République Algérienne Démocratique et Populaire

Ministère de l'Enseignement Supérieur et de la Recherche Scientifique

Université 8 Mai 1945 Guelma

جامعة 8 ماي 1945 قالمة
UNIVERSITE 8 MAI 1945 GUELMA

Faculté des Sciences de la Nature et de la Vie et Sciences de la Terre et de l'Univers
Département d'Ecologie et génie de l'environnement
Laboratoire de domiciliation : Biologie, Eau et Environnement

THÈSE

En Vue de l'Obtention du Diplôme de

Doctorat en Troisième Cycle

Domaine : Sciences de la Nature et de la vie. Filière : Ecologie et Environnement

Spécialité : Agro Ecologie.

Présentée par

GHARBI Meryem

Intitulée

Facteurs déterminant la variation de la distribution et l'abondance des communautés des macro invertébrés des zones humides de Nord-Est Algérien

Soutenue le : 04/11/2025 Devant le Jury composé de :

Nom et Prénom	Grade		
Mr NEDJAH Riad	Pr	Univ. de Guelma	Président
Mme BAALOUDJ Affef	Pr	Univ. de Guelma	Encadreur
Mme HABBACHI Wafa	Pr	Univ. de Annaba	Examinateur
Mr RAMDANI Kamel	MCA	Univ. de Guelma	Examinateur
Mme SANSRI Soraya	MCA	Univ. de Guelma	Examinateur

Année Universitaire : 2025/2026.

People's Democratic Republic of Algeria

Ministry of Higher Education and Scientific Research

University of 8 Mai 1945Guelma

جامعة 8 ماي 1945 قالمة
UNIVERSITE 8 MAI 1945 GUELMA

Faculty of Natural and Life Sciences and Earth and Universe Sciences

Department of Ecology and Environmental Engineering

Domiciliation laboratory: Biology, Water and Environment (LBEE)

Thesis

Submitted in Candidacy for the Degree of Doctorate in Third Cycle

Field: Natural and Life Sciences Stream: Ecology and Environment

Speciality: Agro-Ecology

Presented by:

GHARBI Meryem

Title

Factors determining variation in the distribution and abundance of macroinvertebrate communities in wetlands of north-eastern Algeria

Defended on: 04/11/2025 Before the jury composed of:

Full name	Rank	University	
Mr NEDJAH Riad	Pr	Univ. of Guelma	President
Mme BAALOUDJ Affef	Pr	Univ. of Guelma	Supervisor
Mme HABBACHI Wafa	Pr	Univ. of Annaba	Examiner
Mr RAMDNI Kamel	MCA	Univ. of Guelma	Examiner
Mme SANSRI Soraya	MCA	Univ. of Guelma	Examiner

Academic year: 2025/2026

Acknowledgements

I would like to begin by thanking Allah for giving me the strength and passion to undertake and complete this work.

My heartfelt gratitude goes to the honorable members of the jury who have graciously agreed to review this modest work. In particular, I would like to thank Professor ***Gueroui Yassine*** from the University of Guelma for presiding over the jury, as well as Professor ***Habbachi Wafa*** and Professor ***Bairi Abdelmadjid***, both from the University of Annaba, and Doctor ***Sansri Soraya*** from the University of Guelma, for graciously agreeing to evaluate my work.

Above all, I would like to express my deepest thanks to my thesis supervisor, Prof. ***Affef Baaloudj***, for teaching me to think more independently throughout this research journey. Your expertise has been a guiding light and a source of invaluable learning. Your generosity in sharing knowledge and your constant support have played a key role in my academic and personal growth. For me, you were more than a professor; you were a mother, a sister, and a friend, and that will never be forgotten.

I would also like to express my sincere appreciation to our collaborators over the years: ***Mr Rassim Khelifa*** and ***Mr Patricio R. De Los Ríos-Escalante***. Their thoughtful advice, constructive feedback, and insights helped me to refine my research and expand my horizons. I am deeply grateful for your commitment and the part you played in the success of this work.

This project could not have been completed without your wisdom, guidance and unwavering dedication.

My warm thanks also go to Professor ***Ben Jelloul Mourad*** (University of Tunis), who welcomed me into his team during my internship, and to Dr Jaziri Brahim (University of Tunis), who was a great help with this thesis. I learnt a great deal working alongside him, and I thank him sincerely for that.

I would also like to acknowledge Professor ***Houhamdi Moussa***, Head of the Doctoral Programme, for his helpful support, and ***Mrs Abbas Leila***, the Laboratory Engineer, for all the kindness she showed me over the years.

Gharbi meryem.

Dedication

My most affectionate thanks go to my family, and in particular to my father, who always believed in my success, and to my mother, who surrounded my children with love, affection and tenderness whenever they needed it. I would also like to thank my brother and all my sisters, especially my little sister Ghada, for all their support, dedication and encouragement throughout my studies.

I dedicate this work to the greatest successes of my life, my light in the darkness, my two diamonds, Sadan Sadjida and Yaman Charif. I love you all.

I saved the best until last: this work is dedicated to the person who has always been there for me, through good times and bad, who has held me up through every fall; the love of my life, my better half, my father, my brother, my friend, and above all, my husband, Ahmed Boudria. This success is for you.

Always yours, Meryem.

Abstract:

Benthic macroinvertebrates play an important role in inland waters, inhabiting diverse aquatic ecosystems where communities are structured in terms of space. Macroinvertebrates in some Mediterranean regions, such as North Africa, have not yet been well studied. For this reason, we proposed studying the community structure of water bodies located in north-eastern Algeria. To achieve this, we sampled 12 different types of water bodies: two dams, three rivers, and seven streams, from October 2020 to September 2021. Biotic and abiotic data were collected, and a redundancy analysis (RDA) was performed to determine the role of both types of variables in grouping the sites. Two types of null models were also considered: species co-occurrence and niche sharing to study the potential associations between the reported species, and maximum entropy analysis to model the distribution. The redundancy analysis showed that water velocity and conductivity were the main drivers of the macroinvertebrate community structure. The species co-occurrence results revealed that species associations were random, except for two sites: El Fadjoudj and Ain Ben Baida, which correspond to the Seybouse River. At the same time, there was no niche sharing, and consequently, no interspecific competition, except at the two sites: the Salah Salah stream and the Bouhamdane dam. MaxEnt revealed that the differences in the distribution of specific richness were massive, and that the Seybouse and El Fadjoudj rivers had the highest rate of specific richness.

These results are similar to those of other studies of Algerian rivers and dams, as well as other similar water bodies in Mediterranean climates.

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

Résumé :

Les macroinvertébrés benthiques jouent un rôle important dans les eaux continentales, où ils habitent des écosystèmes aquatiques diversifiés et structurés en fonction de l'espace. Les macroinvertébrés de certaines régions méditerranéennes, comme l'Afrique du Nord, ont toutefois peu été étudiés. C'est pourquoi nous avons proposé d'étudier la structure de la communauté des macroinvertébrés d'eau douce du nord-est de l'Algérie. Dans ce but, nous avons échantillonné 12 types de plans d'eau différents (deux barrages, trois rivières et sept ruisseaux) d'octobre 2020 à septembre 2021. Des données biotiques et abiotiques ont été collectées et une analyse de redondance (RDA) a été réalisée afin de déterminer le rôle des deux types de variables dans le regroupement des sites. Deux types de modèle nul ont également été envisagés : la cooccurrence des espèces et le partage des niches pour étudier les associations potentielles entre les espèces signalées, et l'analyse de l'entropie maximale pour modéliser la distribution. L'analyse de redondance a montré que la vitesse de l'eau et la conductivité étaient les principaux moteurs de la structure de la communauté de macroinvertébrés. Les résultats de l'analyse de cooccurrence ont révélé que les associations d'espèces étaient aléatoires, à l'exception de deux sites : El Fadjoudj et Ain Ben Baida, qui correspondent à la rivière Seybouse. En même temps, il n'y a pas eu de partage de niche, et par conséquent, pas de compétition interspécifique, sauf dans les deux sites du ruisseau Salah Salah et du barrage de Bouhamdane. L'analyse MaxEnt a révélé que les différences dans la distribution de la richesse spécifique étaient massives, et que les rivières Seybouse et El Fadjoudj présentaient les plus grandes richesses spécifiques.

Ces résultats sont similaires à ceux d'autres études sur les rivières et les barrages algériens, ainsi que sur d'autres cours d'eau similaires dans les climats méditerranéens.

Mots clés : macroinvertébrés benthiques, structure des communautés, eau douce, nord-est de l'Algérie.

