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Inventory and pattern of distribution of mayflies (Insecta, Ephemeroptera) in the Draa river basin, southern Morocco

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Abstract

The Draa river basin is located south of the High Atlas Mountain rangee in Morocco. The Ephemeroptera (mayflies) fauna of its three sub-basins: the High, Middle, and Lower Draa are poorly known. This study contributes to the knowledge of Ephemeroptera and its distribution in relation to environmental parameters in this area. The larvae of Ephemeropteran species were collected during six field campaigns in 17 sites using a Surber sampler. A total of thirteen species belonging to ten genera and five families were identified. among which seven taxa were recorded for the first time in the southern Atlas area: *Baetis maurus*, *Baetis rhodani*, *Cheleocloeon dimorphicum*, *Cloeon simile*, *Procloeon stagnicola*, *Labiobaetis neglectus* and *Oligoneuriopsis skhounate*. The limits of distribution of most species can be explained by the increase in water temperature and electrical conductivity especially at lower altitudes.

Key Words

Bioindicators, biodiversity, Draa watershed, High Atlas, mayflies, Morocco

Introduction

Mayflies (order Ephemeroptera) have a worldwide distribution. being absent only in Antarctica and some remote oceanic islands (Barber-James et al. 2008; Jacobus et al. 2019). This order encompasses approximately 3.700 species. 450 genera. and 42 families (Sartori and Brittain 2015; Salles et al. 2018; Jacobus et al. 2019). The Ephemeroptera's larvae live in a variety of freshwater/aquatic habitats. including lakes, wetlands, streams and rivers (Bouchard 2004).

The development cycle of mayflies depends essentially on water. The larvae. after hatching from the egg undergo, a series of molts during their growth (Barber-James et al. 2008). The adult stage (subimago and imago) are the only terrestrial stages with only a short life span: from a few hours to a few days (Brittain 1982). Because of their reliance on water this order is useful in ecological studies particularly in estimating the biological quality and biomonitoring of freshwaters (Bauernfeind and Moog 2000). They have a great bioindicative value with respect to the disturbances undergone by the watercourses, in fact among the Ephemeroptera there are a certain number of species with strict ecological requirements (Bebba et al. 2015). They also have a great importance in the energy flow as they participate massively in the transfer of energy and carbon in the aquatic ecosystem (Bottova et al. 2012) and between the aquatic and terrestrial ecosystems, where they may be consumed by many riparian species such as birds, bats, spiders and lizards (Jacobus et al. 2019).

Since the twentieth and early twenty-first centuries, many mayfly-related studies have been carried out in Algeria (Soldan and Thomas 1985; Gagneur and Thomas 1988; Bebba et al. 2015; Mebarki et al. 2017; Benhadji et al. 2020; Lounaci et al. 2020; Samraoui et al. 2020) and in Tunisia (Boumaiza and Thomas 1986; Yalles-Satha et al. 2021). These studies have allowed to establish a list of 50 Algerian and 25 Tunisian species (Lounaci et al. 2000;

Zrelli et al. 2016 respectively). In Morocco the first studies of mayflies date back to Lestage (1925) and Kimmins (1938). Since 1970 further studies were carried out over almost all of Morocco. In 1983, Dakki and El Agbani 1983) established a first list of 26 species that was subsequently enriched by other authors (Alba-Tercedor and El Alami 1999; El Alami et al. 2000; Berrahou et al. 2001; Himmi et al. 2009; Chahboune et al. 2014; Lamri et al. 2016; El Bazi et al. 2017; Mabrouki et al. 2017, 2019; Berger et al. 2021). Recently a list of 54 species of mayflies was drawn up for Morocco (El Alami et al. 2022). This list has been updated to 55 by the discovery of a new species: *Centroptilum* cf. *luteolum* Kaltenbach, Vuataz & Gattolliat, 2022 (Kaltenbach et al. 2022).

