	0.07	0.09	0.15	0.10	0.09
Bouhamdane I	0.40	0.09	0.10	0.09	0.13	0.20	0.50	0.17	0.50	0.06	0.10	0.14
Salah Salah Salah	0.05	0.04	0.07	0.04	0.05	0.05	0.06	0.06	0.07	0.04	0.02	0.05
Echham	0.08	0.20	0.13	0.30	0.40	0.09	0.10	0.16	0.20	0.40	0.30	0.17
Bouhamdane II	0.15	0.60	0.09	0.14	0.07	0.60	0.20	0.18	0.08	0.50	0.10	0.06
Medjez el bgare	0.08	0.16	0.06	0.10	0.50	0.17	0.30	0.05	0.07	0.60	0.70	0.30
Nitrate (mg/L)												
Seybouse El fadjoudj	0.99	1.26	1.90	2.13	3.16	1.03	0.95	2.03	5.25	3.06	4.51	2.64
Seybouse Bouchegouf	11.32	10.32	8.54	10.54	9.12	7.36	6.14	1.32	5.24	6.87	5.25	9.13
Seybouse Ain Ben Baida	8.36	4.25	9.40	7.32	10.54	6.54	4.50	5.98	734.00	2.32	10.20	1.05
Zimba	9.65	10.08	11.50	7.12	10.30	6.32	8.50	10.64	7.41	6.80	5.12	7.30
Bou sora	7.32	8.98	4.20	6.88	12.64	1.50	3.32	4.80	10.60	8.31	3.21	4.18
Hellia	1.87	0.99	9.68	3.49	5.50	7.84	3.56	1.97	2.36	4.41	1.09	3.24
Charef	4.21	5.12	0.45	0.95	4.65	5.17	0.95	4.21	1.32	6.31	0.96	2.50
Bouhamdane I	6.54	9.68	3.12	7.13	5.03	6.94	4.65	8.16	11.35	9.14	10.64	4.03
Salah Salah Salah	8.30	6.09	7.97	5.32	2.56	7.04	4.67	8.31	4.65	7.20	5.11	4.31
Echham	4.98	5.64	1.35	3.15	6.54	7.99	8.15	3.15	0.97	0.90	0.78	2.36
Bouhamdane II	1.32	3.21	0.56	0.79	1.65	4.32	0.98	3.01	1.16	5.02	2.98	0.98
Medjez el bgare	4.68	5.99	0.99	1.35	4.32	6.12	5.42	8.12	6.19	4.65	3.21	1.21
Water speed (cm/seg)												
Sites	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept
Seybouse El fadjoudj	27	37	36	21	24	31	42	49	51	58	43	49
Seybouse Bouchegouf	53	69	120	49	42	54	103	123	101	82	72	56
Seybouse Ain Ben Baida	65	70	75	89	94	76	108	124	100	94	90	54
Zimba	45	58	96	67	78	89	132	103	108	91	72	61
Bou sora	36	24	27	17	42	48	88	107	120	133	45	40
Hellia	34	38	21	32	30	41	68	79	42	40	39	24
Charef	54	60	66	45	50	51	58	101	74	109	65	57
Bouhamdane I	42	24	54	56	89	90	92	78	62	69	53	51
Salah Salah Salah	86	72	111	24	38	33	57	115	103	64	78	83
Echham	0	0	0	0	0	0	0	0	0	0	0	0
Bouhamdane II	52	73	98	78	82	99	106	112	70	71	62	51
Medjez el bgare	0	0	0	0	0	0	0	0	0	0	0	0

Table 3. Results of invertebrate reported for studied sites (ind/m²).