الملخص:

تلعب اللافقاريات القاعية الكبيرة دورًا مهمًا في المياه القارية، حيث تعيش في النظم الإيكولوجية المائية المتنوعة والمنظمة مكانيًا. ومع ذلك، لم يتم دراسة اللافقاريات الكبيرة في بعض مناطق البحر الأبيض المتوسط، مثل شمال أفريقيا، إلا قليلاً. لذلك اقترحنا دراسة البنية المجتمعية للافقاريات الكبيرة في المياه العذبة في شمال شرق الجزائر. وتحقيقًا لهذه الغاية، قمنا بأخذ عينات من 12 نوعًا مختلفًا من المسطحات المائية (سدان وثلاثة أودية وسبعة جداول) من أكتوبر 2020 إلى سبتمبر 2021. تم جمع البيانات الحيوية واللاحيوية وتم إجراء تحليل التكرار (RDA) لتحديد دور هذين النوعين من المتغيرات في في هذه المواقع. كما تم النظر أيضًا في نوعين من النماذج: التواجد المشترك للأنواع وتقاسم المنافذ للتحقق من الارتباطات المحتملة بين الأنواع المتحصل عليها، وتحليل الحد الأقصى للانتروبيا لنمذجة هذا التوزع. وأظهر تحليل التكرار أن سرعة المياه والتوصيل كانا المحركين الرئيسيين لبنية مجتمع اللافقاريات الكبيرة. كشفت نتائج تحليل التواجد المشترك أن ارتباطات الأنواع كانت عشوائية، باستثناء موقعين: الفجوج وعين بن بيضاء، اللذان يتوجدان في واد سيبوس. في الوقت نفسه، لم يكن هناك تقاسم للمناخ، وبالتالي لم يكن هناك تنافس بين الأنواع، باستثناء موقعي مجرى صالح صالح صالح وسد بوحمدان. كشف تحليل MaxEnt أن الاختلافات في توزيع ثراء الأنواع كانت هائلة، حيث أظهر موقع الفجودج أكبر عدد في للأنواع البحر الأبيض المتوسط.

الكلمات المفتاحية: اللافقاريات القاعية، بنية المجتمع، المياه العذبة، شمال شرق الجزائر.

Table of contents

List of tables

List of figures

Introduction

Introduction:

The notion of the ecosystem was proposed in 1935 by Tansley as the entirety of a system that includes not only the complex of organisms but also the physical factors that integrate the habitat in a broad sense. These systems thus form the basic unit of nature and offer a great diversity in type and size. (Tansley, 1935).

These ecosystems are profoundly altered by human activities, through agriculture, grazing, and land use across the planet. These anthropogenic disturbances have resulted in rapid climate changes, disruptions in the functioning of terrestrial and freshwater ecosystems, as well as a significant loss of biodiversity. (Mooney *et al.,* 2009).

Among the diverse ecosystems impacted by humans, freshwater aquatic environments are no exception. They face various threats such as overexploitation of water resources and species, as well as pollution (Florian, 2019). These environments are biodiversity hotspots compared to their surface area; they host about 10% of all described species while covering only around 0.8% of the Earth's surface (Dudgeon *et al.,* 2006; Strayer & Dudgeon, 2010). Freshwater ecosystems are among the most threatened systems in the world due to these anthropogenic activities (Saunders *et al.,* 2002). They are experiencing a much greater biodiversity decline than even the most affected terrestrial ecosystems (Strayer & Dudgeon, 2010).

Furthermore, the intensification of human activities has altered the physical conditions of aquatic habitats due to changes in the hydrological regime (Nilsson & Berggren, 2000; Richter *et al.,* 2003; Pyron & Neumann, 2008; Borja *et al.,* 2010; Belmar *et al.,* 2013; Boucenna, 2023).

The wetlands of north-eastern Algeria are characterized by big biodiversity of fauna and flora (Samraoui & Samraoui, 2008; Khelifa *et al.,* 2016; Bouali *et al.,* 2021).

Algerian water has a strategic character because of its rare qualities and a disturbed and unbalanced cycle (Bekhouche *et al.,*2017).

A temporary or structural water shortage is observed in Algeria due to the scarcity, fragility, and unequal distribution of water resources. Moreover, as the demand for water increases, the use of surface water becomes inevitable (Belhadj, 2017).

The aquatic organisms that inhabit these environments show preferences and requirements vis-à-vis the various biotic and abiotic factors: when a change occurs in an environment, there are disturbances of the communities that inhabit it (Rouibi *et al.,* 2021; Ferguani & Arab, 2013). Despite all that, the study of macroinvertebrates in Algeria's streams has only been undertaken in recent decades, aiming to create an exhaustive inventory and gain knowledge of their systematics, ecology, and biogeography (Rouibi *et al*., 2021).

Macroinvertebrate communities are highly dependent on the riverine system, and the ecological changes related to drought can strongly shape species composition and abundance. However, riverine macroinvertebrates are also affected by other anthropogenic factors, such as land use, pollution, and water extraction for irrigation, which independently or jointly change the structural integrity of watercourses, as well as the physicochemical characteristics of the ecosystem (khelifa *et al.,* 2021), For all those reasons the selection of the natural territory can encompass the relationship of individuals with their surrounding abiotic and biotic factors (Baaloudj, 2019).

And due to their vulnerability to changes in both biotic and abiotic factors, they're frequently used to evaluate the global health status of aquatic ecosystems (Bakhouche *et al.,* 2017). In addition to their high taxonomic diversity, their central position in the food webs, and a wide range of sensitivity-tolerance to water quality along with physicochemical parameters, offers a more integrated view of ecosystem health (Suárez *et al.,*2022).

The Sharing of the resources available in the environment is one of the principles of the coexistence of the different species in a community, which is one of the main factors determining the distribution, abundance, and diversity of organisms (Toft, 1985).

In light of this importance, it is crucial to identify the pressures exerted on these ecosystems and to better understand how these pressures are distributed in space and the intensity with which they affect natural habitats. This knowledge can contribute to more effective management that better reconciles biodiversity conservation (Richardson *et al.,*2006).

The overall objective of this study is to:

- Assess the ecological integrity of the aquatic environment.
- Do an exploratory analysis study of the benthic invertebrate communities in rivers, dams, and streams in Northeastern Algeria.
- Track the changes in the distribution of macroinvertebrates caused by disturbance in their environment.

- Steady The effect of the global abiotic factors on the Community Structure and determine the potential role of species interactions.

This thesis begins with a general presentation of the biological models studied in the first chapter, after which the context and a general introduction are presented.

leading to a description of the characteristics of the study area in the second chapter.

The third chapter is dedicated to explaining the protocol followed to conduct this study.

Then followed by a presentation of the results obtained and a general discussion, concluding with a recap of the study's achievements.

Chapter 1: Biological materials studied

Chapter 1: Biological materials studied

1.1 Definition:

Freshwater benthic macroinvertebrates. Invertebrates are all animals that do not have a skeleton of bone or cartilage. Of these animals, macroinvertebrates are those that are visible to the naked eye. Benthic macroinvertebrates live on the bottom of streams, rivers, lakes or marshes. They are mainly worms, crustaceans, molluscs, and insects. Benthic macroinvertebrates are an important part of freshwater ecosystems. They provide food for many fish, amphibians, and birds. This is a very diverse group, and the organisms that make it up have different sensitivities to different stresses, such as pollution or habitat alteration. Macroinvertebrates are the organisms most commonly used to assess the health of freshwater ecosystems (Belala, 2022).

Benthic macroinvertebrates are organisms that live most of their lives on the bottom of a water body or at a short distance from it. They have no backbone and are visible to the naked eye. They include aquatic insect larvae, some adult aquatic insects, crustaceans, molluscs, and worms. The main orders of aquatic insects in this category of organisms are as follows: Mayflies, Plecoptera, Trichoptera, Diptera, Coleoptera, Megaloptera, Hemiptera, Odonata and Lepidoptera (Gagnon & Pedneau, 2006).

The invertebrate group is the most diverse in the world, with some 107,259 species of freshwater invertebrates known worldwide. It is characterised by an enormous variety of existing forms and functions in the animal kingdom. Macroinvertebrates play an important role in the processes of aquatic ecosystems; whatever their functional role, they are also involved in the transformation of energy from producers (aquatic and terrestrial vegetation) to higher trophic levels (fish and aquatic birds) (Dambri, 2021).

Aquatic macroinvertebrates can be classified as primary consumers (eating plant material) or secondary consumers (eating planktonic organisms).

Or they can be classified as being close to the base of the food chain. They play a crucial role as they. promote nutrient cycling and reduce the size of organic particles (Callisto *et al.,*2001).

1.2. Macroinvertebrate ecology:

Species select habitats in which survival and reproduction are optimal. One of the most important objectives of aquatic ecology is determining the distribution and abundance of invertebrates and the factors that govern habitat selection. According to Dajoz (1985), the factors influencing the spatial distribution of species in a habitat are mainly abiotic conditions.

Macroinvertebrates inhabit a variety of microhabitats such as rocky substrates, fine sediments, plant debris, and areas of aquatic vegetation. Their distribution is strongly influenced by current velocity, substrate granulometry, dissolved oxygen availability, and water quality. For example, Ephemeroptera and Trichoptera prefer well-oxygenated waters and coarse substrates, whereas Chironomidae and Oligochaetes tolerate more degraded conditions with fine sediments and low oxygen levels (Rosenberg & Resh, 1993).