Despite all those studies concerning Morocco, the Draa's Ephemeroptera remain still almost unknown. The last study of a small part of this basin dates back to 1989 (Bouzidi 1989) followed by the study conducted by Berger in 2017 (Berger et al. 2021). This area is located in a transition zone between the southern Atlas Mountains and the Saharan desert region that is strongly affected by climate change. This area is isolated from other parts of Morocco by the High Atlas Mountain barrier, the humid fresh winds condense the precipitations on the northern slope which leaves the southern slope under the effect of the hot sirocco of the desert with scarcity of precipitations (Ajakane and Boumezough 1996).

The objectives of this study are to update the list of Ephemeroptera by covering a large study area including the Upper, the Middle and a part of the Lower Draa. For this purpose, we have established the list of Ephemeroptera colonizing this basin and complete the inventory of Ephemeroptera for Morocco by adding different streams of the hydrographic network south of the High Atlas. Furthermore, we studied the environmental factors that shape the distribution of Ephemeroptera in the Draa basin, we also aim to locate in the study area the regions that have a high Mayfly diversity.

Materials and methods

Study area

The geography of Morocco is characterized by the presence of four mountain ranges: the Rif in the north and the Atlas in the center, which is divided into three range: the High Atlas, the Middle Atlas and the Anti Atlas). The Draa basin, subject of this study is located in the south of the High Atlas that covers the reliefs of the southern part of the High Atlas until the south of the city of Zagora and extends to the Atlantic Ocean in the West (Fig. 1). This basin is characterized by a heterogeneous topographic configuration: a mountainous zone, a zone of semi-desert plains, desert plains, a zone of desert plateaus and a coastal zone (Agence du Bassin Hydrolique souss massa Drâa 2008). The Draa River basin is located in an arid climate characterized by harsh winter with temperatures below -1 °C and hot summers with average temperatures of 45 °C. The number of rainy days varies between 30 and 40 between September and May (ABH 2012). In the mountainous zone, the climate can be humid, with precipitation that can cross the tops of the mountains.

The Draa basin covers an area of 115 000 km^2 (Agence du Bassin Hydrolique souss massa Drâa 2008) and is subdivided into three sub-basins (Fig. 1): the sub-basin of the Upper Draa is upstream of the El Mansour Eddahbi dam (near the city of Ouarzazate). Several streams, both temporary and permanent drain the Atlas into this dam: Ounilla, Iriri, Fint, Imini, Dades and its tributary Mgoune**.**

The sub-basin of the Middle Draa covers the area downstream of the El Mansour Eddahbi dam to the south of Zagora and extends to Mhamid El Ghizlane. It includes the main watercourse of Draa, which is dry during a large part of the year and whose water flow depends essentially on water releases from the dam.

The sub-basin of the Lower Draa, extends from the area of Mhamid El Ghizlane to the mouth of the Draa river in the Atlantic Ocean.

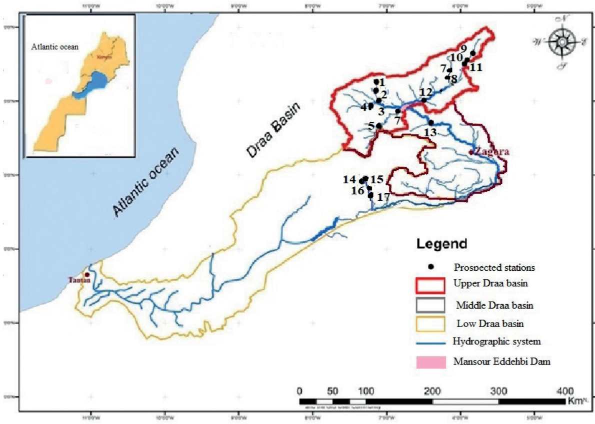

Figure 1. Location of the prospected sites in the sub-basins of the Draa river basin.

