J. Insect Biodivers. Syst. 10 (4), 805–825 *https://jibs.modares.ac.ir*

OPEN ACCESS

Tarbiat Modares University Press | **Research Article** | https://doi.org/10.61186/jibs.10.4.805 | **ISSN**: 2423-8112
Entomological Society of Iran | Biodiversity | *https://zoobank.org/urn:lsid:zoobank.org:BB339CAE-769B-4C28-9BAE-00B048E5E955*

So close, but yet so far: Assessing the community structure of Odonates in two adjacent rivers within different watersheds in Souk Ahras, North East of Algeria

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ABSTRACT. Lotic systems are rapidly changing due to anthropogenic impacts, making it crucial to note the diversity and abundance of Odonates for effective conservation of these running waters. Our study aimed to assess and compare the Odonate communities in two adjacent rivers, Medjerda and Cheref, in Souk Ahras, northeastern Algeria collected during the period from January 2022 to August 2023. In total, 27 species belonging to 7 families and 17 genera were recorded, with three rare species in Numidia, and three Maghrebian endemic species, including *Gomphus lucasii* (Selys, 1850) listed as "Vulnerable" in the IUCN Mediterranean Red List. *Coenagrion mercuriale* (Charpentier, 1840), a locally endangered species, was abundantly present in the Medjerda River. Additionally, the presence of the desert species *Trithemis kirbyi* (Selys, 1891) in Medjerda confirms their northward expansion within Algeria. The Libellulidae were the most dominant family with 11 species. Our findings revealed no significant differences in terms of biodiversity indices (*Richness, Simpson, Shannon, & Pielou's evenness*) between the two rivers. However, significant dissimilarities were observed in Odonate assemblages likely due to habitat and environmental variations. Many factors, such as water pumping, overgrazing, untreated wastewater, and riverbank development, which influence Odonate species, were observed in the two rivers. Consequently, an urgent conservation plan should be put in place to preserve water resources and biodiversity in the region. This study highlights the need for continued monitoring and conservation efforts, especially for rare and threatened species in the face of increasing anthropogenic pressures on these aquatic ecosystems.

Keywords: Odonates, diversity, abundance, rivers, Souk Ahras, Maghreb

Received: 25 May, 2024
Accepted: 31 July, 2024
Published: 06 August, 2024
Subject Editor: Mohsen Mofidi Neyestanak

Citation: Khedir, H., Aouadi, A. & Seddik, S. (2024) So close, but yet so far: Assessing the community structure of Odonates in two adjacent rivers within different watersheds in Souk Ahras, North East of Algeria. *Journal of Insect Biodiversity and Systematics*, 10 (4), 805–825.

INTRODUCTION

Under anthropogenic pressures, signs of a new environmental crisis have multiplied in recent years. Insects are experiencing an alarming decline in terms of abundance, biomass, and distribution range

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(Bazzi et al., 2023). Due to their constant spatial responses to environmental changes, insects can serve as bio-indicators. Therefore, studying insect populations would enable the establishment of continuous environmental monitoring programs, which are crucial for preserving these vital organisms and maintaining the overall health and conservation of ecosystems. Odonates, including dragonflies and damselflies, are one of the most renowned and well-studied insect groups. They currently number 6,407 species worldwide (Paulson et al., 2024). These insects are considered excellent bioindicators due to their sensitivity to environmental changes (Corbet, 2004; Oertli, 2008). Their presence, absence, or abundance can provide valuable insights into the health and quality of both aquatic and terrestrial habitats.

Changes in physical habitat structure, such as marginal vegetation and aquatic plants (Clark & Samways, 1996; Hofmann & Mason, 2005), can affect Odonate species assemblage, as these parameters relate to oviposition sites and habitat selection (Corbet, 1999). Sunlight is also a determining factor in the behaviour of Odonates due to their thermoregulation strategies (De Marco & Resende, 2002, De Marco et al., 2015). Similarly, various physicochemical parameters have been shown to affect the diversity of Odonata species. Water temperature influences the quantity and variety of species present in a location, as they require optimal temperatures to survive, lay eggs, thrive, and emerge as adults (Dallas & Ross-Gillespie, 2015). Popoola and Otalekor (2011), found that there was greater species diversity at relatively lower temperatures compared to results obtained with corresponding temperature increases. In addition, Sato and Riddiford (2008) observed that sites with high salinity and low oxygen concentration affected the distribution of some species of Odonates. Jacob et al. (2017) reported that ponds with good water quality harboured a higher number of Odonates compared to those with poor water quality.

The first studies on the Odonate fauna of Algeria began in the last decade of the first half of the 19th century. These early investigations were notably marked during the years 1840, 1841, and 1842, when the "Scientific Exploration of Algeria" was led by Hippolyte Lucas (1849), a French entomologist and naturalist. Additional contributions were then provided by De Selys-longchamps (1849, 1865, 1866, 1871, 1902), Kolbe (1885), Mclachlan (1897), Martin (1901), Morton (1905), Le Roi (1915), Kimmins (1934), Reymond (1952), Nielsen (1956), and Dumont (1978). Following this initial period of active research, there was a slowdown in work and a decrease in the number of publications on Algerian Odonates. It was not until the 1990s that a renewed dynamic for studying and surveying Algeria's Odonate fauna emerged, ultimately expanding the Algerian checklist to 63 Odonata species by Samraoui & Menaï (1999). This constituted a remarkable list at the time and made Algeria one of the best prospected countries in the Mediterranean basin. Since the establishment of the initial list of Algerian Odonates, various researchers have conducted numerous surveys of Odonate distribution. Notable studies include those by Samraoui & Corbet (2000a, 2000b), Dumont (2007), Khelifa et al. (2011), Hadjoudj et al. (2014), Mahdjoub et al. (2015), Hafiane et al. (2016), Yalles & Samraoui (2017), Bouhala et al. (2019), Chelli & Moulaï (2019), Demnati et al. (2019), El Bouhissi et al. (2022), Mairif et al. (2023), and several others contributing to the expanding knowledge of Odonate diversity in Algeria.

Despite ongoing efforts, our understanding of Algerian Odonate fauna remains largely localized, particularly in the Numidia region of Northeastern Algeria. This region boasts exceptional odonatological diversity (Samraoui & De Belair, 1997, 1998), with an estimated total of 45 species (Samraoui & Corbet, 2000a), constituting three-quarters of all known Algerian species. In our study area, only one survey conducted by Bouhala et al. (2019) covered the Oued Cheref, documenting 21 species. However, the Medjerda River has not been surveyed for Odonates. Therefore, additional and ongoing surveys across various locations are needed to provide a comprehensive account of the Odonate assemblages in the entire territory of Souk Ahras. Our study sought to (1) prepare a checklist of the Odonate fauna in Souk Ahras, especially in Medjerda and Cheref rivers; (2) analyze and compare the ecological characteristics of Odonate distribution between two adjacent rivers, including species composition, and diversity metrics; (3) provide baseline data for future conservation efforts and environmental monitoring in the region, particularly for rare or threatened Odonate species.

MATERIAL AND METHODS

Study area. The study was conducted in Souk Ahras, located in northeastern Algeria, covering an area of 4360 km². Specifically, we selected two major rivers that cross the region, Medjerda and Cheref Rivers (Fig. 1). *Medjerda River* - originates in the semi-arid Atlas Mountains of eastern Algeria at an altitude of approximately 1000 m and flows into the Mediterranean Sea (Gulf of Tunis) (Nouiri et al., 2015). It covers an area of 23.700 km², with a length of 485 Km. Its basin has a total surface of 22000 km², among which 6000km² are located in Algeria (Jelassi et al., 2015). It is characterized by highly developed and dense vegetation (Khoualdia et al., 2014), and a continental climate with Mediterranean influence, with warm summers and cold winters. The precipitation regime is typically Mediterranean with a large mean seasonal flow variability. Agriculture is the main economic activity within the Medjerda basin (Kadir et al., 2020). *Cheref River* - represents the upper course of the Seybouse River, with an area of 2905 km², which originated from the eastern Hauts Plateaux at altitudes ranging from 800 m to 1000 m. The climate is typically Mediterranean, characterized by a rainy season spanning from October to May and a dry season lasting from June to September. Rainfall varies from 350 mm/year upstream to 610 mm/year downstream. The river is frequently utilized as a source of drinking water for grazing livestock and irrigation purposes (Bouhala et al., 2019).

