Egyptian Journal of Aquatic Biology & Fisheries
Zoology Department, Faculty of Science,
Ain Shams University, Cairo, Egypt.
ISSN 1110 – 6131
Vol. 29(4): 3393 – 3410 (2025)
www.ejabf.journals.ekb.eg

Assessment and Conservation of Large Branchiopods Populations in the Wetland Complex of Northeastern Algeria

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ARTICLE INFO

Article History:
Received: June 2, 2025
Accepted: Aug. 5, 2025
Online: Aug. 31, 2025

Keywords:
Large branchiopods,
Northeastern Algeria,
Wetlands,
Fragmentation,
Physicochemical parameters

ABSTRACT

The Aures region's wetlands, located in eastern Algeria's High Plateaus, are ecologically significant because they provide essential habitats for diverse plant and animal species. This study was conducted from June 2022 to May 2023 and focused on four temporary wetlands in the region: Sebkhet El-Tarf, the Gemot ponds, Lake Timerganine, and the Ezzehar pond. Environmental monitoring was carried out, and monthly samples were collected to assess the multivariate associations between water physicochemical properties, local habitat features, and the species richness of large branchiopods. The study revealed that water pH, temperature, salinity, and dissolved oxygen levels exhibited spatial and temporal variations. Principal component analysis (PCA) and dendrogram analyses revealed a contrast between pH and dissolved oxygen, salinity, and species richness. These analyses revealed seasonal patterns: March-April 2023 had high oxygen and salinity, July-August 2022 was warmer, and the winter months showed low pH and species richness compared to late spring. Site differences were mainly driven by temperature, species richness, and habitat state versus salinity and area. Three groups were identified: GP (warm, fragmented, and species-rich); GET (high salinity and large area); and TL/EP (deeper, with higher pH and oxygen).

INTRODUCTION

The Aures region, located in northeastern Algeria, is distinguished by the diversity of its temporary wetlands, which include lakes, ponds, chotts, and sebkhas. These ecosystems play a major ecohydrological role in environmental management and constitute refuges of international importance for a diverse range of flora and fauna **(Wetzel, 2001; Blanco & Roy, 2020)**. Many of these species are endemic **(Ambelu *et al.*, 2013)**, and several sites are listed under the Ramsar Convention, representing a major ecological heritage.

Temporary ponds, also known as ephemeral or seasonal ponds, are aquatic ecosystems filled with water after rainfall or snowmelt and dried up after a few months. They are thus distinct from permanent ponds or lakes **(Williams, 2002)**. They are important for biodiversity because they provide unique habitats for many species, such as frogs, salamanders, and ghost shrimp, which often depend on them for survival because they cannot live in permanent bodies of water **(Williams, 2006; Baldwin, 2011; Batzer & Boix, 2016)**. In addition, temporary ponds retain various synthetic molecules produced by humans (pesticides, drug residues, etc.) and provide environments conducive to the discharge and accumulation of solid waste, metals, etc., exerting significant pressure on the biota present.

Macroinvertebrate species of temporary ponds are represented by different taxonomic groups of Arthropoda. Crustaceans are represented by species belonging to the subclasses of Phyllopoda, Ostracoda, and Copepoda **(Alonso, 1996; Brendonck *et al.,* 2008; Atashbar *et al.,* 2014)**.
In the Mediterranean, they are often regarded as a flagship group of invertebrates for t emporary ponds **(Belk, 1998; Thiéry, 2004; Beladjal *et al.,* 2007)**, and are promoted for monitoring the ecological status of these ponds. However, they are very sensitive to degradation **(Van den Broeck *et al.,* 2015)**.

The biodiversity of freshwater ecosystems is rapidly deteriorating as a result of human activities **(Dahl *et al.,* 2004)** which are endangered due to their small size and shallowness **(Boix *et al.,* 2008)**. Small changes in hydrological regimes can greatly impact the ecological regime of temporary ponds and it is expected that the reduction in rainfall brought about by climate change will affect their hydrology. Temporary ponds have been neglected for years and are affected by human activities, such as agriculture, urbanization, etc.

The wetlands of north-eastern Algeria are home to a rich and diverse fauna of large branchiopods, including rare and endemic taxa **(Vanschoenwinkel *et al.,* 2009; Rais & Amarouayache, 2018; Beladjal & Amarouayache, 2023; Rais, *et al.,* 2024)**. In addition to their aquatic invertebrate biodiversity, these wetlands also provide essential habitats for many bird species, including the migratory greater flamingo (*Phoenicopterus roseus*) and regionally threatened bird species. They provide essential breeding, feeding and resting sites along the main Afro-European migratory routes **(Boumezbeur *et al.,* 2020)**.

However, urbanization has several significant impacts on these ecosystems. According to **Barman *et al.* (2021)**, urban development is causing a loss of more than 60% of these areas, while urban development in surrounding areas is leading to the destruction and fragmentation of their habitats **(Grillas *et al.,* 2004)**. For thousands of years, Mediterranean populations have exploited temporary ponds for agricultural purposes **(Grillas *et al.,* 2016)**.