Seventeen sites were selected in the Draa basin (Table 1), twelve sites are located in the Upper Draa encompassing the mostly permanent streams that feed the El Mansour Eddahbi dam, three sites in Ounilla (St1-3), one in Iriri (St4), two in Fint (St5-6), two in Mgoune (St7-8) and four in Dades (St9-12). We originally selected four sites in the middle Draa, of which st13 and three others downstream between St13 and the city of Zagora in the Draa river. Unfortunately, the dryness of the river in this sub-basin did not allow us to make the sampling since 2020, except for the site at Tamnougalt (St13), which keeps a minimum of water with the releases of the dam. Furthermore, in the Lower Draa, the Draa river is completely dry, here we sampled in four sites that were located in a tributary of the Lower Draa: The Tissint stream (St14-17).

Table 1. List of the sites. UD: Upper Draa; MD: Middle Draa; LD: Lower Draa.

Basin	Site	Name	River	GPS Coordinates	Altitude (m.s.l.)	Sampling dates					
						Jun 19	Fe 20	Oct 20	Ap 21	May 21	Oct 21
UD	St1	Ounilla upstream	Ounilla	31°15.71'N, 7°9.24'W	1724		X	X	X	X	X
UD	St2	Ounilla middlestream	Ounilla	31°8.80'N, 7°8.43'W	1425		X	X	X	X	X
UD	St3	El mellah	Oued El maleh	31°0.69'N, 7°6.01'W	1228	X	X	X	X	X	
UD	St4	Iriri	Iriri	30°56.27'N, 7°12.60'W	1261		X	X	X	X	X
UD	St5	Ait douchene	Fint (up stream)	30°39.46'N, 7°05.56'W	1336		X	X	X	X	X
UD	St6	Tarmigt	Fint	30°51.91'N, 6°50.79'W	1114	X	X	X	X	X	X
UD	St7	Dades upstream	Dades	31°35.61'N, 5°52.36'W	1814		X	X		X	
UD	St8	Gorges de Dades	Dades	31°33.37'N, 5°54.51'W	1753	X	X	X		X	X
UD	St9	Middle Dades	Dades	31°30.28'N, 5°56.72'W	1656		X	X		X	X
UD	St10	Dades downstream	Dades	31°0.72'N, 6°29.61'W	1190		X	X		X	X
UD	St11	Mgoune upstream	Mgoune	31°21.83'N, 6°10.27'W	1545		X	X		X	X
UD	St12	Mgoune downstream	Mgoune	31°20.07'N, 6°10.82'W	1508		X	X		X	X
MD	St13	Tamnougalt	Draa	30°40.40'N, 6°24.36'W	919	X	X	X			X
LD	St14	Akka nait sidi 1 (left)	Tissint	29°54.57'N, 7°19.87'W	584		X	X	X	X	X
LD	St15	Akka nait sidi 2 (right)	Tributary tissint	29°54.71'N, 7°19.87'W	582		X	X	X	X	X
LD	St16	Tissint near the road	Tissint	29°49.54'N, 7°11.92'W	486	X	X	X	X	X	X
LD	St17	Mghimima	Zguid	29°46.81'N, 7°10.10'W	483	X	X	X	X	X	X

Sampling and sorting

The sampling was conducted from June 2019 to October 2021. The first sample in June 2019 was done following a qualitative protocol to know which site we could use in the subsequent samplings. Later, quantitative samplings were carried out using a 0.20 m × 0.25 m Surber sampler with a net mesh size of 500 µm. Twenty spots per site were sampled to cover all microhabitats over a length about ten times the width of the riverbed.

Samples were stored in airtight bottles with 70 % ethanol. Specimens were sorted preliminarily *in situ* to remove sediment and vegetation as much as possible. The final sorting was done in the laboratory under a binocular magnifying glass to separate the specimens to species level using morphological criteria. The identification of the larvae was made using various keys and original descriptions (Müller-Liebenau 1969; Soldan and Thomas 1985; Elliott et al. 1988; El Alami et al. 2000; Tachet et al. 2000; Bouchard 2004; Gattolliat and Sartori 2008).

Water temperature, electrical conductivity and pH.were measured using a multiparameter device (WTW Multiliner Multi 3510 IDS) (Table 2).

Data analysis

The correlations between water temperature, electrical conductivity, pH and species richness were studied using the Pearson correlation coefficient.