They are also key players in ecological cycles. Their spatial distribution is strongly influenced by habitat structure: substrate diversity, flow heterogeneity, and the availability of refugia against predation or hydrological stress. High habitat diversity, therefore, favours high species richness (Wallace & Webster, 1996).

Seasonal variations also affect their dynamics. Some species emerge synchronously with peaks in temperature or flow, highlighting their fine-tuned adaptation to hydrological regimes (Hynes, 1970). Macroinvertebrates also respond differently to disturbance gradients: loss of lateral connectivity in floodplains can reduce functional diversity by limiting trophic interactions and dispersal opportunities (Tockner & Stanford, 2002).

From a functional perspective, classification into functional trophic guilds (shredders, grazers, filter-feeders, predators) provides a better understanding of energy and material flows in rivers (Cummins & Klug, 1979). For example, the dominance of filter feeders downstream and grazers upstream illustrates the longitudinal structuring of communities according to the "River Continuum Concept".

In terms of functional food groups, macroinvertebrates can be classified as shredders, collectors (gatherers or filterers), scrapers, or predators (Cummins & Klug, 1979). According to Cummins and Klug (1979), Wallace and Webster (1996), Cummins *et al.,*(2005), Merritt and Wallace (2009), and Bouchard (2004), Macroinvertebrates can be divided into four groups:

Shredders feed directly on large pieces of organic matter, such as decomposing leaves and wood fragments larger than 1 mm, as well as the associated fungi and bacteria. They transform this matter into fine organic particles, which serve as food for the collectors. The latter are divided into filter collectors, which capture the fine particles suspended in the water, and collection collectors, which recover those deposited at the bottom of streams or lakes. Scrapers, on the other hand, have mouthparts adapted to graze and collect periphyton, attached algae, and microbes present on rocky surfaces and organic substrates. Finally, predators are macroinvertebrates that capture and consume living prey.

1.3. The role of macroinvertebrates:

Macroinvertebrates are constantly faced with environmental problems that can alter their physiology, behavior, morphology, organization, and tracking rate. (Chessman, 1995. Camargo *et al.,*2004).

Macroinvertebrates are key to understanding the structure of function of aquatic ecosystems. (Leraut, 2003), They have been used for decades to assess the state of aquatic ecosystems following environmental disturbances (Satour, 2025). Several studies have assessed the extent of human disturbance in lotic and lentic ecosystems using aquatic insects (Wallace & Webster, 1996).

Macroinvertebrates also form a link in the food web between producers and consumers. the most important in the food chain, such as amphibians, fish, and birds (Merritt *et al.,* 2017; Satour, 2025).

Their presence or conversely, their disappearance after having been present or a notable change in their frequency indicates whether the wetland is in satisfactory condition.

Macroinvertebrates have been widely used in anthropogenic lotic and lentic ecosystems to monitor the accumulation of heavy metals and to detect the presence of insecticides in streams. This is based on tolerance values for specific (Merritt *et al.,* 2017).

1.4. The effect of anthropogenic action on macroinvertebrates:

Pollution is defined as the introduction of substances into the environment, synthetic or natural substances released by humans that are likely to damage ecosystems, forms of energy that are likely to damage ecosystems and their components or structures" (Rosenberg & Resh, 2009). Pollution can be caused by a variety of substances and activities, including sewage and other organic enrichment; fertilizers, such as nitrogen and phosphorus; pesticides, such as herbicides, fungicides, and insecticides; heavy metals, such as cadmium, mercury, and selenium; and organic compounds, such as biphenyls, polychlorinated biphenyls, and aromatic polycyclic hydrocarbons.), industrial atmospheric emissions (sulfur dioxide and NOx, which are precursors to acid rain, and greenhouse gases, such as carbon dioxide and methane), and radiation (such as in the Chernobyl disaster), and heat (thermal pollution from power plants). Other causes include the destruction of habitats, such as habitat fragmentation, canalization of waterways, and the creation of reservoirs (Rosenberg & Resh, 2009).

The complexity of hydrosystems and the multitude of anthropogenic disturbances in northern Algeria, coupled with harsh climatic conditions, has led to rapid and profound fragmentation of invertebrate communities, resulting in a loss of diversity and/or demographic imbalances (Lounaci, 2005). Indeed, the local laws currently in force are insufficient to slow the sharp reduction in regional biodiversity (Boucenna *et al.,* 2023; Satour,2025).

The structure of the macroinvertebrate community has undergone numerous changes as a result of human pressure, habitat fragmentation, and water pollution, many emerging countries have contributed to the reduction in biodiversity (Kaboré *et al.,*2016), this is particularly true for African wetlands, which provide a certain level of food security, commercial goods, and cultural and aesthetic value to the human communities that inhabit them (Triplet, 2009).

1.5. Macroinvertebrates as Bioindicators:

Ecosystem monitoring is defined as surveilling an ecosystem to determine whether the environment is suitable for the survival of organisms by observing the response of living organisms (Cairns & Pratt, 1993). Monitoring programs are generally used to measure the response and recovery of aquatic communities following human-caused disturbances (Beak *et al.,*1973),

Bioindicator organisms commonly used in monitoring programs include algae, macroinvertebrates, and fish also protect biodiversity and improve understanding of the relationships between the physical, chemical, and biological components of an ecosystem (Hershey & Lamberti, 2001).

Aquatic macroinvertebrates such as benthic insects (*Ephemera, Plecoptera*, *Trichoptera*), molluscs, crustaceans, and worms are widely used as bioindicators of the ecological quality of freshwater environments. Their importance stems from several ecological characteristics: they are sensitive to various forms of pollution (organic, chemical, thermal), have low mobility and a relatively long lifespan, and therefore reflect the ecological state of the environment over a long period (Bonada *et al.,*2006; Barbour *et al.,*1999).

This, analysis of macroinvertebrate community composition provides an accurate and persistent picture of the ecological health of rivers and wetlands (Rosenberg & Resh, 1993).

The degree of disturbance in an ecosystem can be assessed. For example, a dominance of tolerant species (e.g. *Chironomidae*, *Tubificidae*) often indicates a degraded environment, whereas a high diversity including sensitive species (e.g. *Heptageniidae*, *Perlidae*) is a sign of good water quality. Many biotic indices, such as the IBGN (Indice Biologique Global Normalisé) or the BMWP (Biological Monitoring Working Party), are constructed on this basis (Bouchard, 2004).

Their use as bioindicators is based on several ecological advantages:

1. They live in direct contact with sediments and water, exposing them to dissolved and particulate pollutants.

2. They have a high level of functional diversity (filter feeders, grazers, predators, etc.), which makes it possible to detect trophic imbalances.

3. Some groups are highly sensitive to pollution (e.g. Ephemeroptera, Plecoptera, Trichoptera), while others are tolerant (e.g. Chironomidae, Tubificidae), allowing a detailed assessment of the quality gradient.

4. Their long-life cycle (several months to a year) takes into account seasonal variations and cumulative effects, in contrast to one-off physico-chemical measurements.

5. They are easy to sample using standardised protocols such as those used for the IBGN in France (Rosenberg & Resh, 1993).

Chapter 2: General characteristics of the study region

Chapter 2: General characteristics of the study region

1.1 The Seybouse basin:

The Seybouse watershed, like the exorheic basins of eastern Algeria, has a significant latitudinal extension. The southern limits of the basin are 120 km from the sea as the crow flies. As a result, the physical environments and climatic and bioclimatic characteristics vary from the upstream basin in the Hautes Plaines to the coast, with implications for both the flow of water and development. (Louamri, 2013).

The Oued Seybouse basin, which covers an area of 6,745 km2, straddles three major physical and bioclimatic areas:

- The Hautes Plaines area to the south domain (the Haut Cherf basin): this is an area with a flat relief, dotted with plains (Sedrata plain, Ain Babouche plain, Tamlouka plain) with a mountainous backdrop;

- The southern Tellian domain: This covers a large area which, morpho-structurally, corresponds fairly closely to the Numidian chain. Several sub-basins belong to this area: the downstream basin of the Oued Cherf; the basin of the Oued Bouhamdane; the tributaries of the Seybouse in the Guelma valley (Oued Halia, Oued Bou Sorra, Oued Zimba left bank tributaries in the Guelma valley); the basin of the Oued Mellah; the Moyenne Seybouse with reliefs framing the Guelma valley (curve framing the valley = 200 to 300 m). On the northern slopes, altitudes rise gradually to 583 m (Kef Es Soud), and Kef El Mansour (932 m). The Southern Slope is more extensive, spatially larger, and has higher altitudes: it corresponds to the northern slopes of the Medjerdah Mountains. The Mahouna djebel culminates at 1051 m (Koudiat Ed Drizina). The northern slopes of the Monts de la Medjerdah are occupied by tributaries of the Moyenne Seybouse and the Oued Mellah basin.