This study investigated and compared the ecological characteristics and distribution patterns of large branchiopods across four adjacent wetlands in northeastern Algeria. It focused on assessing the impact of monthly fluctuations in physico-chemical water parameters on large branchiopod species richness. The results aim to provide baseline data to support future conservation strategies and environmental monitoring in the region, with particular emphasis on the threatened Gemot wetland.

MATERIALS AND METHODS

Study area

Four temporary wetlands were chosen for this study, situated in the High Plateaus Northeast of Algeria (Fig. 1). The climate of the region is semi-arid with a cold winter and several days of snowfall, as well as a hot and dry summer (ONM) with large fluctuations in temperature throughout the year. Annual rainfall is very low, on average 500mm/ year.

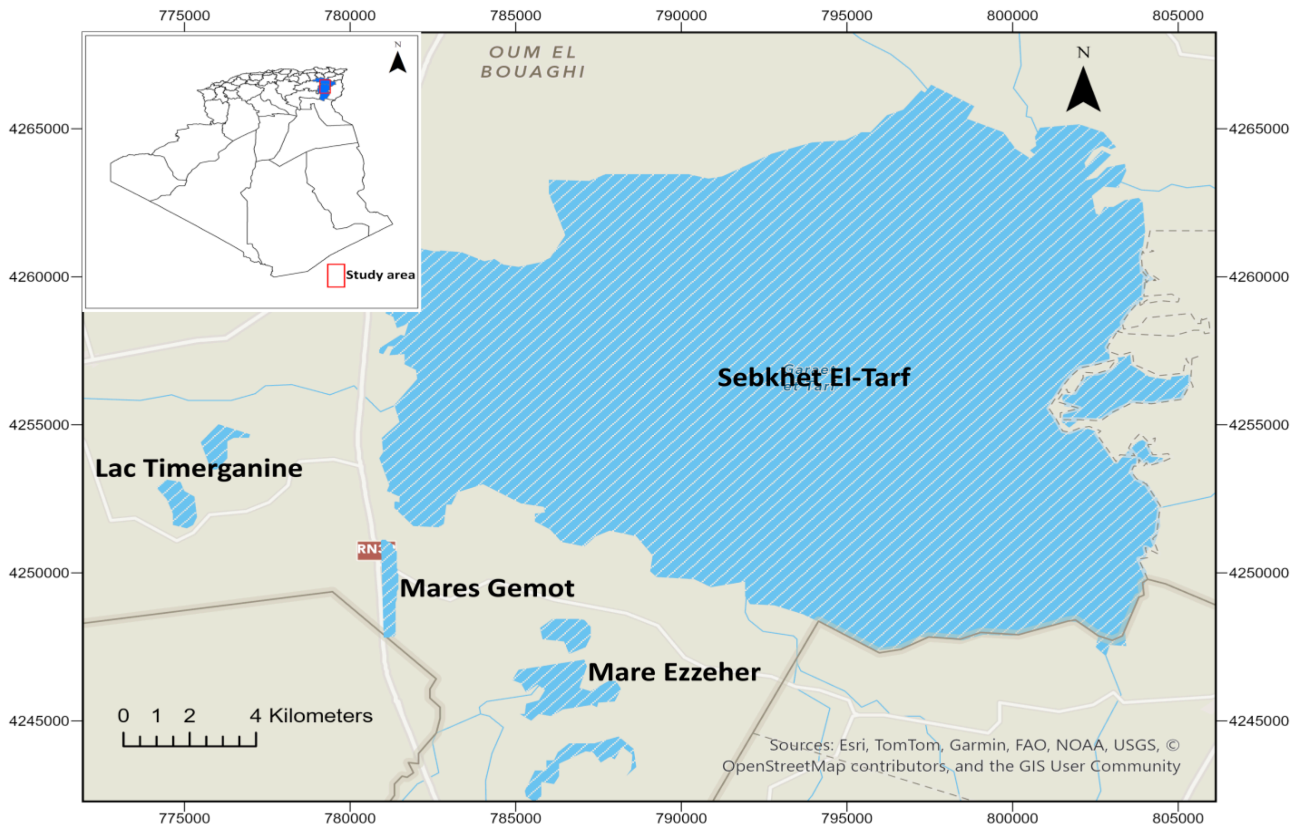


Fig. 1. Study area

The first wetland (Fig. 1) is Sebkhet El-Tarf (35°41'11" N, 07°08'00" E, 834 m altitude), it is a large Salt Lake, covering an area of about 33,460 ha. This sebkha has been classified as a protected site in the Ramsar Convention since February 2004.

The second one is the Gemot Ponds (35° 38’ 52.62’’N, 7° 00’ 45.16’’E, 831 m altitude); these are a group of freshwater bodies located in the high plateaus, near sebkhet El Tarf at the point of view of the hydrographic cycle.