We used a cluster analysis (single linkage agglomerative clustering) using Euclidean distance to cluster sites with similar species composition.

A Correspondence Analysis (CA) based on species presence/absence data (frequencies) from all sampling periods combined was used to visualize differences in species composition between sites. Subsequently environmental variables from the respective sites were fitted to the CA plot, the mean number of specimens over time was used.per each locality. RStudio (version 1.2.5019) and the packages "Vegan" (Oksanen et al. 2019), "car" (Fox and Weisberg 2018) and "ggpubr" (Kassambara 2020) were used for statistical analysis.

Table 2. Physicochemical parameters measured during the sampling periods.

Sites	Temperature (C)		Conductivity (µS)		pH	
	Mean	SD	Mean	SD	Mean	SD
St1	20	4	1921	441	7.31	0.35
St2	19	4	2669	1074	7.45	0.34
St3	22	4	8999	2600	7.31	0.09
St4	20	2	602	34	7.68	0.20
St5	20	4	885	129	7.39	0.10
St6	26	1	1234	129	7.54	0.10
St7	15	5	754	67	7.58	0.50
St8	16	3	829	208	7.56	0.39
St9	16	3	1022	666	7.39	0.27
St10	18	5	1441	1291	7.48	0.26
St11	16	3	1120	614	7.67	0.38
St12	19	2	1126	217	7.40	0.18
St13	25	1	2167	386	7.35	0.07
St14	26	2	8986	2417	7.30	0.08
St15	25	4	6431	3542	7.32	0.15
St16	25	3	13098	5095	7.46	0.31
St17	25	5	13199	938	7.42	0.06

Results

Physicochemical parameters

Temperature was negatively correlated with altitude and pH (Table 2, Fig. 2A, B). Electrical conductivity was negatively correlated with altitude and positively correlated with water temperature (Fig. 2C, D). No correlation was found between pH and water temperature and electrical conductivity.

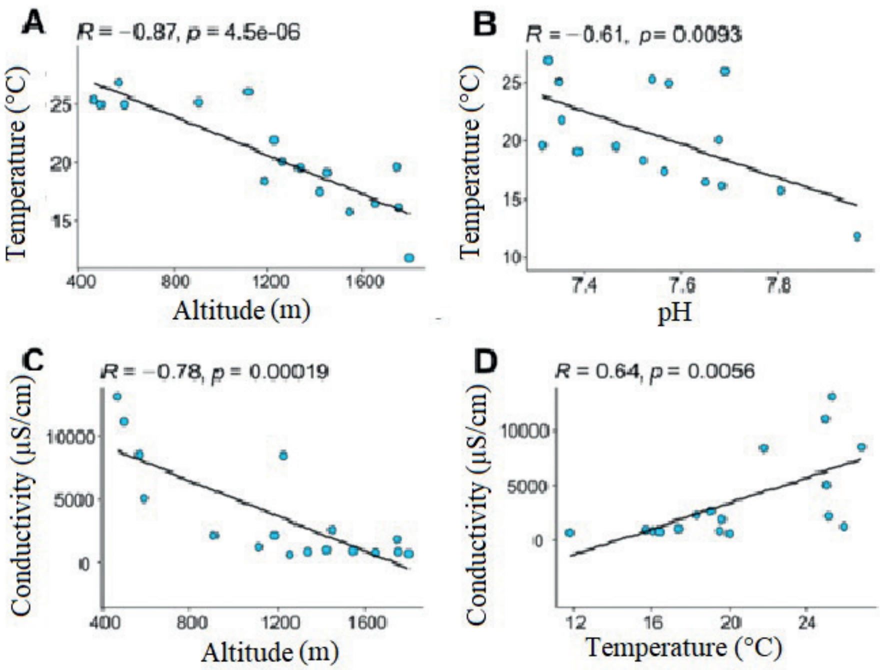

Figure 2. Significant correlation between environmental parameters. **A.** Water temperature/altitude; **B.** Water temperature/pH; **C.** Electrical conductivity/altitude; **D.** Electrical conductivity/water temperature.