site	taxa	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Seybouse El fadjoudj	Gastropoda	1	2	2	0	1	0	0	0	0	0	0	1
	Cerridae	0	1	0	0	0	0	0	0	0	0	0	0
	Gammaridae	8	15	24	4	18	23	31	22	27	21	25	29
	Corixidae	1	2	0	0	3	9	2	5	5	1	1	2
	Coleoptera	0	1	0	3	0	0	0	0	0	0	0	0
	Lepidoptera	8	13	1	11	2	10	2	9	10	11	4	8
	Hydrophilidae	0	0	1	1	0	0	0	0	0	0	0	0
	Siphlonuridae	0	0	2	0	3	7	4	2	4	4	8	6
	Zygoptera	0	0	0	0	0	1	1	0	0	0	0	0
	Noteridae	0	0	0	0	0	1	0	0	0	0	0	0
	Gerridae	0	0	0	0	0	1	1	0	1	0	1	0
	Culicidae	0	0	0	0	0	0	0	0	1	0	0	0
	Mesoveliidae	0	0	0	0	0	0	0	0	1	0	0	0
	Neidae	0	0	0	0	0	0	0	0	0	1	0	0
	Chironomidae	1	0	0	0	0	0	0	0	0	0	0	0
	Baetidae	4	5	0	0	0	0	0	0	0	0	0	2
	Simuliidae	4	3	0	0	0	0	0	0	0	0	0	3
	Haliplidae	0	0	0	0	0	0	0	0	1	0	0	0
Seybouse Bouchegouf	Gastropoda	0	0	1	0	0	0	0	0	0	0	0	0
	Gammaridae	0	0	0	4	5	1	3	1	0	1	0	2
	Corixidae	42	67	12	38	206	74	24	81	49	21	29	62
	Coleoptera	0	0	0	1	0	0	0	0	1	0	0	0
	Caenidae	0	0	0	1	0	1	0	2	0	0	0	0
	Baetidae	1	4	5	10	11	6	5	4	2	11	0	6
	Chironomidae	2	3	0	0	0	0	0	0	0	0	0	2
	Zygoptera	0	0	0	2	0	0	0	0	0	0	0	0
Seybouse Ain Ben Baida	Gastropoda	6	2	0	1	3	2	4	6	1	0	0	1
	Gammaridae	17	29	15	24	11	13	9	24	51	37	12	10
	Corixidae	12	31	17	28	5	25	36	19	13	9	2	3
	Coleoptera	0	0	0	1	0	0	0	0	2	0	4	0
	Caenidae	0	0	1	3	5	1	9	17	4	0	0	0
	Gerridae	0	0	0	0	0	0	0	0	0	1	2	0
	Baetidae	3	1	0	2	0	0	0	0	0	5	9	4
	Chironomidae	0	0	0	0	0	0	0	0	0	2	5	3
Zimba	Caenidae	0	0	0	1	0	0	2	1	2	3	0	0
	Gerridae	0	0	1	0	0	0	0	0	0	0	0	0
	Baetidae	1	0	6	6	1	0	0	0	3	0	0	0
	Chironomidae	2	13	7	10	2	2	12	9	5	12	3	14
	Simulidae	3	3	0	0	2	3	4	4	0	0	0	2
Bou sora	Gastropoda	2	3	7	1	2	4	3	1	3	3	1	4
	Corixidae	2	4	1	0	0	0	0	0	0	3	4	1
	Coleoptera	0	0	1	0	0	0	0	0	2	0	1	0
	Caenidae	0	0	0	2	1	3	1	0	0	0	0	0
	Gerridae	0	0	1	0	0	1	0	0	0	0	0	0
	Chironomidae	0	3	7	14	5	9	16	5	2	7	3	8

Table 3. Continued...