The third site is the Ezzehar Pond (35°37'22.50"N, 7°04'04.49"E, 833 m altitude), which is part of the satellite ponds of Sebkhet El-Tarf (Fig. 1). Its surface area is 35 ha. The last site is Lac Timerganine (35°39'36.72"N, 6°58'09.94"E, 834 m altitude.), which covers an area of 1,460 hectares. This wetland has been classified as a protected site under the Ramsar Convention since 2010. All these sites are therefore subject to the same climatic conditions.

Sampling methods

In this study, four physicochemical parameters; temperature, pH, salinity, and dissolved oxygen (DO) were monthly measured during each sampling using a field multiparameter (ProDSS YSI). The samples of large branchiopoda were collected monthly during the wet period from July 2023 to June 2024 at four (4) sites. Water was filtered through a sieve of 400µm at different sites in order to list the distribution of large branchiopoda species; the specimens were preserved in 70% alcohol.

Statistical analysis

Pearson correlation coefficient was determined between the physicochemical factors (temperature, salinity, pH, and dissolved oxygen). Principal component analysis (PCA), a multivariate technique, is helpful in describing and illuminating the relationships between variables in a variety of data. The principal component analysis was carried out using the correlation matrix. Statistical analyses were performed using the software package Xlstat 2023.

RESULTS

Dual effect of salinity stress and variety on measured water parameters

All the results obtained were subjected to a two-way analysis of variance considering two studied factors: the effect of time with twelve levels (from July 2022 to June 2023) and the effect of site with four levels (SET, TL, GP, and EP). The interaction effect between site and time was also assessed. The mean squares from this analysis are presented in Table (1).

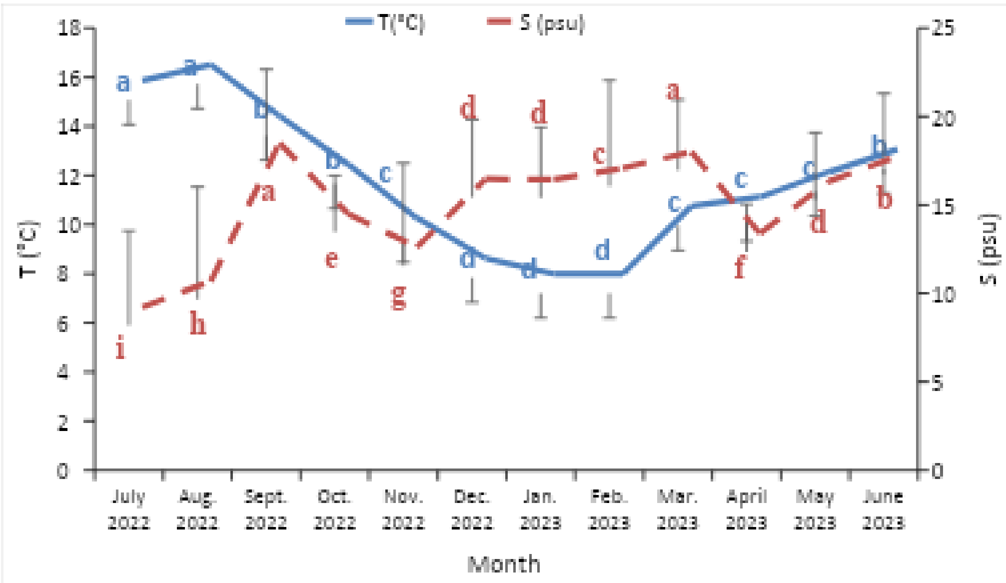
Table 1. Mean squares of the measured water characteristics

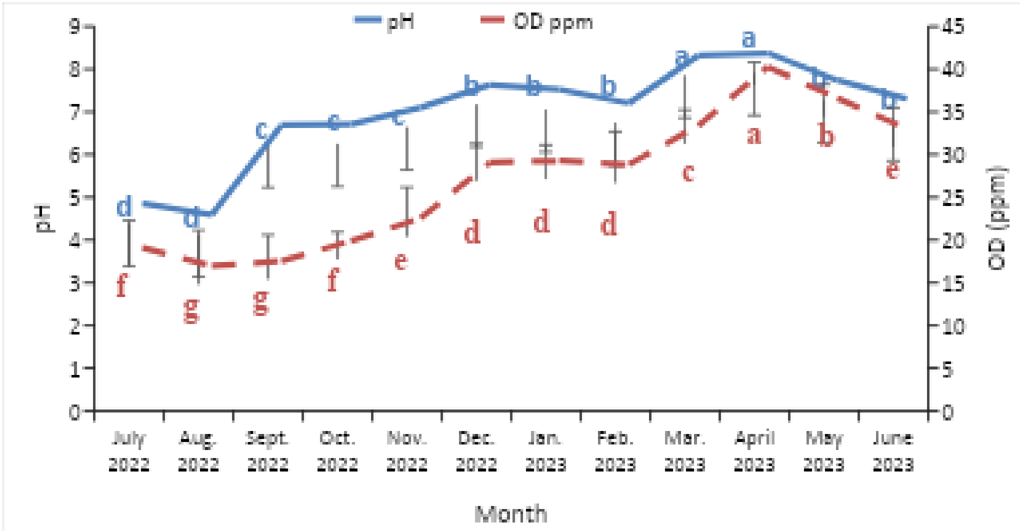
Source of variation	ddl	T(°C)	S(psu)	pH	OD(ppm)	SR
Month effect (M)	11	69.23***	72.17***	1.77**	479.0***	11.40***
Site effect (S)	3	455.94***	2403.18***	10.89***	5306***	29.99***
Interaction effect (TxS)	33	29.22*	144.47***	5.01***	56.83***	10.83***
Error	48	0.39	0.33	0.29	1.76	0.28