The study area is located in the mid-mountain region in the upstream sectors of the watersheds of the two rivers. The land use around the eight sampled stations (Fig. 2) is mainly agricultural. Some individual dwellings are nearby; however, discharge points of untreated sewage are often found. Also, they are marked by a strong influence of anthropogenic activities (Appendix 1A–D). The year 2022 was characterized by scorching summer temperatures and an unusually dry winter, leading to a deficit in precipitation and over-exploitation of water resources. Consequently, the underground water table reserves were depleted, and river flow decreased, leading to a total drying up. This adversely affected the choice of study locations, particularly those along the Cheref River.

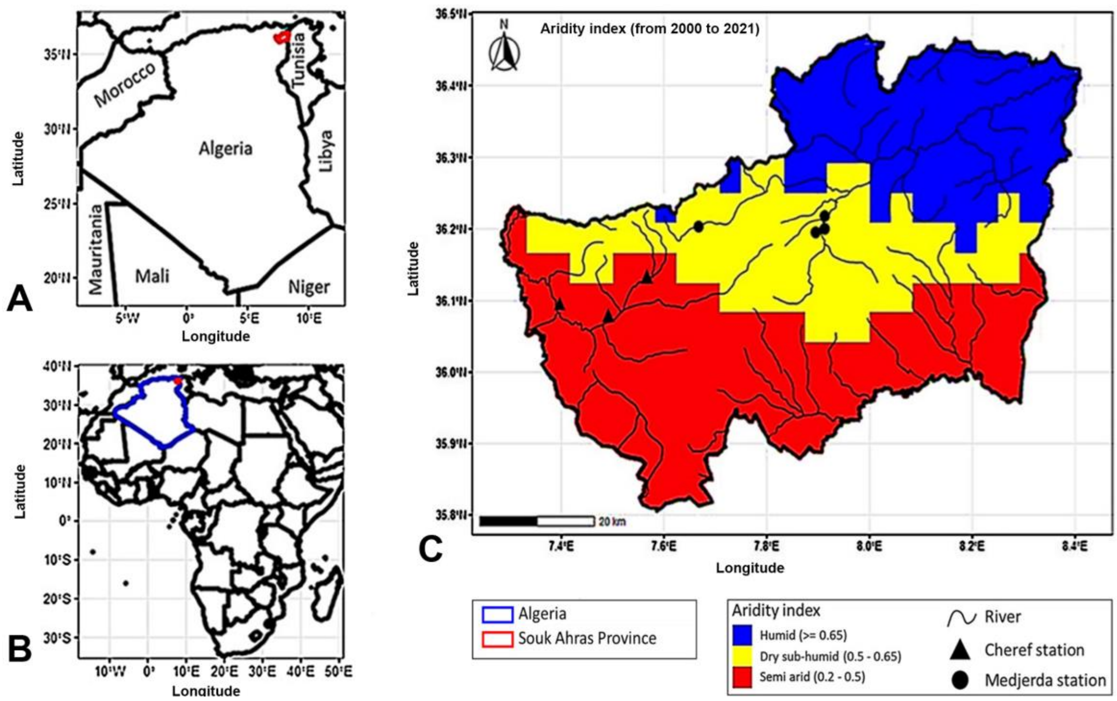

Figure 1. Location of the study area (Souk Ahras in northeastern Algeria). **A.** Broad view map of North Africa, highlighting Algeria and its neighbouring countries; **B.** Map showing the location of Algeria within the African continent; **C.** Detailed map of Souk Ahras Province, indicating different regions based on the aridity index from 2000 to 2021.

Sampling. Adult Odonates were sampled monthly over two years, from January 2022 to August 2023 at 8 stations (5 in Medjerda and 3 in Cheref rivers), selected based on site accessibility and the variability of habitats (Table 1, Fig. 2). For each station, a transect of 100 m was covered about 1 hour under favourable weather conditions. Between 10:00 AM to 2:00 PM. All individuals encountered were counted and to the extent possible identified. Otherwise, they were captured with an entomological net to identify them in the laboratory. The identification was conducted using the determination keys of Dijkstra & Lewington (2007). In addition, photographs of observable specimens were taken using the Canon® EOS 1200D camera with the EF-S 18-55 mm lens.

Data analyses. Diversity indices were represented as follows; Total abundance: denoted by the total number of individuals, species richness (*S*): indicating the overall number of species present (Fisher et al., 1943), Shannon index: defined as $H' = -\Sigma(Pi \times log2Pi)$, where Pi represents the proportion of individuals belonging to the ith species relative to the total number of individuals (*N*). The Shannon diversity index (*H*') equals zero when only one species is present, near zero when one species predominates, and reaches its maximum when all species occur in equal proportions (Shannon, 1948). $Hmax = log2S$ representing the highest possible value of the Shannon diversity index (*H*') for a given number of species. Moreover, the evenness index (*E*) was computed using the equation $E = H' / Hmax$, where H' is the Shannon index and Hmax is the logarithm base 2 of richness, thus calculating the proximity of each species' abundance within a community. It has a range of 0 to 1, where 1 denotes a community in which the abundance of every species is the same (Pielou, 1966). In addition, Simpson's Diversity was calculated using the formula: $D = 1 - \{\Sigma ni\ (ni - 1)/N\ (N - 1)\}$ Where ni represents the total number of individuals for each species, and *N* is the total number of individuals across all species. Simpson index measures the probability that two randomly selected individuals from a sample belong to different species. It ranges from 0 to 1, with 0 indicating no diversity (one species) and 1 representing infinite diversity (Simpson, 1949). Unlike the Shannon index, Simpson's D is less sensitive to rare species and gives more weight to common species, while the Shannon index may be more useful for detecting changes in the overall diversity of a community, including the presence of rare species (Mendes et al., 2008). Finally, relative abundance refers to the ratio of the number of individuals of each species to the total number of individuals, encompassing all species within a given community.

To test for significant differences in ecological metrics between the two rivers, Generalized Linear Mixed Models (GLMMs) were conducted using the function *glmer* from the R package lme4 (Bates et al., 2015). Depending on the nature of the dependent variables (Total Abundance, Richness, Shannon Index, Hmax, Simpson, and Evenness) and the presence of overdispersion, either the gaussian, binomial, negative binomial or Poisson family links were used. The river was considered as a fixed effect, while the site was included as a random effect, allowing for the capture of potential variability within sites across both rivers. Although mixed models are less sensitive to unbalanced data than classical models, GLMMs were weighted according to the number of stations to address the issue of unequal number of stations in the two rivers (Bolker et al., 2015). The weighting was done by incorporating weights into the GLMMs, where each site's weight was inversely proportional to the number of stations in its respective river (Littell, 2002). In addition, to test for differences in terms of total abundance and richness between the two years 2022 and 2023, Generalized Linear Mixed Models were carried out thus including diversity indices as dependent variable, year as independent variable with fixed effect and site as random effect.

In addition, to examine the relationships between diversity indices, Pearson correlation tests were conducted using the "*corr.test*" function from the package psych (Revelle & Revelle, 2015). Subsequently, the correlation matrices were visualized using the corrplot package (Wei et al., 2017). DeBenedictis (1973) emphasizes that positive correlations are expected between diversity indices due to their mathematical definitions, regardless of any underlying biological relationships. However, a negative correlation between evenness and species richness could indeed be a noteworthy finding that deviates from the expected mathematical relationships.