Distribution of species

Thirteen species of Ephemeroptera belonging to ten genera and five families were identified in the basin during the samplings (Table 3), Per site we found from two to eleven species, with one species being present in all sites these (Table 3; Suppl. materal 1).

Concerning the number of species of Ephemeroptera by sub-basin (Fig. 3; Suppl. materal 1): The Upper Draa is the richest with 13 species collected (all species of the basin are present), the Middle Draa is less diversified with six species, the Lower Draa is the poorest with only two species.

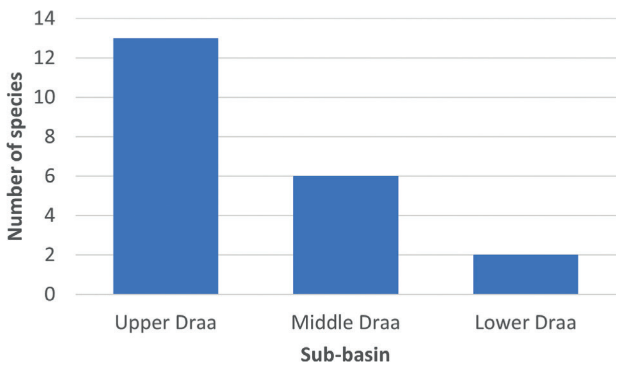

Figure 3. Number of species per sub-basin.

The family of Baetidae was the most diverse, with seven species, *Baetis pavidus* and *Caenis luctuosa* were the most widespread species, with a frequency (the number of sites where the species was found compared to the total number of sites surveyed) of 100% and 88.2% respectively (Table 3). The number of individuals collected varied from one sampling event to another (Suppl. materal 1). However, the presence of the species in each site did not vary (Suppl. materal 1) except for *Oligoneuriopsis skhounate*, which was collected only once in St10.

The number of species richness was negatively correlated with conductivity (Fig. 4A), and the water temperature was negatively correlated with altitude (Fig. 4B), Temperature does not predict species richness in this basin. (Fig. 4C). No correlation was found between pH and the number of species.

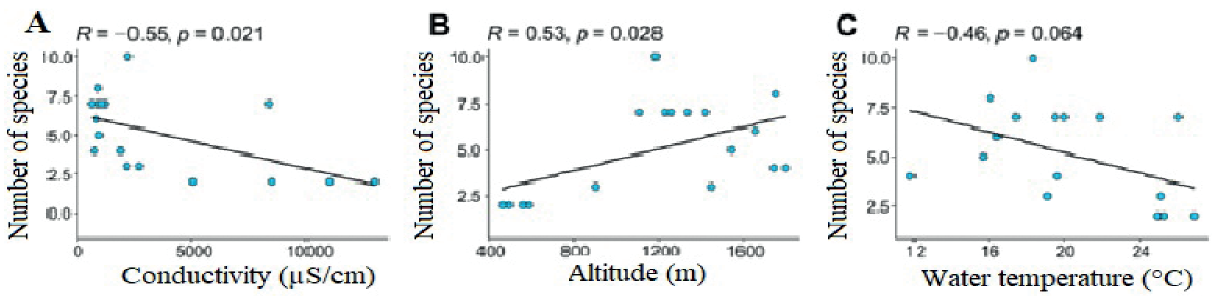

Figure 4. Number of species according to environmental parameters with correlations. **A.** Number of species/electrical conductivity; **B.** Number of species/altitudes; **C.** Number of species/water temperature.

Table 3. Distribution of Ephemeroptera in Draa basin.