The examination of data in Table (1) highlights a highly significant effect of time and an extremely high significant interaction between month and site on all measured parameters. Additionally, the site effect was found to be significant to very highly significant across the entire set of measured variables.

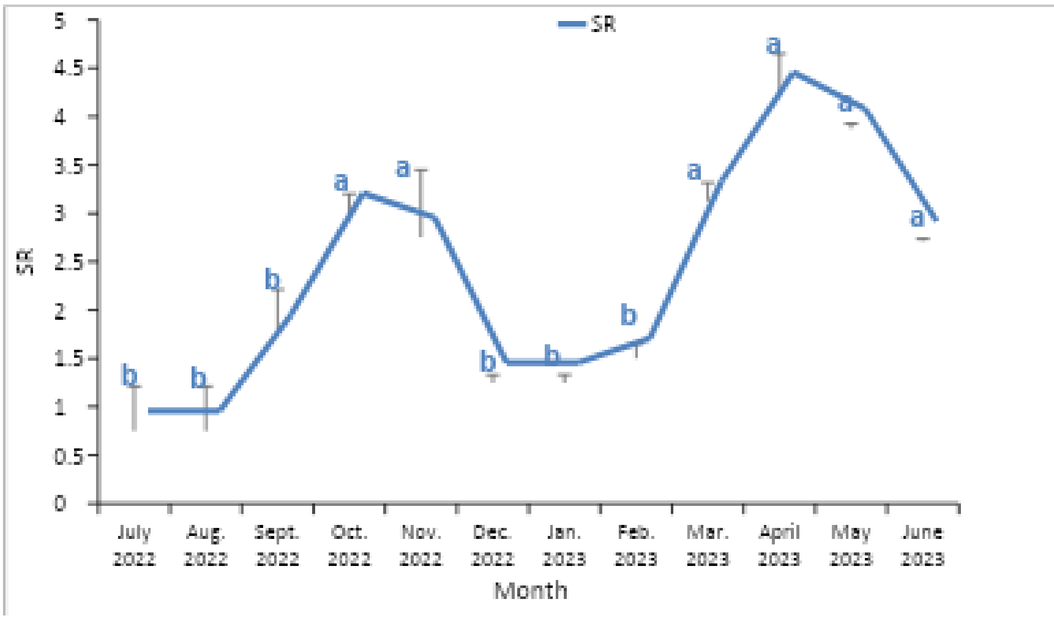
Average monthly effect on water parameters

Water pH, temperature, salinity, and dissolved oxygen levels showed significant temporal variation. The lowest pH (4.14) occurred in August 2022, while the highest (7.91) was in April 2023. Temperature ranged from 7.2°C in winter to 25.72°C in August 2022, forming four distinct seasonal groups. Salinity peaked in September 2022 and March 2023 (~17 psu) and was at its lowest level in July and August 2022 (~8–9 psu). Dissolved oxygen increased over time, with values exceeding 30ppm in spring 2023 and below 20ppm in late summer and the early fall of 2022. Species richness varied monthly and was closely tied to these environmental parameters, forming two main groups: one including March–May 2023 and October–November, and the other comprising the remaining months.





$LSD_{5\%}$= 0,54 (B) $LSD_{5\%}$= 2.012



$LSD_{5\%}$= 2,013

Fig. 2. Average monthly effect on the measured water parameters

Represented by treatment means, homogeneous groups, and LSD5% (Least Significant Difference at 5%). **(A)**: Temperature and Salinity, **(B)**: pH and Dissolved Oxygen, **(C)**: Species Richness.

1.2. Average site effect on measured water parameters

The site had a significant effect on all water characteristics, particularly pH and chlorides. The means of these variables, as well as the homogeneous groups, are presented in Table (2).

Table 2. Average effect of the three studied varieties on the means and homogeneous groups of the measured water parameters

SITE	T(°C)	S (psu)	pH	OD ppm	SR
SET	4.66±3.08 d	28.21±1.9 A	6.43±3.0 b	2.84±1.4 d	1.5±1.7 c
TL	13.04±4.9 b	6.59±1.7 D	6.57±0.7 b	34.16±1.1 a	2.25±0.8 b
GP	14.74±6.1 a	7.35±3.0 C	6.23±0.9 c	31.25±1.7 c	3.8±2.7 a
EP	11.52±2.7 c	13.92±2.7 B	6.9±1.7 a	33.33±2.2 b	1.67±0.9 c
$LSD_{5\%}$	0.362	0.246	0.231	0.569	0.227

The data in Table (2) indicate that the highest values of temperature and species richness were recorded at the GP site, followed by the TL site. The highest pH and dissolved oxygen values were observed at the TL and EP sites, while the highest salinity values were recorded at the GET and EP sites.