- The northern Tellian domain, which includes the maritime Seybouse, the Oued Ressoul basin, Oued Derdar, and the coastal plains. In the extreme north-west, the Edough massif is at an altitude of 1,008 m (Kef Seba) (Louamri, 2013). The Seybouse basin has been subject to hydraulic development aimed at regulating the flow of water since the early 1980s. There are five dams in the Seybouse basin; two are large, with a capacity of 337 hm3 (Foum El Khanga at Zouabi with 157 hm3 and Hammam Debagh at Bouhamdane with 220 hm3) and a regulation potential of 110 hm3. The other three are of intermediate size. A total of 64 artificial ponds with a capacity of 7.5 built to irrigate 7.5 hm3 (Tiffech à Tiffech with 5.8 hm3, Medjez El Bgar à Ain Makhlouf with 2.86 hm3 and El Haria Ben Badis with 1.8 hm3). (Abhcsm, 2009; Khalifa, 2017).

1.2. The vegetation:

The Vegetation cover in northeastern Algeria is largely consistent with that of other climatic regions. Rainfall is a determining factor, but other factors such as soil type, relief, and human activity also play a part. Fires, indiscriminate grazing, felling of forests, and cultivation are all factors that have had a fatal impact on Algerian forests, to the benefit of grassy areas, such as the steppe. In addition, steppe regions are under increasing stress, leading to a deterioration in surface conditions. The appearance of plant formations is generally changing from north to south (Merniz,2021).

The nature of the land in the Seybouse basin, with its combination of altitude, humidity and temperature, results in a highly varied plant cover. Most of the plant cover is composed of a variety of crops. There are two categories: - Agricultural land: represented by major cultivations and olive groves. - Natural vegetation: includes all natural vegetation, forests, scrub, and undergrowth. (Hamzaoui, 2019).

Natural vegetation generally consists of: *Juncus sp., Typha sp., Phragmites australis, Tamarix sp., Nerium oleander, and Lemna minor* (Rouibi *et al*., 2021).

Concerning vegetation on cultivated land. Fruit trees (citrus and winter fruit) are rarely found in eastern Algeria (around 20% of the Algerian total). They are mainly found at the two extremities (south and north), and their numbers diminish towards the high plains. Spring frosts mercilessly exclude them, except on a narrow edge of the upper piedmont. Then, on either side of the High Plains, these fruit trees are found in the southern Tellian basins (Guelma basin, Constantine region), in the southern valleys of the southern massifs: Hodna and Aurès.

The cereal-maize environment extends northwards into the Saf-Saf valleys and even onto the Annaba plain. Cereals are barely developed north of the Babor-Tababor-Sidi Driss limestone sierra. In the south, extending over the sebakhs, the cereal frontier encompasses the southern Hodna foothills, the northern foothills and valleys of the Aurès, the Nememcha, and the Tébessa mountains. Cereals are often grown in conjunction with maize, which is a technical imperative, especially in the northern high plains (Merniz, 2021).

Chapter 2: General characteristics of the study region

1.3. Climatic studies:

All insects are subject to the action of a wide variety of climatic agents in the environment in which they live, conditioning their action and geographical distribution (Dajoz,1975). Climate is the result of different elements such as temperature, rainfall, wind and water, wind and relative humidity, all of which can have a direct or indirect effect on living organisms.

In Algeria, the main limitation of the studies is the difficulty of obtaining quality rainfall data with sufficient temporal depth. After independence, rainfall data are not available at fine spatiotemporal scales. There are only 69 measuring stations in France. What's more, these data are not measured on a daily scale, which is insufficient for studies on an appropriate scale (Lazri *et al*., 2007).

Algeria's climate is characterised by a marine influence in the north and a sub-desert continental trend from the south. The predominant winds are northerly and north-easterly (Haouchine, 2011).

The study region, located in the north of the African continent and in the western Mediterranean, is subject to the influence of the Mediterranean climate. This is determined by meteorological mechanisms developed outside the Mediterranean and is under the influence of the Azores anticyclone. The various oceanic and Saharan air masses are modifiers when they are introduced into the Mediterranean. Cyclonic disturbances bring variable, sometimes heavy rainfall, particularly to mountainous areas. They are followed by long hot or cold, dry periods.

The fundamental characteristics of the climate in the Seybouse watershed can be summarized as follows:

- cold, wet winters with highly irregular rainfall.

- hot, dry summers, with a marked overall drought lasting from June to September (Cherairia,2015).

1.3.1. Precipitation:

Rainfall data are generally obtained from two public bodies: the Office National de la Météorologie (O.N.M) and the Agence Nationale des Ressources Hydrauliques (A.N.R.H), on a daily and monthly basis. Generally speaking, the amount of information provided by rainfall stations varies from one station to another. Data series vary in size, with of course the existence

In this context, identifying a reliable data source proved challenging, as each option contained significant gaps.

The climatological data presented in this chapter were collected at the Guelma weather station over 14 years (ONM, 2024).

Table 1: Average monthly rainfall in the study region over the period (2012-2024).

Month	jan	feb	mar	Apr	may	jun	jul	aug	sep	oct	nov	dec
Avg	90,7	103,64	81,22	59,52	38,7	16,01	4,00	15,85	45,2	51,14	70,15	82,21

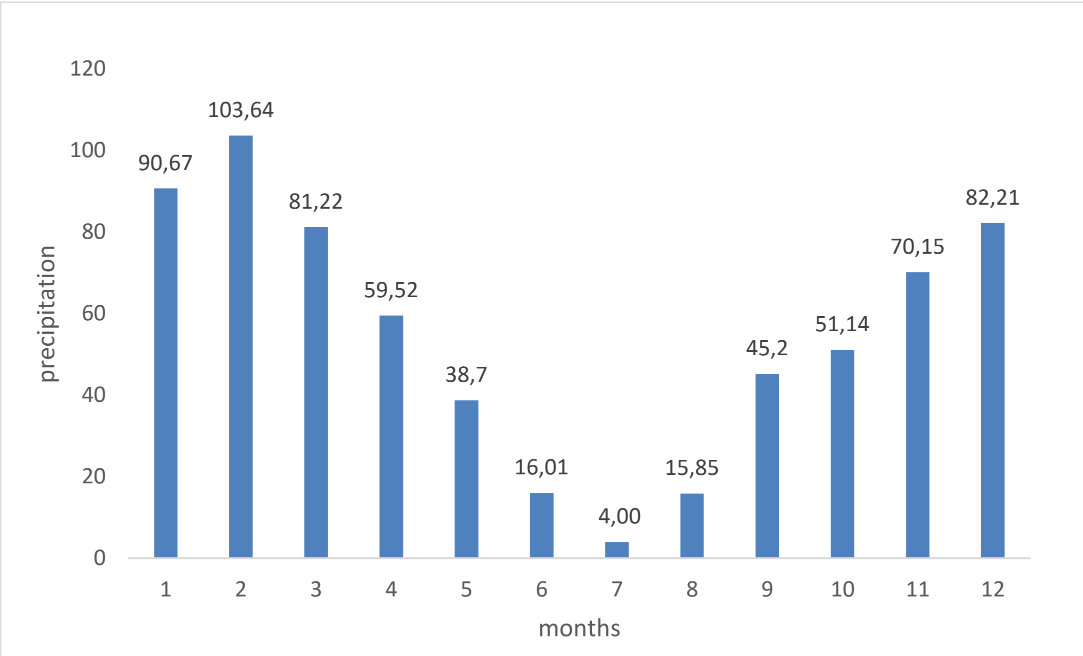


Fig 1: Monthly variation in rainfall in the region (2012-2024).

Precipitation is a fundamental factor in characterising a region's climate. It plays a key role in groundwater recharge and the hydrological behaviour of rivers. In the study region, rainfall is characterised by a high intensity in winter and a remarkable decrease in summer (Hamzaoui, 2019). In other words, the regional climate is typically Mediterranean, with a long hot dry season (8 months) and a short rainy season (4 months). (Rouibi *et al*, 2021).

rainfall variability in north-east Algeria is governed by two types of factors:

- regional factors (atmospheric circulation and air masses) and local factors (the Mediterranean Sea, the two Atlas Mountains, and the Sahara).

Chapter 2: General characteristics of the study region

The geography of rainfall is subject to multiple constraints at various interlocking scales. Starting with global atmospheric circulation (zonal scale), the distribution of rainfall is influenced by the shape of the continents, by the layout of the main mountain ranges, by the orientation of these features (coasts, relief) concerning the dominant flows, and by the continent's climate. among other factors. On a more regional scale, the profile of the mountains, the extent of the orientation and depth of the valleys, and the existence or otherwise of low passes are some of the factors that determine the extent of rainfall. On a local scale, exposure, vegetation density, and the overall roughness of the relief can also affect rainfall (Fig. 2) (Descroix *et al*., 2001).