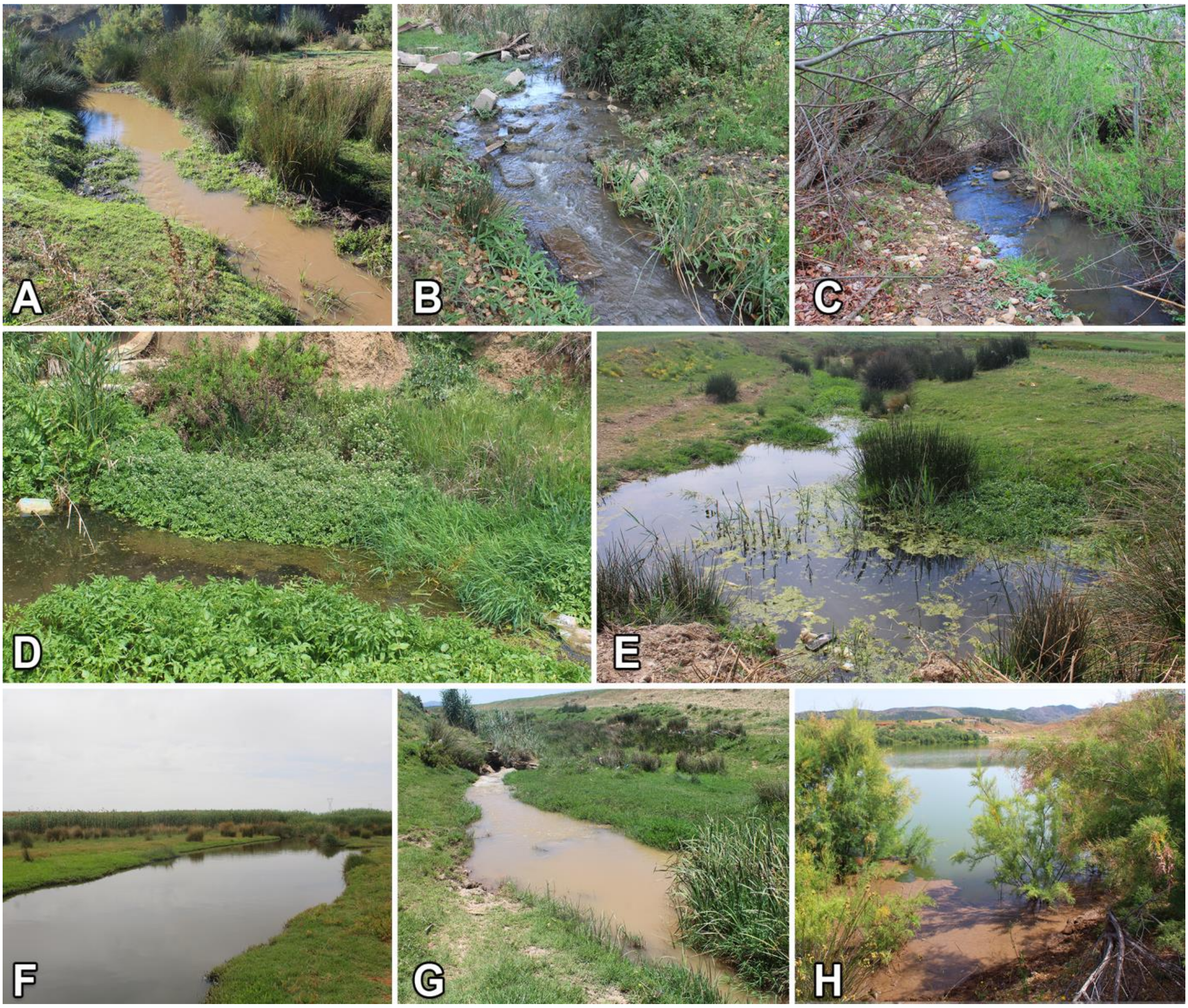

Figure 2. Sampling stations. **A–E.** Medjerda; **A.** Station Z1; **B.** Station Z2; **C.** Station Z3; **D.** Station Kh1; **E.** Station Kh2; **F–H.** Cheref; **F.** Station O.Ch; **G.** Station O.Kr; **H.** Station B O.Ch.

The mathematical pattern can be considered as the null model, against which the influence of empirical, biological effects could be tested (Stirling & Wilsey, 2001). We used the function '*ggvenn*' from the *ggvenn* R package (Yan & Yan, 2023) to create a Venn diagram displaying common and exclusive taxa between the two rivers. In addition, Bray-Curtis dissimilarity (beta diversity) was calculated using the function '*vegdist*' to assess the compositional dissimilarity between the two rivers based on abundance data. Bray-Curtis ranges from 0 (identical species composition) to 1 (completely dissimilar species composition). A non-metric multidimensional scaling (NMDS) analysis based on the Bray–Curtis dissimilarity index was performed using the function "metaMDS". Subsequently, a permutational analysis of variance (PERMANOVA) was performed utilizing the "*adonis2*" function to examine the composition and distribution of Odonates across the two rivers. All statistical analyses and graphics were carried out using R software 4.2.2 (R Development Core Team, 2024). Diversity indices, Bray-Curtis dissimilarity, NMDS, and Permanova were carried out using the package vegan (Oksanen et al., 2008), and graphics were generated using the package *ggplot2* (Wickham, 2011).

Table 1. Selected stations in the Medjerda and Cheref rivers.

Rivers	Stations	Coordinates Altitude (m)	Temperature (°C)	Water depth (cm)	Vegetation
Medjerda	Z1	36°12'45.4" N 07°54'40.2" E 598 m	16.60 ± 2.37	19.96 ± 4.00	*Scirpoides holoschonus, Juncus* sp., *Dittrichia viscosa, Tamarix gallica,Sonchus maritimus, Typha* sp., *Rubus fruticosus, Nasturtium officinale, Helosciadium nodiflorum*
	Z2	36°12'02.3" N 07°54'26.1" E 618 m	17.40 ± 2.32	28.38 ± 14.96	*Sonchus maritimus, Juncus* sp., *Typha angustifolia, Tamarix gallica, Mentha Sauveolens. Salix* sp., *Helosciadium nodiflorum; Nasturtium officinale, Dittrichia viscosa*
	Z3	36°11'51.8" N 07°54'15.7" E 620 m	18.40 ± 2.41	16.96 ± 2.82	*Tamarix gallica, Sonchus maritimus, Helosciadium nodiflorum, Salix* sp, *Mentha Sauveolens, Populus nigra, Typha angustifolia, Nasturtium officinale.*
	Kh1	36°12'09.5" N 07°39'59.6" E 812 m	17.00 ± 3.78	25.65 ± 5.68	*Xanthium strumarium, Typha* sp., *Juncus acutus, Paspalum distichum, Phragmites australis, Nasturtium officinale, Dittrichia viscosa, Scirpoides holoschoenus, Sonchus maritimus, Helosciadium nodiflorum,Tamarix galicca*
	Kh2	36°12'07.0" N 07°40'00.1" E 818 m	17.00 ± 3.07	36.9 ± 9.46	*Helosciadium nodiflorum,Typha* sp., *Tamarix gallica, Dittrichia viscosa, Jucus* sp., *Nasturtium officinale,Sonchus maritimus, Paspalum distichum*
Cheref	O.Kr	36°07'51.1" N 07°34'03.3" E 796 m	19.63 ± 5.37	21.61 ± 7.21	*Typha angustifolia, Typha latifolia,Mentha Sauveolens, Nasturtium officinale, Phragmites australis, Dittrichia viscosa, Scirpoides holoschoenus*
	O.Ch	36°04'28.5" N 07°29'32.1" E 749 m	19.22 ± 7.05	15.82 ± 5.06	*Phragmites australis, Paspalum distichum, Juncus acutus, Typha, latifolia, Schoenoplectus lacustris*
	B O.Ch	36°05'27.0" N 07°23'51.2" E 738 m	22.27 ± 5.35	–	*Potageton* sp., *Tamarix gallica, Diplotaxis erucoides*

RESULTS

Totally, 7706 individuals, classified into 27 species (20 in the Medjerda River and 22 in the Cheref River), 7 families and 17 genera have been identified (Fig. 3). The Libellulidae are the most diverse family with 11 species, followed by Coenagrionidae (8 species), Lestidae, Aeshnidae and Gomphidae (2 species). The Calopterygidae and Platycnemididae were the least abundant families each represented by one species. The results of our observations are shown in Table 2. The majority of the observed species are classified as least concern (LC) on the North African and Mediterranean IUCN Red Lists (Riservato et al., 2009; Samraoui et al., 2010). However, *Coenagrion mercuriale* (Charpentier, 1840), is considered a near-threatened species (NT) on the Mediterranean red list and endangered (EN) on the North African red list. *Gomphus lucasii* (Selys, 1850), figure as vulnerable (VU) on both Red lists. In terms of endemism, three Maghrebian species have been recorded, namely *Platycnemis subdilatata* (Selys, 1849), *Enallagma deserti* (Selys, 1871) and *Gomphus lucasii*.