Species\ Sites	*Caenis pusilla*	*Caenis luctuosa*	*Choroterpes atlas*	*Baetis maurus*	*Baetis rhodani*	*Baetis pavidus*	*Labiobaetis neglectus*	*Procloeon stagnicola*	*Cheleocloeon dimorphicum*	*Cloeon similie*	*Oligoneuriopsis skhounate*	*Ecdyonurus rhothchildi*	*Rhithrogena* sp.	Species richness
St1	+	+			+	+								4
St2		+				+								2
St3		+				+	+		+	+				5
St4		+	+			+		+	+	+				6
St5		+			+	+	+	+	+	+				7
St6		+	+			+	+	+	+	+				7
St7	+			+	+	+						+		5
St8	+	+			+	+	+					+	+	7
St9	+	+			+	+						+		5
St10	+	+	+		+	+	+			+	+	+	+	10
St11	+			+	+	+						+	+	6
St12	+	+		+		+						+	+	6
St13		+	+		+	+								4
St14		+				+								2
St15		+				+								2
St16		+				+								2
St17		+				+								2
Frequency	41.2	88.2	23.5	17.6	47.1	100	29.4	17.6	23.5	29.4	5.9	35.3	23.5	

The first two axes of the CA explained 47.2% of the total variation (Fig. 5). According to the CA plot, *Caenis luctuosa* and *Baetis pavidus* are present in almost all areas, even those with higher conductivity and higher water temperature (St314-17). One cluster of sites is associated with the correlated variables of lower altitude and higher temperature (Fig. 2A) and contains species like *Cheleocloeon dimorphicum* and *Cloeon similie*. The cluster of St10 is associated with the presence of *Oligoneuriopsis skhounate*, Sites St1, St2, St7, St9, St11 and St12 can be clustered by their altitudes, with the presence of species adapted to these altitudes, such as *Ecdyonurus rotschildi*, *Rhithrogena* sp. and *Caenis pusilla*.

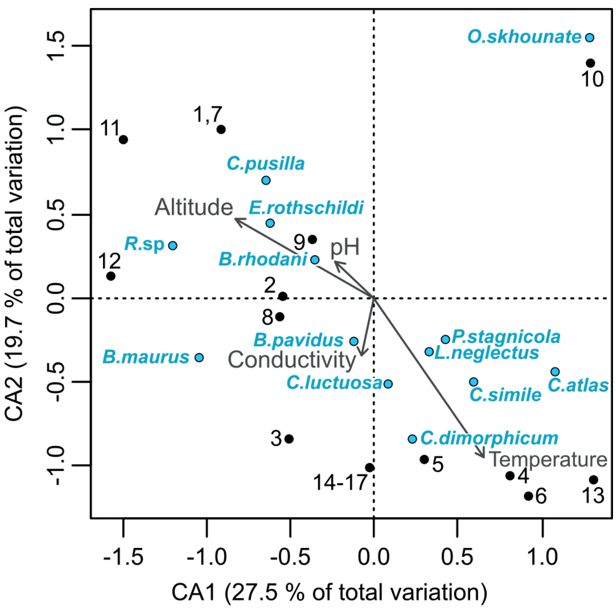

Figure 5. CA ordination plot (Scaling 2) with the relationship between environmental variables and Ephemeropteran species.

Discussion

Among the thirteen species found in this area. seven species were recorded for the first time in the Upper Draa sub-basin: *Baetis maurus*, *Baetis rhodani*, *Cheleocloeon dimorphicum*, *Cloeon simile*, *Labiobaetis neglectus*, *Procloeon stagnicola* and *Oligoneuriopsis skhounate*, but no new species were recorded for the whole basin. We found four Maghrebian endemic species: *Cheleocloeon dimorphicum*, *Procloeon stagnicola*, *Ecdyonurus rotschildi*, *Choroterpes atlas*; three Iberian-Maghrebian endemic species: *Baetis maurus*, *Labiobaetis neglectus*, *Oligoneuriopsis skhounate*; three Palearctic species: *Baetis rhodani*, *Cloeon similie*, *Caenis luctuosa*; one Atlanto-Mediterranean species: *Baetis pavidus*; and one European-Mediterranean species: *Caenis pusilla*, *Rhithrogena* sp. was not identified to species level as only imagos can be identified specific level.