Altitude, being a factor of amplification by orographic forcing, combined with hillside exposure, shows an irregularity in Cv values between north-facing and south-facing slopes. As a result, rainfall variability increases with altitude on the north-facing slopes of the Tellian Atlas; conversely, Cv decreases with altitude on the south-facing slopes of the Saharan Atlas (Merniz,2021).

It's not so much the absolute altitude that counts as the presence of slopes likely to help trigger convection when there is a sufficient source of moisture in the vicinity.

As a result, we can conclude that the spatial variability of annual rainfall in north-east Algeria can be explained by several factors: latitude, continentality, altitude combined with exposure and the effect of mountain barriers, and to a lesser degree by longitude (Ronchail & Gallaire, 2006).

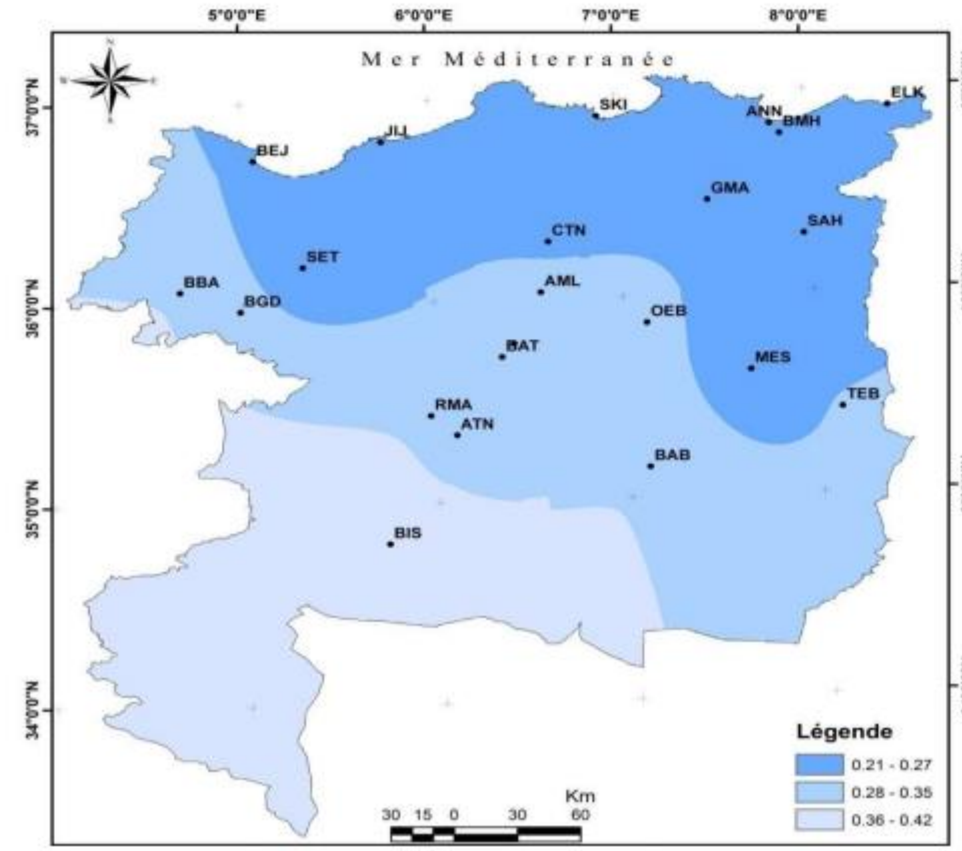


Figure 2: Spatial distribution of the coefficient of variation of annual rainfall in eastern Algeria (1978-2010); source: Merniz,2021.

1.3.2. Temperature:

The average annual temperature for the region as a whole is around 17.80°C, and average annual rainfall varies between 635.65 mm and 665.96 mm in the lower Seybouse and from 589.5 mm to 597. 5 mm in the middle Seybouse. The water reserve (RFU) begins to replenish from November onwards, reaching a maximum of 100 mm from December until April, when there was a surplus of 198.64 mm, 203.7 mm, 153.89 mm, and 152.9 mm respectively for the Salines, Pont Bouchet, Guelma, and Héliopolis stations. From May onwards, the RFU begins to run out until June, when it becomes zero, a period that reflects an agricultural deficit (Hamzaoui, 2019).

Chapter 2: General characteristics of the study region

- Average monthly temperatures:

Table 2: Average monthly temperature in the study region over the period (2012-2024) (ONM, 2024).

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Avg	15,69	10,05	12,42	24,97	19,21	24,06	27,34	27,34	23,61	20,23	14,71	14,71

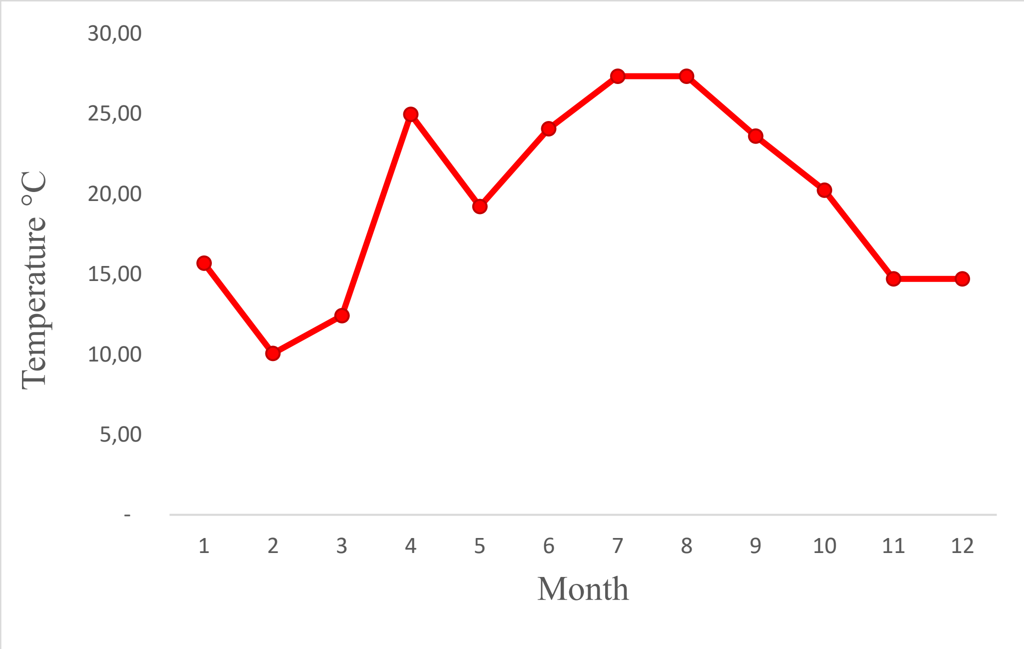


Fig 3: Curve representing average monthly temperatures in the region (2012-2024).

2. Umbro-pluviothermal diagram:

The umbro-pluviothermal diagram of Gaussen and Bagnols is a graphical method used to define the dry and wet periods of the year, where the months are plotted on the abscissa, and the precipitation (P) and temperature (T) on the ordinate, with P=2T. The length of the dry period is directly related to the duration of submergence and the dynamics of the water body.

The figure shows the umbrothermal diagram for the Guelma region, based on average monthly rainfall and temperature data calculated over a period of 14 years.

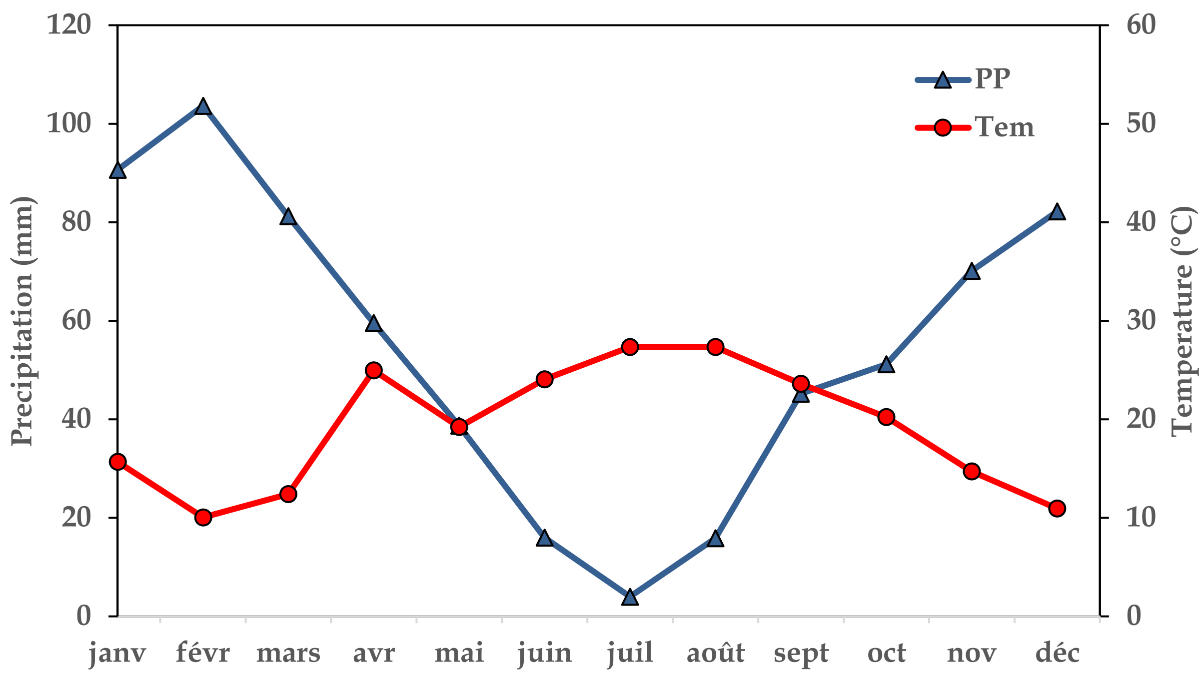


Fig 4: Umbro-pluviothermal diagram (2012-2024).