site	taxa	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Hellia	gastiropode	3	4	1	2	6	1	1	2	1	4	1	1
	Chironomidae	4	16	10	5	15	17	12	19	3	6	18	20
	Siphlonuridae	5	4	3	6	1	2	2	0	0	0	0	6
	Caenidae	0	0	0	0	0	0	0	0	0	0	0	0
	Culicidae	6	14	16	21	14	10	9	16	11	3	8	10
	Zygoptera	0	2	1	1	1	0	0	0	0	0	0	0
	Hydrophilidae	4	2	1	2	1	1	0	0	2	1	1	2
	Aeshnidae	0	0	1	0	0	0	0	0	0	0	0	0
	Noteridae	0	2	0	0	0	0	0	0	0	0	0	0
Charef	Gammaridae	0	0	0	0	0	9	6	4	2	7	5	0
	Corixidae	6	8	10	12	9	8	9	11	12	6	9	2
	Chironomidae	6	2	4	0	5	1	2	9	9	4	13	4
	Baetidae	0	0	0	2	1	4	2	1	4	12	20	17
	Siphlonuridae	0	0	2	2	2	1	2	0	5	0	0	0
	Caenidae	0	1	0	0	0	1	0	1	0	2	1	0
	coléoptère	1	0	1	9	0	0	1	0	2	0	0	1
	hydropsychidae	1	0	0	0	0	2	0	0	0	0	0	3
	Culicidae	0	0	0	0	1	0	0	1	0	0	0	0
	Hydrophilidae	0	0	5	0	6	1	0	0	0	0	0	0
	Mesoveliidae	0	1	2	0	0	0	0	0	1	0	0	0
	hydromitridae	0	0	1	0	0	1	1	0	1	0	0	0
	Simuliidae	2	1	0	0	0	0	0	2	1	1	2	5
Bouhamdane I	Gastropoda	1	2	3	2	0	0	3	2	5	0	0	1
	Gammaridae	91	82	35	160	79	56	201	40	39	19	63	52
	Corixidae	9	3	13	0	0	0	0	0	0	9	2	12
	Coleoptera	0	0	0	1	0	1	4	1	0	0	0	0
	Hydrophilidae	0	0	0	1	0	0	0	0	0	0	0	2
	Siphlonuridae	0	0	2	0	0	0	1	0	0	0	0	1
	Hydropsichidae	1	0	0	0	0	0	0	0	0	0	0	1
	Caenidae	0	1	2	0	0	0	0	0	0	0	0	2
	Gerridae	0	0	0	0	0	1	0	0	0	0	0	0
	Baetidae	12	8	5	6	0	0	5	4	9	0	0	2
	Mesoveliidae	0	1	0	0	0	0	0	0	0	0	0	0
	Chironomidae	11	6	9	15	4	5	8	2	0	0	16	10
	Zygoptera	0	0	0	0	1	0	0	0	0	0	0	0
Salah salah salah	Gastropoda	0	2	2	0	0	4	6	1	1	0	0	0
	Gammaridae	49	56	61	34	25	41	33	74	39	45	57	29
	Coleoptera	0	0	0	0	0	0	0	0	0	0	0	1
	Siphlonuridae	84	46	19	42	39	16	12	21	34	13	0	0
	Caenidae	0	0	0	22	19	24	21	15	0	0	0	2
	Gerridae	0	1	0	1	0	0	0	0	0	0	0	1
	Chironomidae	0	3	0	0	0	0	0	0	0	0	3	2
	Baetidae	0	82	14	13	20	52	14	0	0	6	0	2
	Simuliidae	1	3	0	0	0	0	0	0	0	0	0	0
	Hydropsichidae	37	54	12	17	20	4	4	1	2	0	0	0
	Curculionidae	0	1	0	0	0	0	0	0	0	0	0	0
	Oligochaeta	0	3	0	0	0	0	0	0	0	0	0	0
	Aeshnidae	0	0	1	0	0	0	0	0	0	0	0	0
	Rotschildae	3	0	0	0	0	0	0	0	0	0	0	0

Table 3. Continued...