A higher number of species was registered in the Cheref River compared to the Medjerda River, with 22 and 20 species, respectively. Fifteen species were common between the two rivers i.e., *Calopteryx haemorrhoidalis* (Vander Linden, 1825), *Platycnemis subdilatata, Coenagrion mercuriale, Anax imperator* (Leach [*in* Brewster, 1815]), and *Gomphus lucasii*. Five species including *Sympecma fusca* (Vander Linden, 1820), *Lestes barbarus* (Fabricius, 1798), *Trithemis kirbyi*, *Sympetrum meridionale* (Selys, 1841) and *Paragomphus genei* (Selys, 1841) were characteristic of Medjerda and seven species were exclusive to Cheref such as *Coenagrion puella kocheri* (Schmidt, 1960), *Ischnura pumilio* (Charpentier, 1825), *Enallagma deserti, Anax Parthenope* (Selys, 1839), *Trithemis annulata* (Palisot de Beauvois, 1805), *Sympetrum fonscolombii* (Selys, 1840) and *Brachythemis impartita* (Karsch, 1890) (Fig. 4). Bray-Curtis index between the sites or samples "Cheref" and "Medjerda" showed a high level of dissimilarity (0.702).

Figure 3. Certain species of Odonates identified from Cheref and Medjerda Rivers, Algeria. **A.** *Anax imperator* (Leach [*in* Brewster, 1815]); **B.** *Calopteryx haemorrhoidalis* (Vander Linden, 1825); **C.** *Platycnemis subdilatata* (Selys, 1849); **D.** *Orthetrum nitidinerve* (Selys 1841); **E.** *Sympetrum striolatum* (Charpentier, 1840); **F.** *Sympetrum fonscolombii* (Selys, 1840); **G.** *Ceriagrion tenellum* (de Villers, 1789); **H.** *Crocothemis erythraea* (Brullé, 1832); **I.** *Erythromma lindenii* (Selys, 1840); **J.** *Coenagrion mercuriale* (Charpentier, 1840); **K**. *Orthetrum chrysostigma* (Burmeister, 1839); **L.** *Coenagrion caerulescens* (Fonscolombe, 1838); **M.** *Brachythemis impartita* (Karsch, 1890); **N.** *Gomphus lucasii* (Selys, 1850); **O.** *Orthetrum coerulescens* (Fabricius, 1798); **P.** *Ischnura graellsii* (Rambur, 1842); **Q.** *Trithemis kirbyi* (Selys, 1891); **R.** *Trithemis annulata* (Palisot de Beauvois, 1805); **S.** *Orthetrum cancellatum* (Linnaeus, 1758); **T.** *Paragomphus genei* (Selys, 1841).

Table 2. The checklist and Relative Abundance (RA%) of Odonates species recorded in the two rivers (LC, Least concern; NT, Near Threatened; VU, Vulnerable).

Family	Taxa	RA (%)		Red List
		Medjerda	Cheref	Mediterranean basin
Calopterygidae	*Calopteryx haemorrhoidalis* (Vander Linden, 1825)	09.71	03.17	LC
Platycnemididae	*Platycnemis subdilatata* (Selys, 1849)	41.02	24.84	LC
Coenagrionidae	*Coenagrion mercuriale* (Charpentier, 1840)	21.42	00.19	NT
	Coenagrion caerulescens (Fonscolombe, 1838)	18.98	01.83	LC
	Coenagrion puella kocheri (Schmidt, 1960)	00.00	00.69	LC
	Ischnura graellsii (Rambur, 1842)	03.62	37.09	LC
	Ischnura pumilio (Charpentier, 1825)	00.00	00.69	LC
	Enallagma deserti (Selys, 1871)	00.00	07.71	LC
	Erythromma lindenii (Selys, 1840)	00.06	07.40	LC
	Ceriagrion tenellum (de Villers, 1789)	02.16	01.56	LC
Lestidae	*Sympecma fusca* (Vander Linden, 1820)	00.16	00.00	LC
	Lestes barbarus (Fabricius, 1798)	00.02	00.00	LC
Aeshnidae	*Anax imperator* (Leach in Brewster, 1815)	00.26	01.00	LC
	Anax parthenope (Selys, 1839)	00.00	00.08	LC
Libellulidae	*Orthetrum coerulescens* (Fabricius, 1798)	01.34	02.33	LC
	Orthetrum nitidinerve (Selys 1841)	00.31	00.69	LC
	Orthetrum cancellatum (Linnaeus, 1758)	00.04	00.04	LC
	Orthetrum chrysostigma (Burmeister, 1839)	00.10	00.04	LC
	Crocothemis erythraea (Brullé, 1832)	00.31	01.07	LC
	Trithemis annulata (Palisot de Beauvois, 1805)	00.00	00.34	LC
	Trithemis kirbyi (Selys, 1891)	00.10	00.00	LC
	Sympetrum fonscolombii (Selys, 1840)	00.00	05.72	LC
	Sympetrum striolatum (Charpentier, 1840)	0.040	00.15	LC
	Sympetrum meridionale (Selys, 1841)	0.040	00.00	LC
	Brachythemis impartita (Karsch, 1890)	00.00	02.86	LC
Gomphidae	*Gomphus lucasii* (Selys, 1850)	00.29	00.53	VU
	Paragomphus genei (Selys, 1841)	00.02	00.00	LC

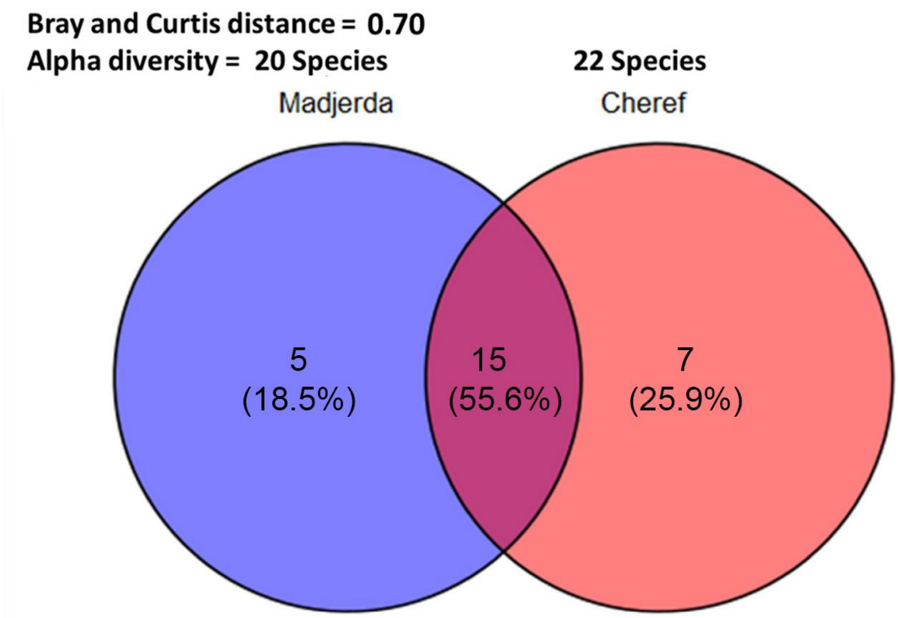

Figure 4. Venn diagram illustrating exclusive and shared Odonate species between Cheref and Medjerda Rivers, Algeria.