1.4. Emberger Climagram:

On the basis of the climate's overall humidity and winter severity, Emberger (1930, 1945, 1955, 1971) defined six sub-climates within the Mediterranean bioclimate. This is characterised by the rainfall-thermal quotient Q2 (Dajoz, 2006), which is calculated using the following formula:

$Q2 = 2000 P/(M^2 - m^2)$

Where:

P: Annual precipitation in millimetres.

M: The average maximum temperature of the warmest month, expressed in degrees Kelvin.

m: The average minimum temperature of the coldest month, expressed in degrees Kelvin.

Table 3: Shows the calculation of the rainfall-thermal quotient for the Guelma station.

Station	**Precipitation (mm)**	**M (°C)**	**m (°C)**	**Q2**
Guelma	971,55	35,32	5,13	109,67

With a Q2 value of 109.67, our region (Guelma) falls within the bioclimatic zone characterised by subhumid vegetation and mild winters.

Chapter 2: General characteristics of the study region

The wilaya of Guelma is classified as having a sub-humid climate according to the method used to calculate the rainfall/temperature quotient.

2. Study area:

The basin of Seybouse is located in northeastern Algeria. It covers a total surface of approximately 6471 km2. It consists of 42 rivers (Baaloudj *et al*., 2020), including our 12 sites (Figure 5, Table 4). Among the 12sampling site, we chose 2 dams: Bouhamdane II, whose area extends over 13,000 ha with a capacity of 2.8 million m3, and Medjez el Bgare, with a capacity of 2,86 million m3, 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).

Table 4: 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

Chapter 2: General characteristics of the study region

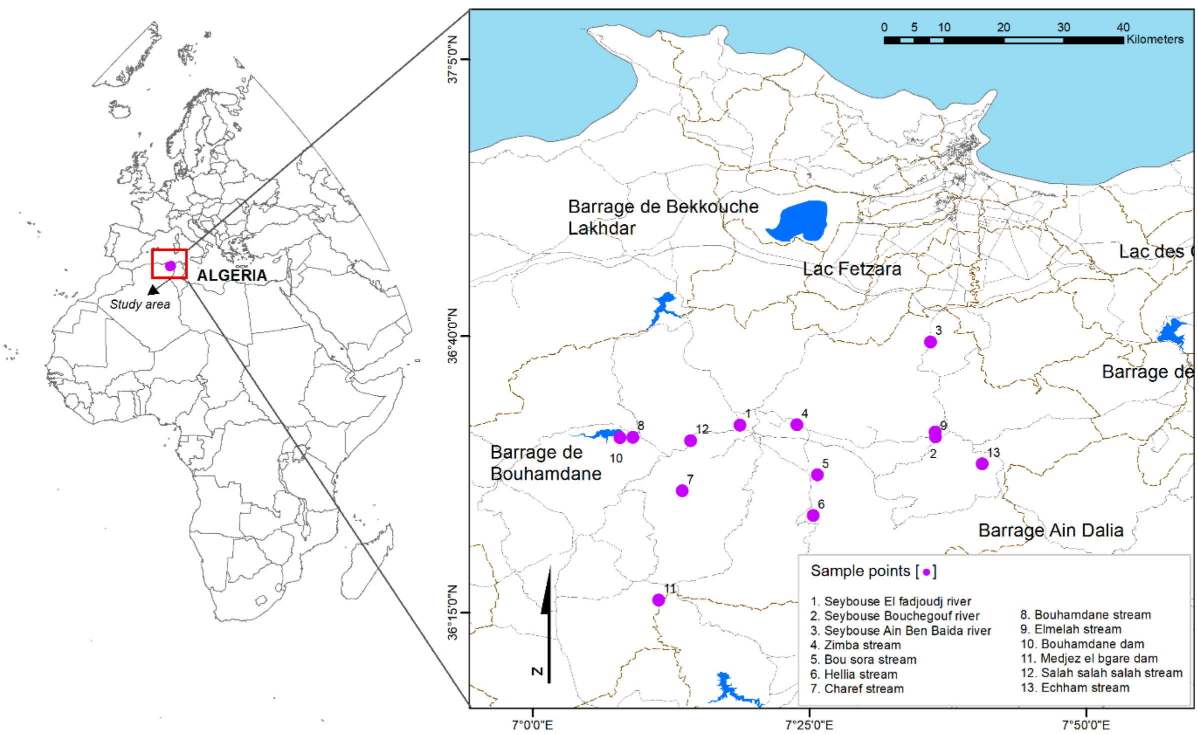


Figure 5: Geographic distribution of the study sites in Northeast Algeria.

2.1. Characterization of the study area:

The Seybouse River in northeastern Algeria originates west of the town of Guelma at Medjez Amar, where its two main tributaries, the Oued Cherf and the Oued Bouhamdane, meet. After a 150 km journey, it empties into the Mediterranean Sea. (Debeiche,2002).

The Seybouse River originates west of the town of Guelma in northeastern Algeria at Medjez Amar, where its two main tributaries, the Oued Cherf and the Oued Bouhamdane, meet. After a 150 km journey, the Seybouse empties into the Mediterranean Sea. The Oued Seybouse basin is one of the largest in Algeria, the third largest after the Oued El Kebir du Rhumel and the Medjerdah-Mellegue. It covers 6,471 km² (Debeiche, 2002).

2.2. Geographical Location and Morphology:

The Seybouse Basin is divided into six main sub-basins, making it the second largest basin in eastern North Africa after the Medjerda (Blayac, 1912).

The study area is located in northeastern Algeria and is an integral part of the Oued Seybouse watershed. The basin is bordered by the Mediterranean Sea to the north and by the eastern extension of the Annaba-Bouteldja aquifer system, and by the Nador. N'Bail Mountains, to the west by the Edough Massif and the Houara and Debagh Mountains, and to the south by the Mahouna, Ain Larbi, and Sedrata mountains. It is divided into six main sub-basins. After the Medjerda, it is the largest basin in eastern North Africa. (Blayac, 1912).

The Constantinois-Seybouse-Mellegue watershed is located in the northeastern part of Algeria. It covers 43,000 km². It encompasses 14 wilayas (departments): 9 are entirely within it: Annaba, Tébessa, Skikda, Jijel, Constantine, Guelma, Souk Ahras, and Oum El Bouaghi, Mila, and 5 are partially included: Batna, Béjaïa, Khenchela, Sétif, and Tébessa.

The Constantinois-Seybouse-Mellegue watershed comprises five main basins:

1. Côtiers Constantinois: 11,509 km²: East, Center, West.

2. Kebir Rhumel: 8,811 km²

3. Seybouse: 6,471 km²

4. Constantinois High Plateaus: 9,615 km²

5. Medjerda-Mellegue: 7,942 km². (Reggam, 2015).

The Seybouse watershed is divided into three distinct physiographic terraces:

The Upper Seybouse, which comprises sub-basins 14-01, 14-02, and 14-03;

The Moyenne-Seybouse, which covers sub-basins 14-04.

The Basse-Seybouse comprises sub-basins 14-05 and 14-06 (Table 1) (Ghachi 1986).

Table 5: Surface distribution of the Seybouse Subbasins (A.B.H., 1999).

Sub-basin	Surface area (km²)	General character
14-01	1739	Upper Seybouse
14-02	1166	Average Seybouse
14-03	1136	Average Seybouse
14-04	818	Average Seybouse
14-05	555	Average Seybouse
14-06	1057	Lower Seybouse
Total	6471	

Chapter 2: General characteristics of the study region

Hydrographic network

The hydrographic network consists of all the watercourses and permanent tributaries through which runoff flows and converges at a single discharge point for the watershed.