site	taxa	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Echham	Gastropoda	0	1	1	3	1	0	2	1	3	0	0	0
	Chironomidae	0	2	1	4	2	1	6	0	0	0	0	2
	Baetidae	1	3	0	2	0	0	0	0	0	0	1	0
	Siphlonuridae	3	8	2	11	21	19	10	15	3	2	0	0
	Caenidae	0	0	1	0	0	0	0	0	0	0	1	0
	Coleoptera	0	0	0	1	0	0	0	0	0	1	0	0
	Hydrophilidae	0	0	2	1	0	0	0	0	0	0	0	1
	Gerridae	0	0	0	0	0	0	0	0	0	1	0	1
Bouhamdane II	Corixidae	14	28	34	12	9	0	0	0	0	0	0	16
	Coleoptera	1	0	2	1	4	0	0	0	1	0	0	1
	Hydrophilidae	1	0	0	0	0	0	0	0	0	0	1	0
	Siphlonuridae	0	0	9	11	29	17	0	8	0	0	0	0
	Hydropsichidae	0	0	0	1	2	0	0	0	0	0	0	0
	Caenidae	0	0	0	5	7	4	2	6	1	4	3	5
	Chironomidae	3	9	6	7	2	5	9	3	4	1	1	3
	Zygoptera	0	0	0	0	1	0	0	0	0	0	0	0
Medjez el bgare	Corixidae	16	10	7	11	6	10	13	9	23	12	17	10
	Coleoptera	2	4	3	3	1	2	0	2	1	6	1	2
	Lepidoptera	0	0	0	3	0	0	0	0	0	0	0	0
	Siphlonuridae	3	1	2	0	0	0	0	0	0	0	0	1
	Caenidae	0	1	0	0	1	1	0	0	0	0	0	0
	Mesoveliidae	0	0	0	0	1	0	0	0	0	0	0	0
	Chironomidae	19	25	28	31	21	29	18	26	14	31	15	30
	Culicidae	0	2	4	0	1	0	0	0	2	1	0	0

Community Structure: the results of RDA revealed for abiotic parameters that the main contributor parameters are water velocity, pH, turbidity for RDA1, and dissolved oxygen, turbidity and pH for RDA2 (Table 4). Whereas for biotic variables the main contributor parameters were Gammaridae, Corixidae and Baetidae for RDA1, and Gammaridae, Siphlonuridae, Chironomidae, Hydropshicidae and Baetidae for RDA 2 (Table 4). The RDA revealed that ten sites are relatively similar in biotic and abiotic parameters, nevertheless there are two different sites, first site Bouhamdane I stream has high depth and high pH with high Corixidae and Chironomidae abundances, whereas the second site Salah Salah Salah stream, is characterized by high water speed, high conductivity and high abundance of Gammaridae, Hydropsichidae, Baetidae and Siphlonuridae (Figure 2).

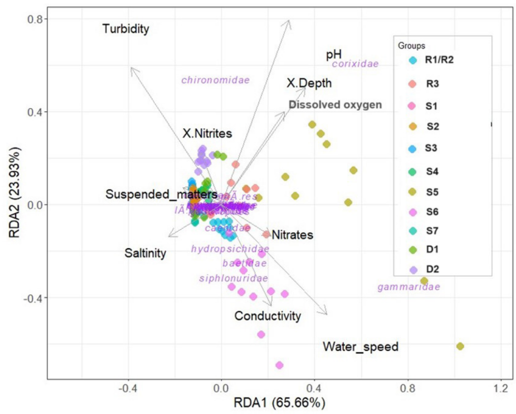

Figure 2. Redundancy analysis (RDA) of the macroinvertebrate communities of aquatic systems for studied sites. A forward modeling procedure selected turbidity, pH, conductivity, and water speed as predictors (Code sites see Table 1).

Null model in ecology: the results of co-occurrence of species of the sampled sites showed a pattern of random co-occurrence (or absence of structured pattern), except in two sites of Seybouse river: El fadjoudj (P = 0.002) and Ain Ben Baida (P = 0.001), where the co-occurrence of species showed a structured pattern (Table 5). Whereas the niche sharing results revealed that there is no niche sharing and in consequence, there is no interspecific competition except in the two sites: Salah salah salah stream and Bouhamdane II dam (P = 0.0010 and P = 0.0080, respectively), which there is niche sharing that leads to the existence of interspecific competition (Table 6).

Table 4. Contribution of abiotic and biotic parameters for studied sites.