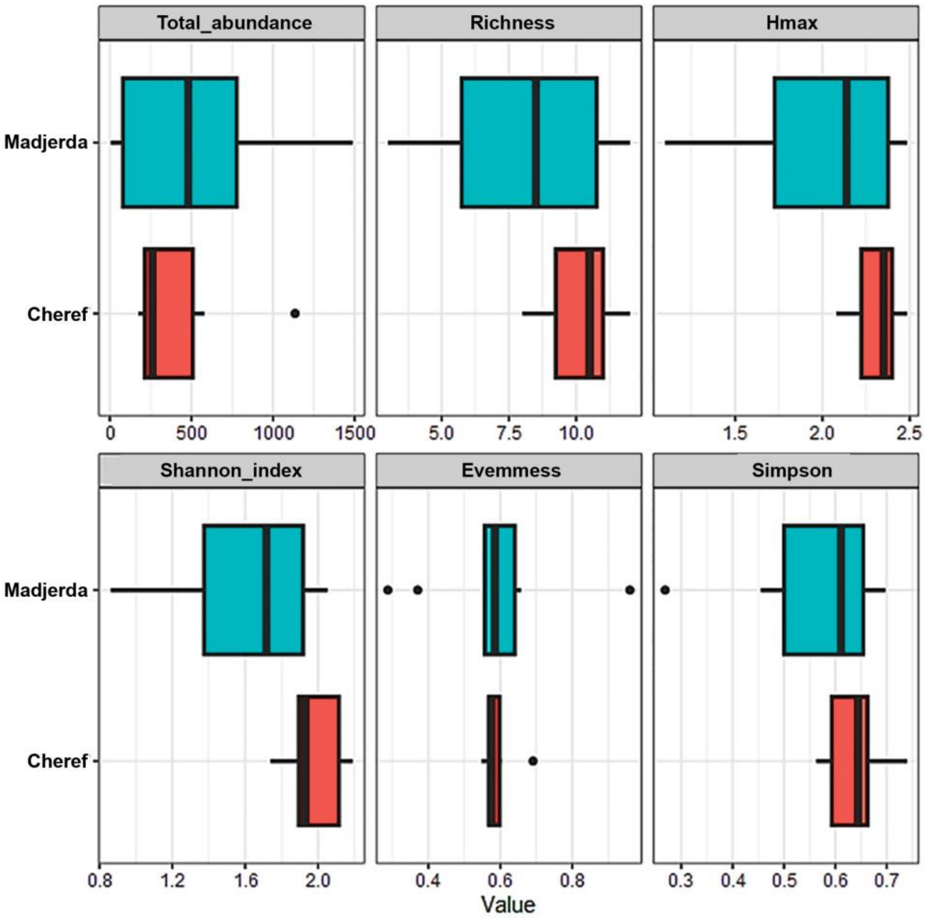

Figure 5. Boxplots displaying diversity indices for Cheref and Medjerda Rivers, Algeria.

In addition, the Cheref River exhibits slightly higher values for several diversity indices (Hmax, Shannon, Simpson, Pielou's evenness indices) than the Medjerda River (Fig. 5). On the contrary, the Medjerda river had a higher average abundance per station at 1017, compared to the Cheref river's with of 873.66. However, it's noteworthy that there is no significant difference between the two rivers across all ecological metrics (Table 3). The results of GLMMs indicated that 2022 was significantly higher than 2023 in terms of total abundance (*Z value*=*-14.3, P-value*<*0.001*), though no significant difference was recorded in richness (*Z value*=*-0.672, P-value*=*0.502*).

The correlation matrix (Fig. 6) shows that there is a significant negative correlation between evenness and both Hmax (*P-value*<*0.05, R*=*-0.57*) and richness (*P-value*<*0.05, R*=*-0.51*), and a positive correlation with Simpson index (*P-value*<*0.01, R*=*-0.51*). Hmax is negatively correlated with both Richness (*P-value*<*0.001, R*=*-0.57*), and total Abundance (*P-value*<*0.05, R*=*-0.5*), thus indicating lower maximum diversity at sites with higher richness/abundances, likely due to dominance by some abundant species. In addition, the Shannon index was positively correlated with Simpson, Richness and Hmax. Richness shows a strong positive correlation (*P-value*<*0.001, R*=*0.98*) with Hmax, suggesting that sites with higher overall abundances tend to have more species present. However, Richness is negatively correlated with Evenness *(P-value <0.01, R*=*-0.51*), indicating that sites with higher species richness often have less evenly distributed abundances among those species. The non-metric multi-dimensional (NMDS) ordination analysis revealed a significant difference in species composition along the two rivers (Fig. 7). This compositional divergence was confirmed by the PERMANOVA analysis (Table 4) highlighting that Odonates species composition differed significantly between the Cheref and the Medjerda rivers (*P value < 0.001, F*=*4.8149*).

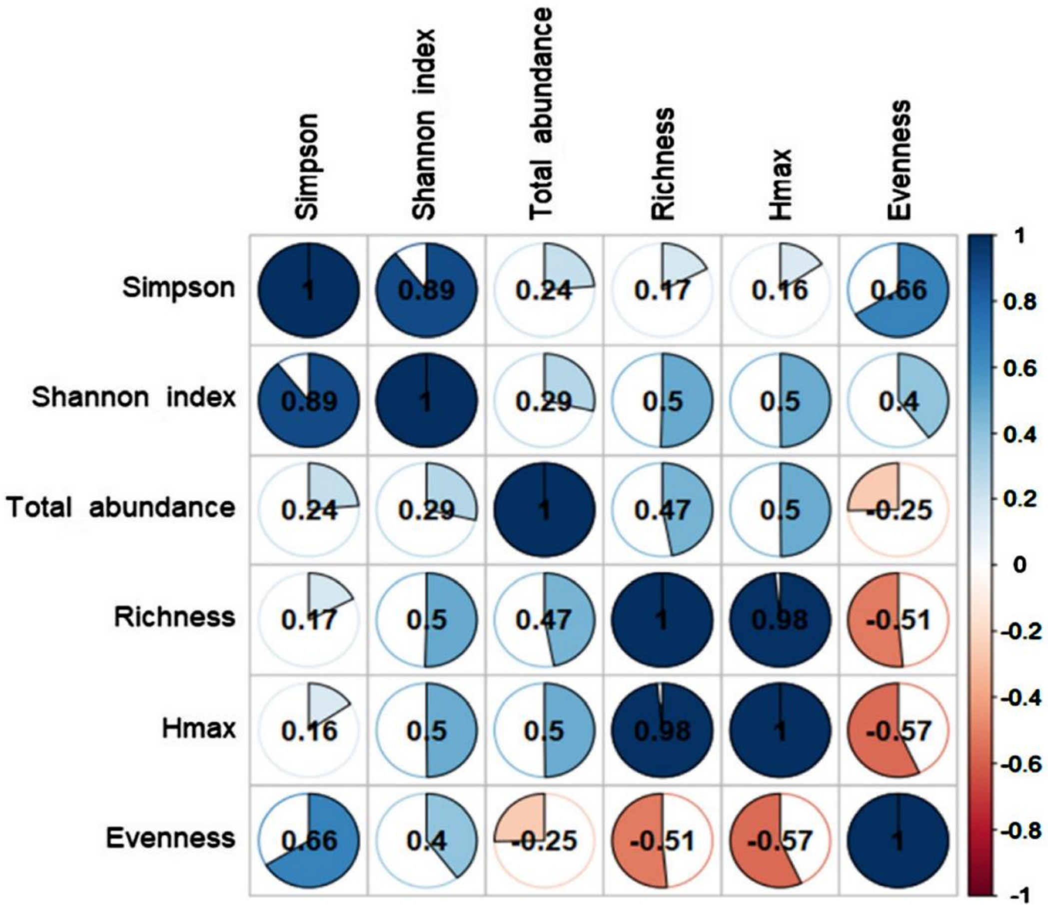

Figure 6. Pearson's correlation matrix between diversity parameters, representing the Odonate diversity and assemblages in Souk Ahras

Table 3. Generalized linear mixed model (GLMM) for comparison of ecological metrics between Cheref and Medjerda rivers.

	Estimate	*Std. Error*	*Z-value*	*P-value*
Total abundance				
Intercept	5.8315	0.4904	11.892	<0.01
Medjerda	-0.2849	0.6266	-0.455	0.649
Species richness				
Intercept	2.3191	0.3136	7.395	<0.001
Medjerda	-0.2273	0.4710	-0.483	0.629
Evenness				
Intercept	-0.52209	0.38995	-1.339	0.181
Medjerda	-0.04372	2.87345	-0.015	0.988
Simpson index				
Intercept	0.63921	0.09849	6.490	<0.001
Medjerda	-0.07223	0.13929	-0.519	0.604
Shannon index				
Intercept	1.3685	0.2020	6.774	<0.001
Medjerda	-0.2505	0.2857	-0.877	0.381
Hmax				
Intercept	2.3100	0.3334	6.929	<0.001
Medjerda	-0.3066	0.4715	-0.650	0.515