The hydrographic network map shows the confluence of Oued Cherf (Souk-Ahras) (88.61 km) and Oued Bouhamdane (37.49 km) of Oued Cherf (Souk Ahras) (88.61 km) and Oued Bouhamdane (37.49 km) giving rise to the Oued Seybouse (134.74 km). The main tributaries of the Oued Seybouse are: Oued Maiz, Oued Zimba, Oued Skhoune, Oued Bou Sorra, Oued Fragha, Oued Djefeli, and Oued Meboudja, etc.

Oued Cherf results from the confluence of two streams: the first, Oued Krab, and the second, Oued Tiffech. The junction of the Oued Ghrieb and the Oued Zenati gives rise to Oued Bouhamdane. (Reggam, 2015).

3. Study sites presentation:

1. **The Seybouse River:** Oued Seybouse rises at Medjez Amar, where Oued Charef meets Oued Bouhamdane. It then crosses the commune of El Fedjouj, where our first study site is located. Continuing its course for over 45 km from south to north across the Guelma Bouchegouf plain, it reaches our second site. Its total input is estimated at 408 million m³ per year at the Bouderoua station (Aïn Ben Beida commune), which is the last Oued Seybouse site we studied. (Benhamza *et al*., 2015; Chaoui, 2007; Charlot, 1978; Guettaf, 2015; Kachi, 2015). and is part of the country's largest river basin.

•**Length**: Approximately 225 kilometers.

•**Basin Area**: 6,471 square kilometers.

•**Average Discharge**: 11.5 cubic meters per second at Guelma and Annaba. (Mouassa *et al*, 2018).

Vegetation: average density.

GPS coordinates: 36º 48.12’ N; 07º 41.56’ E

Figure 6: Seybouse El Fedjoudj river (Gharbi,2023).

Vegetation: average density.

GPS coordinates: 36º 49.56’ N; 07º 72.29’ E

Figure 7: Seybouse Bouchegouf river (Gharbi,2023).

Vegetation: very high density.

GPS coordinates: 36º 56.44’ N; 07º 74.19’ E

Figure 8: Seybouse Ain Ben Baida River (Gharbi,2023).

2. **Zimba stream:** Zimba is a stream located in the Guelma Province of northeastern Algeria, specifically within the Seybouse River basin. It serves as a tributary to the Oued Seybouse, which is a significant watercourse in the region. (Bechaa *et al.,* 2024).

Vegetation: very low density.

GPS coordinates: 36º 26.02’ N; 07º 28.47’ E

Figure 9: Zimba stream (Gharbi, 2023).

3. **Bou Sora stream:** Bou Sora is an intermittent tributary of Oued Endja, which in turn is a sub-tributary of Oued Cherf. Oued Cherf then flows into the main river (Belhadj, 2017).

Vegetation: high density.

GPS coordinates: 36º 39.22' N; 07º 52.40' E

Figure 10: Bou sora stream (Gharbi, 2023).

4. **Hellia stream:** The Oued Hellia is a stream located in the Guelma Wilaya in northeastern Algeria. Rising in the Aurès Mountains, it flows through several communes before emptying into the Mediterranean Sea. (Chirouf & Moumene, 2015).

Vegetation: high density.

GPS coordinates: 36º 20.47' N; 07º 31.23' E

Figure 11: Hellia stream (Gharbi, 2023).

5. **Charef stream:** The Oued Charef basin is located in northeastern Algeria. Bordered by the wilayas of Souk Ahras, Guelma, and Oum El Bouaghi, it is part of the Seybouse watershed. The basin is triangular in shape and covers 2,900 km², with a perimeter of 57 km. The Oued Hellia is a stream located in the Guelma wilaya in

northeastern Algeria. Rising in the Aurès Mountains, the Hellia River flows through several communes before emptying into the Mediterranean Sea. (Bouhala, 2012).

Vegetation: low density.

GPS coordinates: 36º 42.31' N; 07º 31.32' E

Figure 12: Charef stream (Gharbi, 2023).

6. **Bouhamdane stream:** The Oued Bouhamdane is a stream in northeastern Algeria, primarily flowing through the Guelma region. Rising in the region's mountains, it flows into the Seybouse, a major stream in the area. (Touati *et al.*, 2016).

Vegetation: very high density.

GPS coordinates: 36º 27.45' N; 07º14.38' E

Figure 13: Bouhamdane stream (Gharbi, 2023).

7. **Salah Salah Salah stream:** This stream, located in the commune of the same name in the Guelma wilaya, is a secondary tributary that forms part of the hydrographic network of the Seybouse basin. This watercourse plays an important ecological and hydrological role, especially during the rainy season, when it contributes to the flow of the Bouhamdane stream.

Vegetation: very high density.

GPS coordinates: 36º 47.17' N; 07º 34.11' E

Figure 14: Salah Salah Salah stream (Gharbi, 2023).

8. **Echham stream:** is a small river in the wilaya of Guelma commune of Oued Cheham in north-eastern Algeria. It flows mainly through rural agricultural areas. It is part of the hydrographic network of the Seybouse basin.

Vegetation: high density.

GPS coordinates: 36º 37.21' N; 07º 63.06' E

Figure 15: Echham stream (Gharbi, 2023).

9. **Bouhamdane Dam:** The Bouhamdane Dam is located approximately 25 kilometers northwest of Guelma in northeastern Algeria. Near the commune of Hammam Debagh, it sits within the Bouhamdane and Hammam Debagh enclaves and has a capacity of 220 million cubic meters.

Vegetation: very low density.

GPS coordinates: 36º 27.48’ N; 07º 13.56’ E

Figure 16: Bouhamdane dam (Gharbi, 2023).

10. **Medjez el bgare Dam:** The Medjez El Bgaré Dam is located in the Aïn Makhlouf commune, which is part of sub-basin 14-03. It has a capacity of 2.86 cubic meters.

Vegetation: very low density.

GPS coordinates: 36º 22.03’ N; 07º 29.04’ E

Figure 17: Medjez el Bgare dam (Gharbi,2023).

Chapter 3 : Materials and Methods

1. **Materials :**

1.1. Field equipment:

- Nets for collecting samples.

- Plastic tubes.

- 96% ethanol for preserving samples.

- Multi-parameter

- A digital camera.

- A notepad

- GPS.

Figure 18: Field equipment

1.2. Laboratory equipment:

- A binocular magnifying glass.

- Biological materials.

- Entomological guides.

- Flasks.

- Pliers.

- Pitrie dishes.

- Gloves.

- Absorbent paper.

- Alcohol and distilled water.

Figure 19: Laboratory equipment.

2. **Methods:**

2.1. On the ground:

2.1.1 Sampling:

The choice of the sampling stations is based on:

- The accessibility of the site and its proximity (certain sites are hardly accessible, therefore some of them were not visited regularly).
- Density of the surrounding vegetation.
- Remoteness from urban regions and Sources of pollution (industrial areas).
- the altitude of the sampled region.

2.1.2. Sampling plan:

Sampling was conducted at 12 stations from October 2020 to September 2021, with one visit per month. Each station was sampled over a consistent duration, ensuring coverage of the entire visible area to maximize sample representativeness and homogeneity. Sampling was carried out between 08:00 and 16:00. Monthly visits were scheduled on fixed dates, with slight adjustments of two to three days when necessary due to weather conditions.

2.1.3 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 [O2], pH, nitrate, nitrite, salinity, and water temperature) in each site monthly.

We used a 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.

Macroinvertebrate collection was carried out using a large landing net with a 1 mm mesh size, which was repeatedly submerged across the entire station area to ensure sampling homogeneity and maximize specimen collection. The collected specimens were preserved in tightly sealed tubes containing 96% ethanol to prevent sample degradation.

Each sample was accompanied by a field data sheet containing the following information:

♦ Date, time, and location of sampling

♦ Observations or remarks noted during the sampling process.

Figure 20: Physico-chemical parameter measurement sampling.

2.1.4 The water speed measurement:

Water speed is a physical factor that directly affects the organisms that inhabit these environments, and this variable also affects other factors in waterways such as substrate composition, food supply, and dissolved oxygen levels (Sandin & Johnson, 2004). The velocity of the current depends on the current, substrate, and width of the riverbed, and increases with depth and the slope (Bebba, 2017).

The water speed is measured using a float: two people stand in the riverbed, separated by a distance of 10 m. One of them, situated upstream, throws the float in the direction of the current and times the time taken for the float to reach the other person. The speed will be equal to the distance/time ratio, expressed in m/s. We use the following formula to calculate the speed of the current: **v=l/t**, where:

v: Current speed (m/s),

l: Distance of 5 metres (m),

t: Travel time (s).

We repeat the measurement 3 times and take the average.

2.1.5 Depth measurement and width:

The width of the bed of a watercourse is a factor that influences the velocity, temperature, and oxygenation of the water (Dajoz, 2000). The width of the bed of rivers with full banks and the width of the wetted waterbed are measured on at least three transects perpendicular to the axis of the river using a decameter. Depth is an important ecological parameter.