Average effect of the month × site interaction on measured water characteristics

The interaction between month and site significantly influenced water parameters. The highest temperature (27.0°C) occurred in August 2022 at the GP site, and the lowest (2.5°C) in December 2022. Salinity peaked in March 2023 at the GET site (46.0 psu) and was lowest at the GP site (3.7 psu) in the same month. pH ranged from 5.3 (August 2022, GP site) to 10.4 (April 2023, EP site). Dissolved oxygen varied widely, from 2.3 ppm (June 2023, GET site) to 55.3 ppm (April 2023, GP site). The GP site showed the highest species richness, likely due to neutral pH, moderate temperature (15°C), high oxygen, and low salinity. For salinity (S), March 2023 at the GET site shows a notably high value, with an average of 46.0 ± 0.8 psu, while the same month at the GP site recorded the lowest salinity, with an average of 3.7 ± 0.2 psu.

Table 3. Average effect of the interaction between the four sites and the twelve months on the means and homogeneous groups of the parameters measured in the waters of the studied wetlands

	SET					TL					GP			
	T(°C)	S (psu)	pH	OD	SR	T(°C)	S (psu)	pH	OD	SR	T(°C)	S (psu)	pH	OD
July 2022	-	-	-	-	-	19.2±1.0	8.3±0.3	6.0±0.4	26.2±0.4	1	26.8±1.1	11.7±0.2	5.8±0.4	24.9±0.8
Aug. 2022	-	-	-	-	-	21.0±1.4	9.9±0.2	5.8±0.5	16.5±0.5	1	27.0±0.7	13.0±0.6	5.3±0.07	26.2±0.5
Sept. 2022	10.2±0.3	38.4±1.2	7.1±0.8	3.2±0.3	2	16.0±1.4	8.7±0.9	6.6±0.6	16.4±0.5	2	14.5±0.3	10.4±0.2	5.5±0.6	24.4±0.09
Oct. 2022	5.3±0.4	26.1±1.2	7.1±1.2	3.4±0.5	2	14.3±1.4	7.4±0.5	6.8±0.4	26.1±0.3	3	15.9±0.8	8.1±0.7	5.4±0.6	23.2±0.2
Nov. 2022	3.2±0.4	21±0.8	8.5±0.6	3.6±0.4	2	11.9±0.4	6.6±0.5	7±0.3	38.0±1.6	3	14.2±0.2	6.2±0.3	5.4±0.5	12.2±0.02
Dec. 2022	2.5±0.7	39.6±0.9	8.5±0.6	3.3±0.2	2	9.3±0.2	5.4±0.4	6.6±0.4	38.4±2.2	1	11.7±0.6	5.1±0.2	6.2±0.4	27.1±1.6
Jan. 2023	4.9±0.02	39.2±0.07	7.6±0.5	3.9±0.2	2	6.3±0.3	5.2±0.3	7.2±0.4	40.3±1.5	1	10.0±0.4	4.6±0.4	7.3±0.5	25.5±0.4
Feb. 2023	3.4±0.6	43.1±0.2	7.4±0.6	4.0±0.4	2	5.7±0.4	4.5±0.4	7.4±0.6	36.8±0.4	2	8.2±0.4	4.1±0.4	6.4±0.2	26.9±1.5
Mar. 2023	6.6±0.8	46.0±0.8	7.8±0.5	3.8±0.5	2	9.8±0.5	4.4±0.3	7.5±0.6	36.2±1.1	2	9.6±0.6	3.7±0.2	6.9±0.5	36.0±1.2
April 2023	4.6±0.6	26.9±0.2	7.8±0.6	3.4±0.4	2	11.8±0.6	5.4±0.2	6.4±0.5	47.4±1.2	4	10.5±0.2	4.2±0.2	7.4±0.2	55.3±1.5
May 2023	6.5±0.8	28.1±0.8	7.6±0.5	3.2±0.6	1	15.4±0.5	6.6±0.3	5.9±0.6	44.0±1.1	4	12.1±0.6	8.9±0.2	6.6±0.3	46.1±1.4
June 2023	8.8±0.4	30.2±0.7	7.7±0.8	2.3±0.2	1	18.3±0.3	6.8±0.5	5.6±0.01	39.5±1.4	3	14.5±0.5	8.8±0.5	7.2±0.01	39±0.3
$LSD_{5\%}$	1.256	1.155	1.083	2.667	1.1	1.256	1.155	1.083	2.667	1.1	1.256	1.155	1.083	2.667

Intervariable Relationships

The relationships between measured variables were analyzed separately by site and month using PCA and dendrograms. For the site-based PCA, the first two axes explained 56.5 and 41.22% of the variance. Axis 1 contrasted temperature, species richness, and habitat state (positively correlated) with salinity (S) and area (negatively correlated), while Axis 2 was positively associated with pH, depth, and dissolved oxygen. The PCA revealed three site groups: GP (positively linked with Axis 1), GET (negatively linked), and an intermediate group (TL and EP). Overlay analysis showed that GP waters were warm, fragmented, and rich in species; GET waters had high salinity and a larger area; EP and TL were deeper with higher pH and oxygen levels.