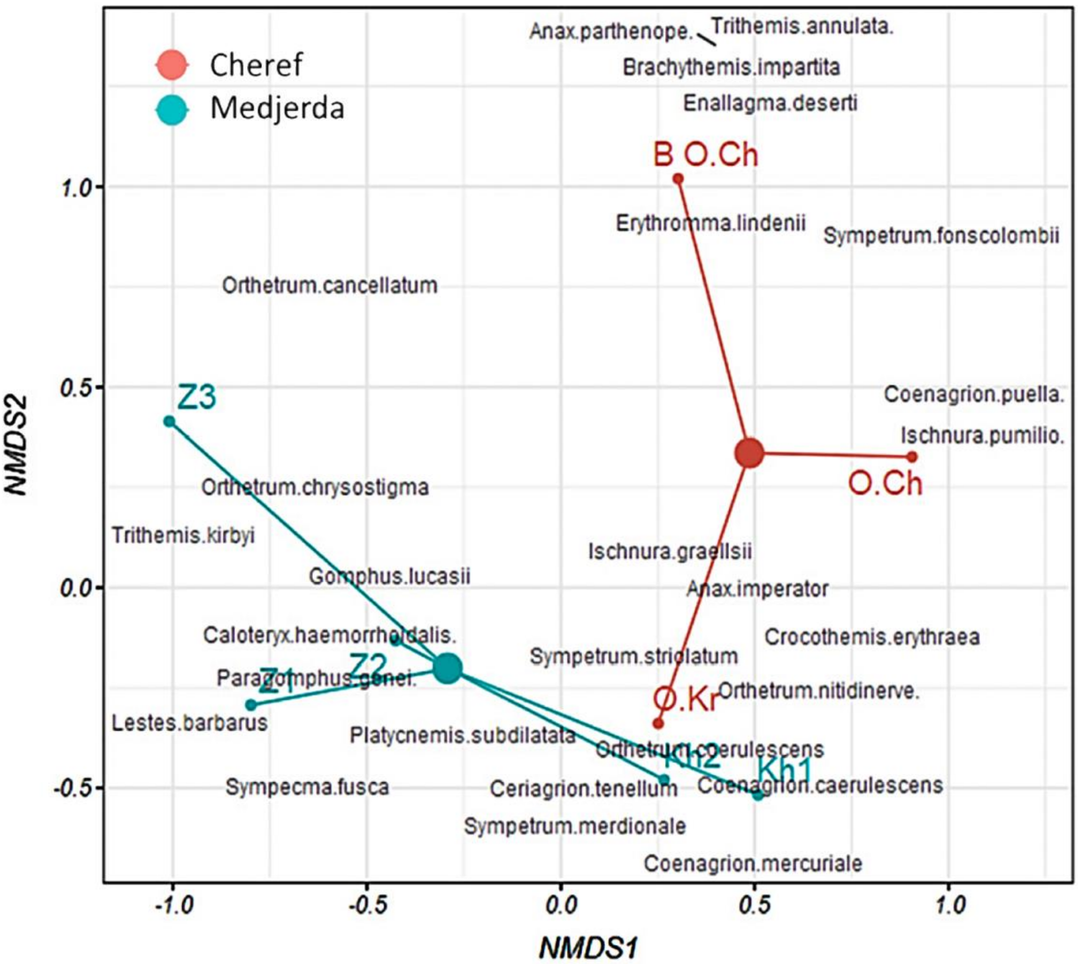

Figure 7. Non-metric multidimensional scaling (NMDS) ordination plot (stress = 0.0000052) illustrating odonate assemblages. Grey text represents species names; large circles show centroids (average positions) for each river; small circles indicate individual sampling stations.

Table 4. Permutational multivariate analysis of variance (PERMANOVA) for testing the effect of river on Odonate Assemblages.

	Df	Sum of Squares	*R2*	*F*	*P-value*
River	1	1.2816	0.26	4.81	0.001 ***
Residual	14	3.7264	0.744		
Total	15	5.0079	1		

Specifically, Cheref showed a stronger association with species such as *Coenagrion puella kocheri*, *Ischnura pumilio*, *Enallagma deserti*, *Anax Parthenope*, *Trithemis annulata*, *Brachythemis impartita*, and *Sympetrum fonscolombii*, whereas Medjerda was predominantly characterized by species like *Sympecma fusca*, *Lestes barbarus*, *Orthetrum chrysostigma*, and *Trithemis kirbyi*. This spatial divergence suggests that these rivers harbour somewhat distinct communities of species. Nonetheless, despite this segregation, there were also some generalist-shared species, including *Sympetrum striolatum*, *Ischnura graellsii* and *Anax imperator*. Additionally, The O.Kr station, a tributary of the Cheref River, appears to have a faunal composition similar to that of the Kh1 and Kh2 belonging to the Medjerda River.

DISCUSSION

A preliminary list of 27 species belonging to 17 genera and 7 families was established, representing 42% of the total number of Odonates found in Algeria (Samraoui & Menaï, 1999). This richness is considerable for our pristine region comparable to that recorded in the Haute Mina sub-basin (23 species) (Senouci & Bounaceur, 2021), the Chott Melghir basin (11 species) (Demnati et al., 2019), the Theniet El Had National Park (18 species) (Mairif et al., 2023) and Boussellam river (23 species) (Chelli et al., 2020), on the contrary, it is significantly lower compared to the results mentioned by Khelifa et al. (2011) in the Seybouse watershed (35 species). This result was also affected by different factors, including the number of stations, the conditions of the study area and the observation period. The family Libellulidae dominated over other recorded families, present in all inventoried stations and numerically representing significant importance with 11 species. This predominance has been reported by many researchers (Mairif et al., 2023; Khelifa et al., 2011; Chelli et al., 2020; Asrori et al., 2023; Mapi-ot et al., 2013). The Libellulidae represents the most abundant family in the Maghreb and throughout the Mediterranean basin (Chelli et al., 2020) and one of the two largest families in the world (Mapi-ot et al., 2013). Most of its species have good flying abilities and a fairly high level of tolerance to various environmental disturbances (Susanto, 2021). The negative relationships between richness and evenness suggest that as communities gain more species, they tend to become less evenly distributed in terms of abundance (dominance by a few species) (DeBenedictis, 1973), where this pattern is more frequent in aquatic systems (Soininen et al., 2012). These varying Relationships highlight the complex interplay of factors that influence the richness-evenness relationship, including study scale (Soininen et al., 2012), ecosystem type, organismal properties, disturbance (Kimbro. & Grosholz, 2006), or due to dominant species outcompeting others (MacDonald et al., 2017), leading to less equitable distributions.

Endemic to North Africa, *Platycnemis subdilatata* was the predominant and most common species in the Medjerda River, its dominance is also mentioned by Khelifa (2017) in the Seybouse watershed. In addition to its ability to lay a large number of eggs and produce multiple generations per year, it has shown a preference for habitats consisting of slow streams with a relatively stable water regime, rich in aquatic and riparian vegetation conducive to oviposition and successful larval development, and even providing shelter from predators. On the other hand, the dominance of *Ischnura graellsii* in the Cheref River has been confirmed by Bouhala et al. (2019). This species exploits calm, slightly flowing, and brackish water (Louboutin et al., 2015), conditions that characterize our stations. The same study showed that the two species are able to adapt to and tolerate disturbed habitats. They have been found to inhabit areas affected by significant human activity, including the presence of plastic debris, building material waste, sewage, and algae.

The importance of species abundance in the Medjerda River is attributed to a significant proliferation of Platycnemididae and Coenagrionidae. Where 62% of the population concentrates on three species namely: *Platycnemis subdilatata* (2086), *Coenagrion mercuriale* (1089) and *Coenagrion caerulescens* (965). Which implies an inequitable distribution of individuals among the different taxa. Medjerda appears to be a good habitat for the species of these two families, due to its diverse vegetation and the presence of dense macrophytes, providing ecological niches for mating, oviposition, emergence, roosting and perching (Dijkstra & Clausnitzer, 2014; Seidu et al., 2019). The difference in water temperature between the two rivers also plays a crucial role in this distribution. The Medjerda River is generally more favourable. It offers thermal conditions closer to their optimal range, allowing for good larval development and activity (Corbet, 1999). Significant seasonal variations were observed in species abundance in both rivers, with peak periods in summer and spring (Appendix 3), as well as an annual variation caused by the heavy rains that hit the region in 2023. Habitat loss, landscape modification, and bank erosion, combined with a deterioration in water quality and the displacement of eggs and larvae, also contribute to this marked reduction in the population.