Abiotic parameters	RDA1	RDA2	Biotic parameters	RDA1	RDA2
Conductivity	0.21251	-0.43752	Gastropoda	-0.05397	-0.13124
Salinity	-0.22754	-0.13752	Cerridae	-0.00824	-0.00028
Dissolved oxygen	0.28896	0.79407	Gammaridae	5.72518	-1.51984
Water speed	0.45217	-0.47284	Corixidae	4.09584	2.61951
pH	0.35848	0.50338	Coleoptera	0.04063	0.16735
Maximum depth	0.26918	0.39926	Lepidoptera	-0.32861	-0.08261
Turbidity	-0.38860	0.59137	Hydrophilidae	-0.03915	-0.03915
Suspended matter	-0.16719	0.07395	Siphlonuridae	0.36986	-1.36389
Nitrite	-0.09016	0.22593	Zygoptera	-0.01445	0.01007
Nitrate	0.21388	-0.13527	Noteridae	-0.01623	0.00053
			Gerridae	0.00382	-0.02201
			Culicidae	-0.46235	0.19171
			Mesoveliidae	0.01011	-0.00206
			Neidae	-0.00237	0.00148
			Chironomidae	-0.18756	2.31843
			Baetidae	0.70620	-1.06112
			Simuliidae	0.01194	-0.09667
			Haliplidae	0.00189	0.00049
			Hydropsichidae	0.26201	-0.81679
			Caenidae	0.19012	-0.40667
			Aeshnidae	0.00174	-0.00723
			Hydromitridae	0.01130	-0.01047
			Curculionidae	0.00035	-0.00664
			Oligochaeta	0.00105	-0.01991
			Rotschildae	0.01182	-0.01267

Table 5. Species co-occurrence null models' data.

Codes site	Observed index	Mean index	Standard effect size	Variance	P
R1	2.375	2.179	2.960	0.004	0.002*
R2	4.786	3.939	5.232	0.026	0.001*
R3	1.928	1.972	-0.271	0.026	0.581 n.s
S1	5.100	5.112	-0.058	0.423	0.673 n.s
S2	3.733	3.734	-0.004	0.050	0.450 n.s
S3	0.142	0.142	Not detectable	0.000	0.999 n.s
S4	5.692	5.572	1.215	0.009	0.146 n.s
S5	2.449	2.451	-0.020	0.011	0.501 n.s
S6	2.681	2.413	2.400	0.012	0.222 n.s
S7	5.178	5.078	0.380	0.069	0.347 n.s
D1	2.449	2.451	-0.020	0.011	0.501 n.s
D2	1.143	1.218	-1.032	0.005	0.907 n.s

Code site see Table 1; *"P" values lower than 0.05 denoted structured patterns in species associations; "P" values upper than 0.05 denoted presence of random in species associations, or not significant (n.s) structured pattern.

Table 6. Niche sharing null models' data.

Codes site	Observed index	Mean index	Standard effect size	Variance	P
R1	0.2412	0.2295	0.6945	0.0002	0.2290 n.s
R2	0.2927	0.2706	0.5867	0.0014	0.2450 n.s
R3	0.4056	0.3689	1.0983	0.0011	0.1250 n.s
S1	0.3368	0.3552	-0.3311	0.0030	0.5890 n.s
S2	0.3841	0.3807	0.0734	0.0021	0.4040 n.s
S3	Not detectable	Not detectable	Not detectable	Not detectable	Not detectable
S4	0.3263	0.3523	-1.1739	0.0049	0.9020 n.s
S5	0.2952	0.2717	1.0307	0.0005	0.1530 n.s
S6	0.3488	0.2428	4.4634	0.0005	0.0010 *
S7	0.2863	0.2846	0.0434	0.0015	0.4340 n.s
D1	0.4375	0.3172	3.3137	0.0013	0.0080*
D2	0.3590	0.3640	-0.1690	0.0008	0.5270 n.s

Code site see Table 1; *"P" values lower than 0.05 denoted niche sharing and in consequence interspecific competition; "P" values upper than 0.05 denoted absence of niche sharing, or not significant (n.s) effect.