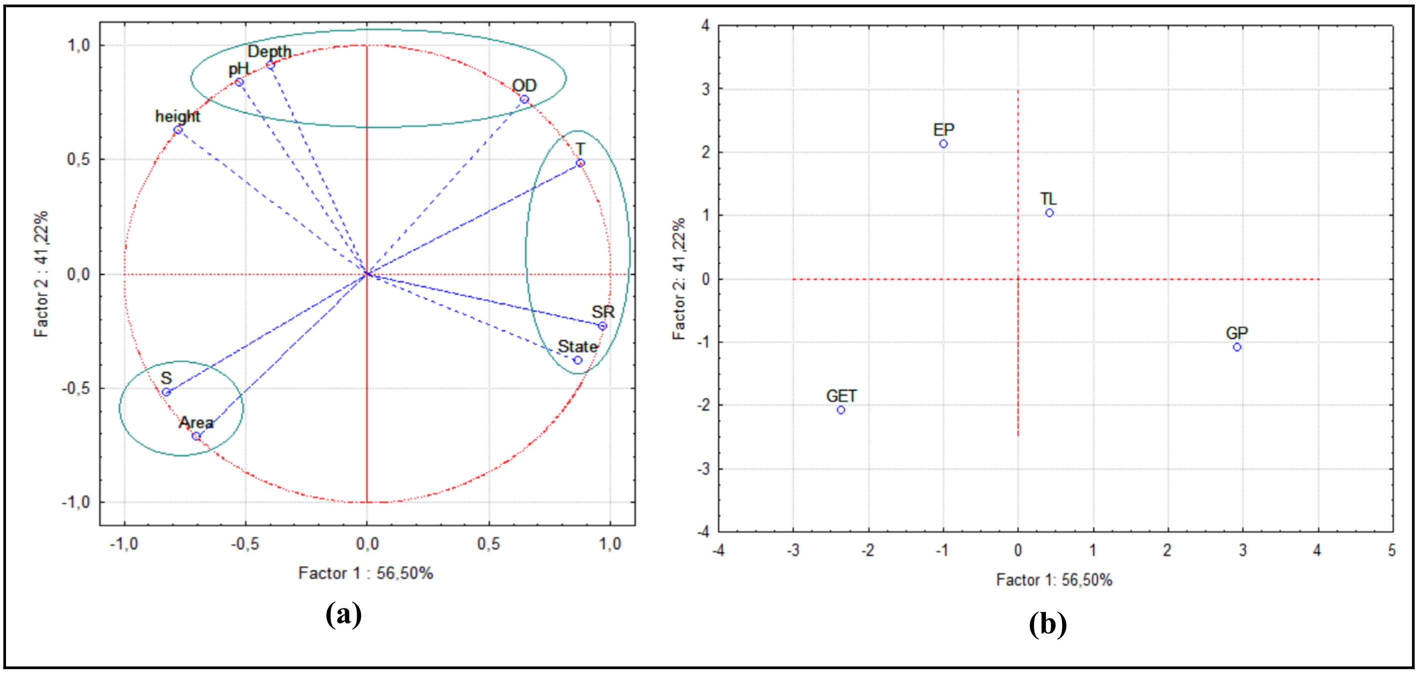


Fig. 3. Projection (a) of the parameters and (b) of the sites on the 1-2 plane of the Principal Component Analysis.

The PCA based on months revealed that the first two axes explained 53.82% and 29.49% of the variance. Axis 1 showed a contrast between pH (negatively correlated) and both dissolved oxygen and salinity (positively correlated). On Axis 2, pH and species richness were negatively correlated. The PCA projection distinguished temporal patterns: March and April 2023 were opposed to July and August 2022 on Axis 1, while winter months (Dec 2022–Feb 2023) were opposed to May and June 2023 on Axis 2. Overlay analysis revealed that March–April 2023 waters had high oxygen and salinity, summer months were warmer, and winter months were marked by low pH and low species richness compared to late spring (May–June 2023).