High Atlas endemic species that have been reported on the northern slopes of this mountain rangee, mainly *Alainites oukaimeden* and *Baetis berberus* (El Alami et al. 2022) were not found in the south slope of the Draa basin. A species of Heptageniidae *Ecdyonurus rothschildi* cited by Bouzidi in 1989, in the river of Ounilla in the west of the Upper Draa basin was no longer found in that river but was collected further east in the rivers of Dades and Mgoune. The same author found *Oligoneuriella skoura* in the Mgoune and Dades Rivers in 1989, but these two species were not found in the entire area in this study. Some species with wide distribution in other regions, such as *Ecdyonurus rothschildi* (El Alami et al. 2022) are confined to high altitudes in the Draa Basin. *Oligoneuriopsis skhounate* which has a wide distribution in Morocco (Mabrouki et al. 2017), was only found in one site in a low altitude with low conductivity.

According to topographic and climatic conditions, the Draa basin is divided into three zones: a zone at high altitude in the reliefs of the southern slopes of the High Atlas where three rivers with strong current with low conductivity and low water temperature flow (Ounilla, Mgoune and Dades), this zone is characterized by cold water species such as *Ecdyonurus rothschildi*, *Rhithrogena* sp., *Baetis rhodani*, *Caenis pusilla* and *Baetis maurus*. A second intermediate zone located in the valley of the Ouarzazate basin which is part of the South Atlas furrow where the climate is less cold than the high mountain zones (Iriri Fint and Ait Douchene) and where the conductivity is not very high, we find the species *Cheleocloeon dimorphicum*, *Cloeon simile*, *Procloeon stagnicola*, *Labiobaetis neglectus* and *Choroterpes atlas* in addition to the species of wide ecological range: *Caenis luctuosa* and *Baetis pavidus*. Finally in a third Saharan zone with high conductivity and high summer temperature (Tissint, Mghimima and Akka nait sidi) we find the resistant euryhaline species *Caenis luctuosa* and *Baetis pavidus*.

The absence of larvae of *Oligoneuriopsis skhounate* during all the samples collected from September 2020 to April 2021 can be explained by the phenomenon of diapause caused by the low winter temperatures (Zrelli et al. 2010).

Ephemeroptera in this area are affected by physicochemical parameters, the irregularity of the Draa rivers caused by climatic factors such as periods of summer drought, autumnal floods, or periods of high flow after snow melt (as was the case in the spring of the year 2021). Human factors also highly impact the Ephemeroptera diversity, in peculiar in relation to the intake of water from the rivers for agricultural activities, this intake is accentuated during the dry seasons which can completely dry up the river during years of severe drought. These flow fluctuations directly impact the community of aquatic macroinvertebrates whose life cycles are intimately linked to the aquatic environment.

In the Middle Draa, rainfall scarcity and repeated droughts have impacted the river's flow, which now relies almost solely on releases from the El Mansour Eddahbi dam. The excessive use of water in agriculture further exacerbates the situation, leading to a lack of permanent water flow in the river. This has resulted in drying up of several sites which we found to be rich in macroinvertebrates in 2019. After falling dry since February 2020, we were only able to sample a small puddle that remained from dam releases and showed low macroinvertebrate richness

In our study, the distribution of Ephemeroptera was limited by conductivity with fewer species found in high saline sites, furthermore, we found a nearly significant negative correlation of species richness and water temperature. With increasing temperatures and salinity levels in the future (Williams 1999) we can assume a loss of some additional stenotherm species (Kaczmarek et al. 2021).

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Responsibility for the content of this publication lies with the author.

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Supplementary material 1

Inventory of species of Draa basin collected in all trips

Authors: Mokhtar Benlasri

Data type: List of the species sampled in the Draa basin

Explanation note: The list with the number of each species in each sample during the study period.

Link: https://doi.org/10.3897/alpento.7.96436.suppl1

Supplementary material 2

Parameters mesured during the samples

Authors: Mokhtar Benlasri

Data type: Database of the measured physico-chemical parameters

Explanation note: The database of the measured physico-chemical parameters in every site during all the field trips.

Link: https://doi.org/10.3897/alpento.7.96436.suppl2