Many species are considered as habitat generalists and were noted in the two rivers at different elevations and in stations with various levels of impact such as *Ischnura graellsii* and *Platycnemis* *subdilatata*. Other species show specific distributions across the Medjerda and the Cheref rivers, largely due to the mosaic of riparian habitat present, which meets the ecological needs of different species. Additionally, the heterogeneous climate factor along both rivers contributes to these distributions. Cheref River is characterized by very high temperatures and very low rainfalls during the summer season (Appendix 2A–B), which affects the availability of water in the region. This temporary character requires the presence of species that are able to adapt to these difficult conditions like *Enallagma deserti, Sympetrum fonscolombii, Anax imperator, Anax parthenope, Crocothemis erythraea, Trithemis annulata and Brachythemis impartita.* These species have been known for their tolerance of arid conditions for a long time (Suhling et al., 2003). Also, pioneer species such as: *Ischnura pumilio* (Merlet & Itrac-Bruneau, 2016). *Coenagrion puella kocheri* is a rare species in Algeria (Samraoui & Corbet, 2000a), and its status in this country is of great concern (Ferreira et al., 2016). It has appeared only once and at a single station in the Cheref river. Therefore, it is crucial to study it to understand the dynamics, habitat requirements, and dispersal ability of this stenotypic species, A recent research based on molecular data has indicated that the North African *Coenagrion puella (Coenagrion puella kocheri)* could represent a distinct phylogenetic lineage from its European counterpart, which fuels questions about its conservation status (Ferreira et al., 2016). *Paragomphus genei* and *Trithemis kirbyi*, both desert species were recorded in the Medjerda River, with the latter expanding northwards due to climate change (Chelmick & Pickess, 2008; Holuša, 2008). It has crossed the Saharan Atlas and is now reproducing along the Algerian coastline and in southern Europe (Boudot et al., 2009; Cano Villegas & Conesa Garcia, 2009). The first mentions of the species in eastern Algeria appeared in 2011 in the Seybouse basin (Khelifa et al., 2011). With only a few individuals, the last record was in the Kebir-East and the Seybouse watersheds (Yalles & Samraoui, 2017). Also, *Coenagrion mercuriale,* considered endangered regionally (El Bouhissi et al., 2022), was recorded in abundance in Medjerda. In accordance with its ecology, the species has been observed in well-exposed, shallow streams, fairly slow-moving, with a low but permanent flow. With helophytes such as *Nasturtium officinale* and *Juncus sp* providing egg-laying support for adults and a micro-habitat for larvae. In winter, temperatures are higher than average, with little variation throughout the year. This helps to prevent freezing and drying up of watercourses (Thompson et al., 2003). This explains why this species is preferably found in sites supplied by groundwater or springs, which ensure the maintenance of these temperatures.

Our survey in Medjerda River also enabled us to detect a significant population of *Coenagrion caerulescens.* This species was often found in the company of *Coenagrion mercuriale*. It was last found in Sebdou (Morton, 1905) and Mascara (Navas, 1922; Lacroix, 1925). Recently, the species has been documented in the Seybouse watershed (Khelifa et al., 2011), Isser River (Bouchelouche et al., 2015), Kebir-East, Seybouse and Rhumel rivers (Yalles & Samraoui, 2017), and in the Haute Mina sub-basin (Senouci & Bounaceur, 2021). The rarity of species and the lack of prospecting effort in other regions can explain the current state of knowledge.

The Lestidae, limited to 2 species, *Sympecma fusca* and *Lestes barbarus* were infrequently recorded on the Medjerda River. This small number is probably due to a dispersion of the population from another region. Their rarity has been reported by Khelifa et al. (2011) in the Seybouse basin and by Senouci & Bounaceur (2021) in the Haute Mina sub-basin. This study has established a preliminary list of the Odonate species present in the Medjerda and Cheref rivers, revealing remarkable diversity with the presence of rare, threatened, and endemic species. Unfortunately, the quality of the Medjerda River is deplorable due to its location in agricultural, industrial and urban settings (Appendix 2C), where it receives wastewater and irrigation effluents (Guasmi et al., 2012), making it the most polluted river in the region (Djabri et al., 2012). Hence, it is essential to adopt targeted conservation strategies encompassing ecological restoration, urban planning, and community involvement (Fox & Cundill, 2018). In addition, long-term, and regular monitoring is required to identify and protect the reproduction and emergence areas of the Odonates, which play a key role in their life cycle, and to monitor and evaluate the effectiveness of the applied management measures.

These results underline the importance of an extensive sampling effort in this still poorly prospected region of Algeria while expanding the surveys to cover both lotic and lentic ecosystems and various bioclimatic gradients. A more comprehensive understanding of the Odonate communities in different aquatic habitats is essential for implementing appropriate and effective long-term conservation strategies. Sampling efforts should also aim to better understand the distribution ranges, phenology, and reproduction fitness of the Odonate and its responses to ongoing climate change and anthropogenic pressures. In conclusion, a better understanding of the distribution, ecology, and population dynamics of Odonate is indeed essential for implementing appropriate and effective long-term conservation measures for these sensitive insect communities.

AUTHOR'S CONTRIBUTION

The authors confirm their contribution to the paper as follows: All authors participated in the conceptualization and design of the study, as well as in drafting and/or critically revising the manuscript. The authors read and approved the final version of the manuscript.

FUNDING

This research was funded by the Ministry of Higher Education and Scientific Research, Algeria.

AVAILABILITY OF DATA AND MATERIAL

The specimens listed in this study are deposited in the the laboratory of Science and Technology of Water and Environment, Mohamed-Cherif Messaadia University, Souk Ahras, Algeria, and are available from the curator, upon request.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

This study only included plants and arthropod material, and all required ethical guidelines for the treatment and use of animals were strictly adhered to in accordance with international, national, and institutional regulations. No human participants were involved in any studies conducted by the authors for this article.

CONSENT FOR PUBLICATION

Not applicable.

CONFLICT OF INTERESTS

The authors declare that there is no conflict of interest regarding the publication of this paper.

ACKNOWLEDGMENTS

We would like to express our gratitude to Mr. Messaadia Wassim for his assistance in transporting the authors to the study stations and for his support in the field. The authors also acknowledge the Subject Editor and the anonymous reviewers for their valuable comments.