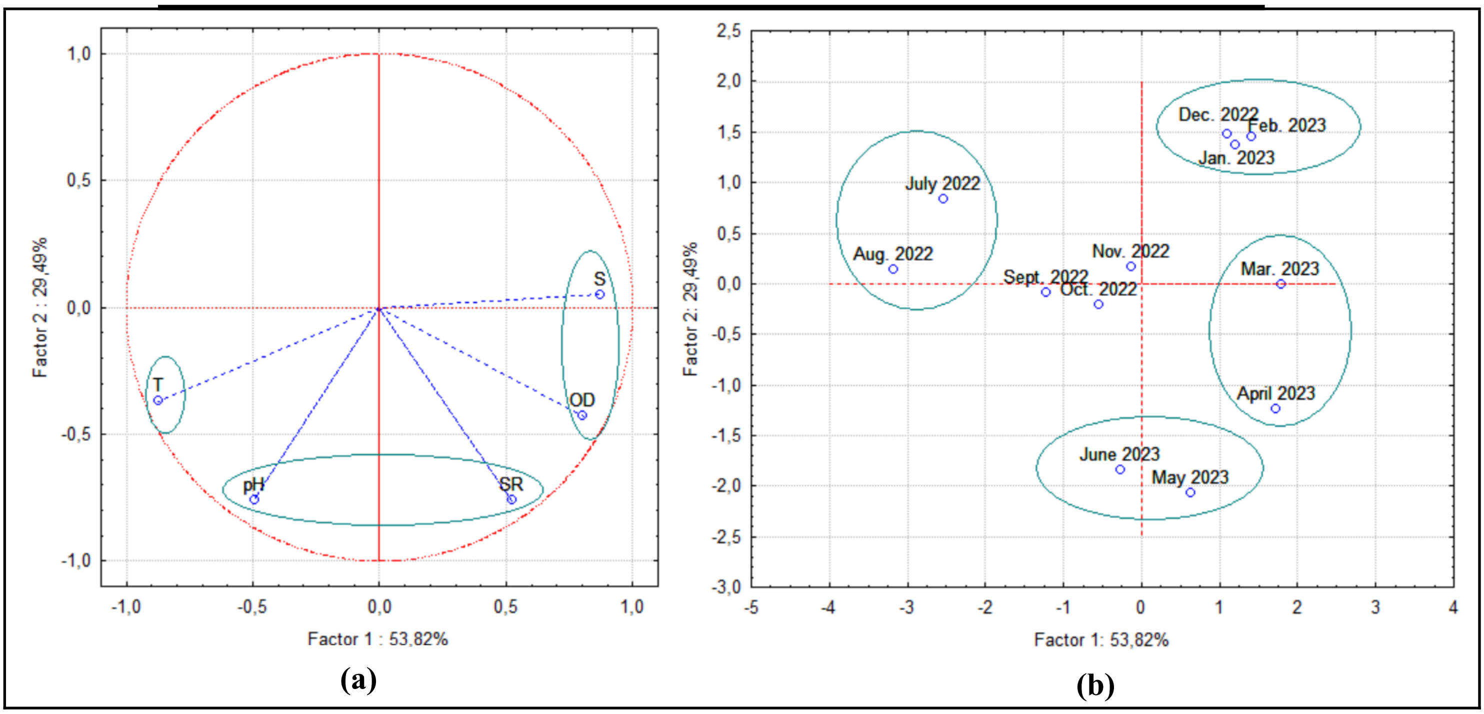


Fig. 4. Projection **(a)** of the parameters and **(b)** of the months on the 1-2 the plane of the Principal Component Analysis. Anthropogenic

1. Anthropogenic effects

Fig. (5) illustrates the dual impact of anthropogenic pressures on the ecosystem of Gemot wetland. Specifically, through pollution from human waste and landscape fragmentation. The visible presence of solid waste, sewage discharge, and possible chemical contaminants reflected.

Fig. 5. Anthropogenic Impacts on the ecological integrity of the Gemot Wetland ecosystem.

DISCUSSION

Temporal variation and environmental influence

This study highlights the dual influence of salinity stress and spatial variability on key physicochemical parameters, such as temperature (T), salinity (S), pH, dissolved oxygen (DO), and large branchiopod species richness (SR), across monthly intervals and geographically distinct wetland sites in the Aures region of northeastern Algeria. Statistically significant effects of time and site, as well as their interaction, underscore the dynamic and heterogeneous nature of these aquatic systems.

Seasonal fluctuations in water temperature and pH reflect broader climatic patterns. Peak temperatures recorded in July and August 2022 coincide with increased evaporation rates, concentrating salts and organic matter and contributing to lower pH levels. A similar phenomenon was reported by **Kapoor and Pande (2015)** in salinity-stressed fenugreek systems. Our observation of an extremely low pH level of 4.14 ± 2.98 in August 2022 highlights the vulnerability of shallow wetland systems to acidification during arid periods. **Rais and Amarouayache (2018)** found that temperature and salinity both significantly influence the distribution of *Phallocryptus spinosa* and *Branchinectella media* in Algerian wetlands. Furthermore, **Poff *et al.* (2002)**, **Soultan *et al.* (2019)**, **Ghosh *et al.* (2020)** and **Woolway *et al.* (2022)** emphasized that climate change poses serious threats to biodiversity in Afro-Arabian regions, potentially leading to ecological collapse.