4. Discussion

The result proved by the RDA analysis, revealed water velocity, pH, turbidity, and dissolved oxygen are the most important abiotic conditioning factor for composition of benthic communities, it is due because high velocity are associated with running waters in upper zones of river course that under natural conditions have low conductivity, high pH, high oxygen level [O_2] and low turbidity that in consequence the environment has low productivity for that can sustain the species diversity (Baaloudj et al., 2022). The presence of high velocity water is a stressor agent that don´t allow the assessment of benthic invertebrates (De los Ríos-Escalante et al., 2020a). Whereas sites with low pH, low oxygen level [O_2], high turbidity, low velocity are associated with lower zones of river course with high conductivity due high nutrients and mineral concentrations due the accumulation from medium and upper zones, that in consequence generate environments with high productivity and high species abundances (Baaloudj et al., 2022). The most abundant taxa for all sites are Corixidae and Gammaridae, and the most abundances were reported mainly between February to June, that would correspond to Northern Hemisphere spring that would corresponds to the end of short-wet season (Chaib et al., 2023).

The RDA also denoted, that ten sites were relatively similar in abiotic and biotic parameters. Whereas two sites were different in the biotic parameters, mainly abundance of specific groups for Salah salah salah stream (Gammaridae, Hydropsichidae, Baetidae and Siphlonuridae) and Boudhame I stream (Corixidae and Chironomidae) was reported for sites with high nutrients concentrations and organic matter inputs from upper zones of the river, surrounding basin, it is because these groups are tolerant to high organic matter concentration waters (Haouchine, 2011; Zebsa et al., 2014a, b; Khelifa et al., 2016; Baaloudj et al., 2020; Rouibi et al., 2021). These kinds of benthic invertebrate structure were like other descriptions for Algerian and Moroccan rivers (Bagella et al., 2010; Baaloudj et al., 2020; Zouggaghe, 2020; Rouibi et al., 2021; Chaib et al., 2023).

The results of null model species co-occurrence denoted random absence (or structured pattern) in species associations was reported for two sites of Seybouse river (El fadjoudj and Ain ben baida). This result corresponds, to marked differences in species composition for both sites, due to differences in water velocity and conductivity for each site, because Ain ben baida due its location in upper zone of river course (lotic river) would have high water velocity and low conductivity, whereas El fadjoudj due its location in lower zone of river course (lentic river) would have low water velocity and high conductivity. It is because the water velocity decreases from upper to lower zones along river course, due topographical conditions, whereas the conductivity varies along river course due variations in nutrients and mineral inputs from surrounding basin due natural conditions (Figueroa et al., 2003; Rouibi et al., 2021). These results are like descriptions for Algerian (Chaib et al., 2023; Baaloudj et al., 2022) and Chilean rivers (De los Ríos-Escalante et al., 2020a).

The results of null model niche sharing, denoted its absence such as was observed for sites Salah Salah Salah stream and Bouhamdane II dam, both sites share the characteristic of high conductivity and low water velocity, that in consequence would provide the environmental conditions in example nutrients or organic matter concentration for allow the presence of niche sharing and in consequence the presence of interspecific competition (De los Ríos-Escalante et al., 2020b).

As conclusion, the results of our study revealed the existence of marked differences in community structure in term of diversity and dominant species for studied sites. The potentials causes would be the marked geographical isolation and environmental heterogeneity of studied sites, as well as the spatial differences within same water body, in example between same river course (Boix et al., 2009; Figueroa et al., 2003, 2007, 2013; De los Ríos-Escalante et al., 2020a; Vega et al., 2020; Barile et al., 2021; Figueroa and De los Ríos-Escalante, 2021; Chaib et al., 2023). However, further ecological studies would be necessary to better understand the functions of this ecosystem in Algeria.

Acknowledgements

The present project was financed by projects MECESUP UCT 0804, and the authors express their gratitude to M.I. and S.M.A., for their valuable suggestions for improve the manuscript. Also, we thank Ministère de l'Enseignement Supérieur et de la Recherche Scientifique (MESRS) for funding the project. We thank Dr. Dambri Besma for helpful advice in macroinvertebrate sampling,

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