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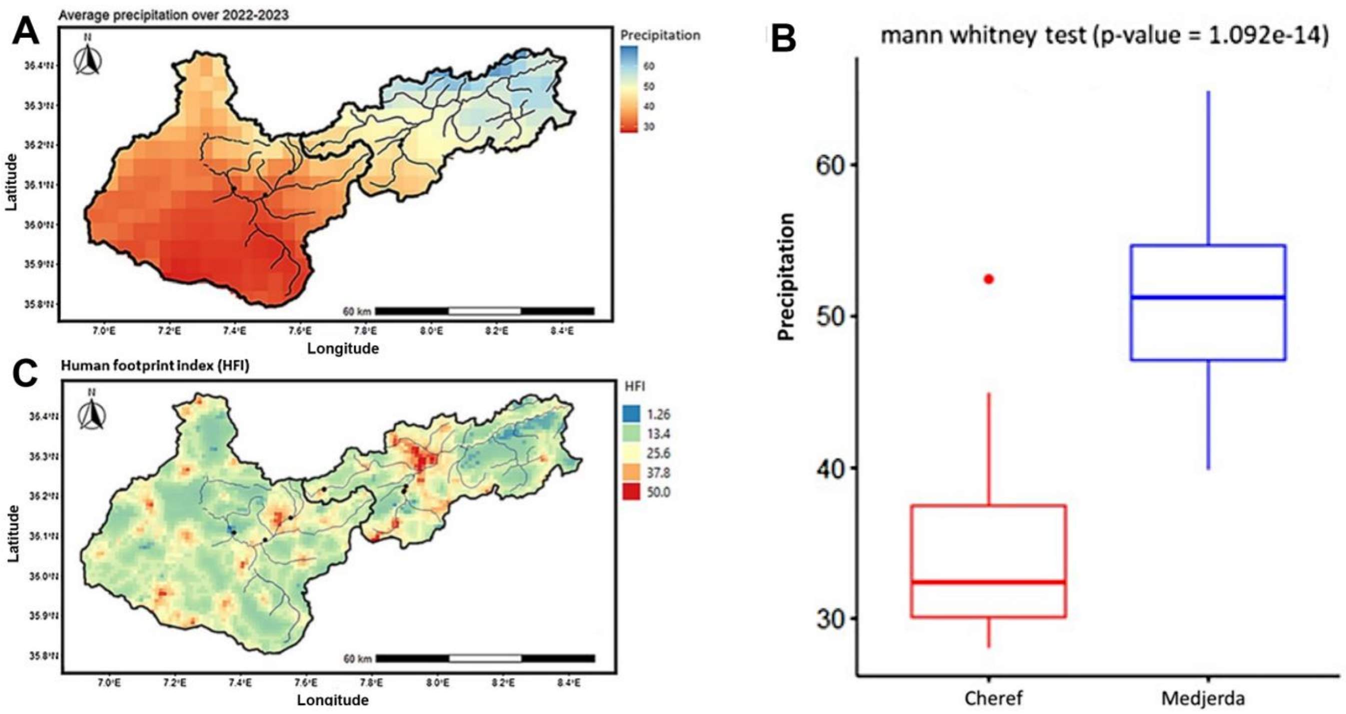
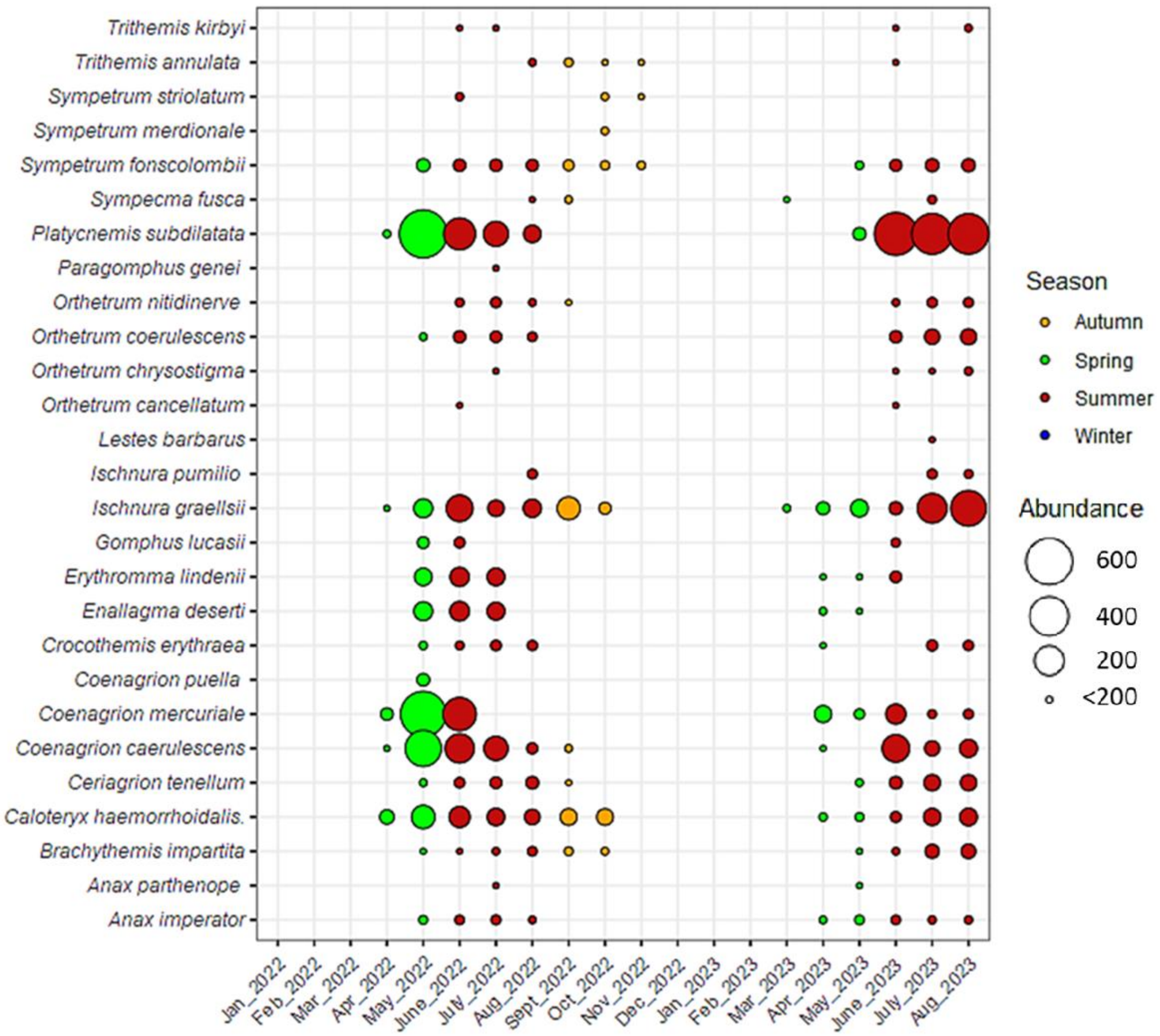
Appendix 1. Anthropogenic pressures in Medjerda and Cheref rivers. **A.** Water pumping; **B.** Grazing; **C.** Resident's waste; **D.** Destruction of riparian vegetation.

Appendix 2. A. Average precipitation patterns over (2022–2023); **B.** Difference in Average precipitation between the two rivers; **C.** Human Footprint Index (HFI) in Cheref and Medjerda in 2022 (Mu et al., 2022).



Appendix 3. Ballonplot illustrating monthly and seasonal distribution of Odonates species (the size of circle is proportional to abundance values).



بسیار نزدیک، اما هنوز هم پرفاصله: ارزیابی ساختار جمعیت طیاره‌مانندها در دو رودخانهٔ مجاور با حوضه‌های آبریز متفاوت، در سوق اهراس، شمال شرق الجزایر

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| **تاریخ دریـافت:** ۰۵ خرداد ۱۴۰۳ | **تاریخ پذیرش:** ۱۰ مرداد ۱۴۰۳ | **تاریخ انتشار:** ۱۶ مرداد ۱۴۰۳ |

چکیـده: فراچرخه‌های آبی به‌سرعت و متاثر از فعالیت‌های انسانی در حال تغییر هستند و بنابراین توجه به تنوع و فراوانی طیاره‌مانندها برای حفاظت مؤثر از آب‌های جاری ضروری است. هدف از این مطالعه، ارزیابی و مقایسه جوامع طیاره‌مانندها در دو رودخانه مجاور، مدجردا و چرف، در سوق اهراس، شمال شرق الجزایر بود که از ژانویه ۲۰۲۲ تا اوت ۲۰۲۳ جمع‌آوری شده است. در مجموع، ۲۷ گونه متعلق به ۷ خانواده و ۱۷ جنس ثبت شد که شامل سه گونه نادر در نومیدیا و سه گونه بومی مغرب‌زمین بود که از جمله آن‌ها می‌توان به *Gomphus lucasii* (Selys, 1850) اشاره کرد که در فهرست قرمز منطقهٔ مدیترانه‌ای IUCN به‌عنوان گونهٔ آسیب‌پذیر ذکر شده است. گونهٔ *Coenagrion mercuriale* (Charpentier, 1840)، یک گونه محلی در خطر انقراض، به فراوانی در رودخانه مدجردا حضور داشت. همچنین وجود گونه بیابانی *Trithemis kirbyi* (Selys, 1891) در مدجردا موید انتشار آن در مناطق شمالی الجزایر است. خانواده Libellulidae با ۱۱ گونه، آرایه غالب منطقه بود. یافته‌های ما نشان داد که تفاوت معناداری از نظر شاخص‌های تنوع زیستی (غنای گونه‌ای، سیمپسون، شانون و شاخص یکنواختی پیلو) بین دو رودخانه وجود ندارد. با این حال، تفاوت‌های معناداری در مجموعهٔ گونه‌های طیاره‌مانندها مشاهده شد که احتمالاً به‌دلیل تنوع زیستگاهی و محیطی است. عوامل متعددی مانند پمپاژ آب، چرای بیش از حد، ورود فاضلاب تصفیه‌نشده و توسعه حاشیه‌نشینی در مجاورت رودخانه که بر حیات طیاره‌مانندها تأثیر می‌گذارند، در هز دو رودخانه مشاهده شد. بنابراین، باید یک برنامه حفاظت فوری برای حفظ منابع آبی و تنوع زیستی در این منطقه تدوین شود. این مطالعه بر نیاز به نظارت مداوم و تلاش‌های حفاظتی، به‌ویژه برای گونه‌های نادر و تهدیدشده در برابر فشارهای فزاینده انسانی بر این اکوسیستم‌های آبی تأکید دارد.

واژگــان کلیدی: طیاره‌مانندها، تنوع، فراوانی، رودخانه‌ها، سوق اهراس، مغرب