Salinity levels peaked in September 2022 and March 2023, likely due to seasonal variations in the water balance, such as reduced rainfall and increased evaporation, which limit dilution and enhance mineral accumulation. These results are consistent with those of **Zeng *et al.* (2013)**, who observed increased elemental toxicity in barley under dual waterlogging and salinity stress. Similarly, **Fu *et al.* (2023)** demonstrated altered water uptake and ion regulation in wheat subjected to the dual stresses of waterlogging and salinity, reinforcing the idea that salinity variability imposes physiological constraints on aquatic organisms.

Multivariate patterns: Principal component analysis (PCA)

In line with recent studies on temporary Mediterranean ecosystems **(Gómez *et al.,* 2019; Martínez *et al.,* 2020)**, principal component analysis (PCA) revealed that communities of large branchiopods (anostracans, notostracans, and conchostracans) were mainly structured according to several environmental gradients related to the temporary nature of their habitats. In the wetlands of northeastern Algeria, these gradients were pH, temperature, salinity and dissolved oxygen content. An increase in salinity, and dissolved oxygen content was observed, along with a decrease in pH. This situation is probably due to evaporation and mineral dissolution. There was also a negative correlation between pH and species richness, indicating the predominance of acid-tolerant species in low pH environments, as reported by **Silva *et al.* (2017)**. Seasonal variations reveal marked temporal dynamics, with conditions favorable to the emergence of cohorts in spring (March-April) and more restrictive conditions in summer and winter. These variations correspond to the cycles of drying and refilling of temporary environments **(Fernandez *et al.*, 2021)**. These results confirm the importance of physical and chemical factors, as well as their seasonal variability, in the structuring of temporary aquatic communities.

Spatial patterns and site influence

Significant differences were observed in the spatial distribution of all measured parameters across the four sites: Sebkha El-Tarf, Lake Timerganine, Gemot Pond, and Ezzehar Pond. This variation highlights the impact of local environmental conditions, including land use practices, anthropogenic pressures, and degrees of habitat fragmentation. Gemot Pond, the most fragmented site, showed the greatest sensitivity to environmental changes, possibly due to reduced connectivity and ecological resilience. **Mulinge (2023)** reported that landscape changes such as deforestation and urbanization lead to declines in species diversity, which supports this interpretation. These results have important implications for their conservation in a context of climatic and anthropogenic pressures **(Arthington *et al.*, 2018)**. Recent inventories in Europe also highlight the importance of monitoring large branchiopods as indicators of ecological quality **(Thiéry *et al.*, 2019; Cart & Thiery, 2025)**. Environmental stressors, such as climate change, have adverse effects on crustacean communities, affecting their diversity, abundance and functioning. Pollution, whether chemical (heavy metals, pesticides, etc.) or organic (eutrophication, oil spills), can cause poisoning, reproductive disorders, reduced growth, and even mass mortality. Habitat fragmentation, often caused by dam construction or urbanization, isolates crustacean populations, reducing their ability to move around to feed, reproduce, and escape predators, thereby decreasing their genetic diversity and resilience. Toxic pollutants, such as neurotoxic insecticides and other organic pollutants, are among the most toxic to cladocerans, including *Daphnia magna* **(Sánchez-Bayo, 2006; Soltanighias *et al.*, 2024)**. Research on *Artemia franciscana* has shown that certain psychotropic drugs, such as fluoxetine and deprehnil, alter locomotion, light habituation, and neurotransmitter levels (serotonin and dopamine) **(Dick et al., 1998; Kohler *et al.*, 2021)**. These changes reflect neurotoxicity that could reduce survival and reproduction in contaminated environments **(Bello *et al.*, 2021)**.

CONCLUSION

This study highlights the vulnerability of temporary wetlands to anthropogenic and climatic pressures (physico-chemical changes, climate change, and changes in hydrological regimes), which pose major threats to aquatic biodiversity. To address these issues, immediate and thoughtful action is needed. By reducing greenhouse gas emissions, preserving natural habitats, and decreasing pollutants, we can help mitigate the negative effects of climate change. Gemot Pond is not just a geographical area, it's also a precious ecological element that requires our vigilance and safeguarding. Upon prioritizing preservation actions, we can ensure the sustainability of this wetland ecosystem, which supports both wildlife (a hot spot for large Branchiopoda) and local communities for future generations.

Ethical Approval: Not applicable.

Consent to Participate: Not applicable.

Consent to Publish: All authors approved the manuscript to be published.

Authors Contributions: Lynda Rais and Noudjoud Maghni Study conception and design were performed by Mahrez Boulabeiz. Lynda Rais performed the data acquisition, sample preparation, and chemical analysis. First draft was written by Lynda Rais with contributions from Noudjoud Maghni, and Somia Lakhdari. Statistical analyses were carried out by Dalila Addad. All authors have read and approved the final manuscript.

Funding: Not applicable.

Competing Interests: The authors declare no competing interests.

Data Availability: All data supporting this article are provided within the article (and its supplementary files).

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