The depth of the water influences the warming of the water and thus the distribution and proliferation of thermophilic flora and fauna. The depth of the watercourse also influences the dissolved oxygen content (Bouhala, 2020). Depth is measured at each station using a decameter immersed in the water 3 times and averaged.

2.2. In the laboratory:

2.2.1 Samples sorting and identification:

A preliminary sorting was conducted in the field, during which large debris was removed from the sample and macroinvertebrates were collected into tubes containing 96% ethanol for preservation.

Further sorting and taxonomic identification (at the family level) were carried out in the laboratory under an OPTIKA binocular stereomicroscope, following established identification keys (Tachet et al., 2012; Greenhalgh & Ovenden, 2009). The procedure followed these steps:

♦ Initial separation of taxa visible to the naked eye.

♦ Samples were rinsed to remove debris, and benthic organisms were carefully extracted using fine tweezers from sediment, plant material, and algae.

♦ Specimens were blotted dry using absorbent paper, then sorted into Petri dishes containing a drop of distilled water.

♦ Taxa were identified under the stereomicroscope, and photographs were taken of all specimens.

♦ Identified taxa were counted and preserved in separate ethanol vials, each labeled with the identification, number of individuals, collection date, and sampling station.

Figure 21: Sorting and identification of macroinvertebrate samples.

2.2.2. Data analysis:

To determine the relationship between the abiotic factors and the composition of benthic communities (based on abundance), we used the redundancy analysis (RDA) model (Legendre and Legendre, 1998). Before 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, 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 ordi R2 step 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 uses simulation to compare co-occurrence patterns to null expectations. (Gotelli & 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 & Entsminger, 2007; Carvajal-Quintero *et al*., 2015).

The niche amplitude can be maintained or reshuffled; when retained, it preserves each species; specially when it 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 & Ellison, 2013; Carvajal-Quintero *et al.,* 2015).

The RA3 model keeps the amplitude while rearranging the zero conditions (Gotelli & 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).

To further understand the compositional structure of benthic macroinvertebrate communities in lentic and lotic habitats, we performed non-metric multidimensional scaling (NMDS) ordinations based on Bray–Curtis distances and the Wisconsin square-root transformation. We used the adonis2 function of the vegan package (Oksanen *et al.,*2020).

MaxEnt was used to construct The ecological response curves generated by Maxent are a necessary diagnostic tool for understanding the functional relationship between the predicted probability of occurrence of a species and each environmental variable. These curves show how the logistic output, representing habitat suitability or the probability of occurrence, varies along the gradient of a particular predictor, usually with the other variables held at their mean values calculated over the presence sites. The mathematical 'features' (linear, quadratic, hinge, threshold) that Maxent chooses or is forced to use to fit the model thus determine the shape of each curve (e.g. linear, unimodal, sigmoidal or stepwise) and provide vital information about the ecological tolerances, optima and limiting factors of the species about each environmental variable under consideration.

Using Excel (2016), we determined the abundance of the benthic macroinvertebrates sampled, as well as changes in the values of the physicochemical parameters measured.

Macroinvertebrate species richness and spatial distribution were mapped using ArcGIS PRO.

Chapter 4: Results

1. **Results:**

1.1. Influence of abiotic variables:

- **Conductivity (mS/cm):**

Conductivity is a very important parameter for population dynamics; overall water mineralisation is assessed using conductivity tests (Huliot, 2014).

The histogram showing the monthly changes in conductivity at the sampled sites for the period from October 2020 to September 2021 shows that

- A higher average conductivity at the Salah Salah stream site during December.
- The lowest average conductivity and marked at the site of Hellia stream.
- Minor differences between the sampled sites (Fig. 22).

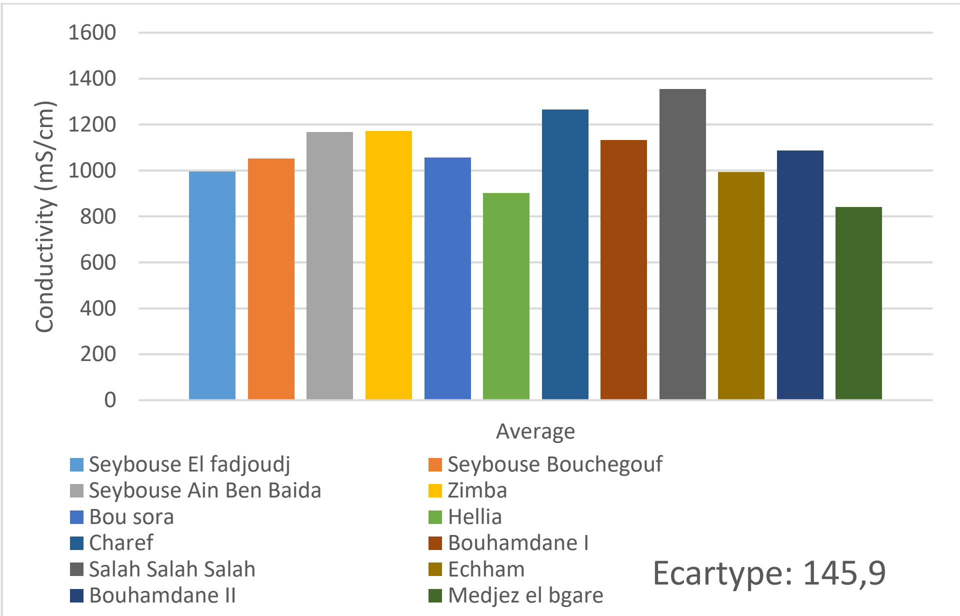


Figure 22: Histogram of average conductivity recorded at the study sites.

- **Salinity (g/L):**

Salinity is a limiting factor for aquatic life and a key indicator of the ecological quality of surface waters. An increase in salinity disrupts the osmotic balance of freshwater organisms, leading to a reduction in macroinvertebrate diversity and the dominance of tolerant species, often indicative of degraded environments (Kefford, 2002).

The highest salinity value is found at the Zimba stream site with 0.6 (g/L), while the lowest value is recorded at the Charef stream site with an average of 0.4 (g/L) (Fig. 23).

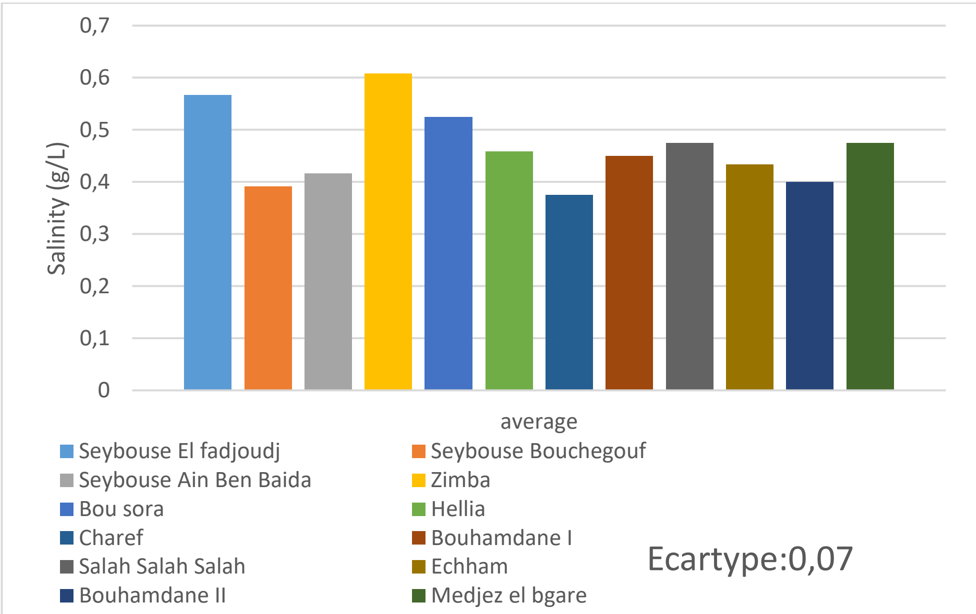


Figure 23: Histogram of average salinity recorded at the study sites.

- **pH:**

pH is a fundamental indicator of the chemical quality of watercourses, directly affecting the solubility of nutrients and the toxicity of heavy metals. Variations in pH can alter the metabolism, reproduction, and survival of many aquatic organisms, particularly sensitive macroinvertebrates such as mayflies and whipworms. Maintaining a neutral to slightly alkaline pH is therefore essential for the ecological stability of watercourses (Camargo, 2006).

After the analysis of the Ph data recorded during our period of study, we found that the Ph is alkaline in most of the months of the years of study followed by the site of Seybouse Bouchegouf which is porche of alkaline in December, January and February against the other site which is slightly balanced to the Toure of the neutral aquatic environments (Fig.24).

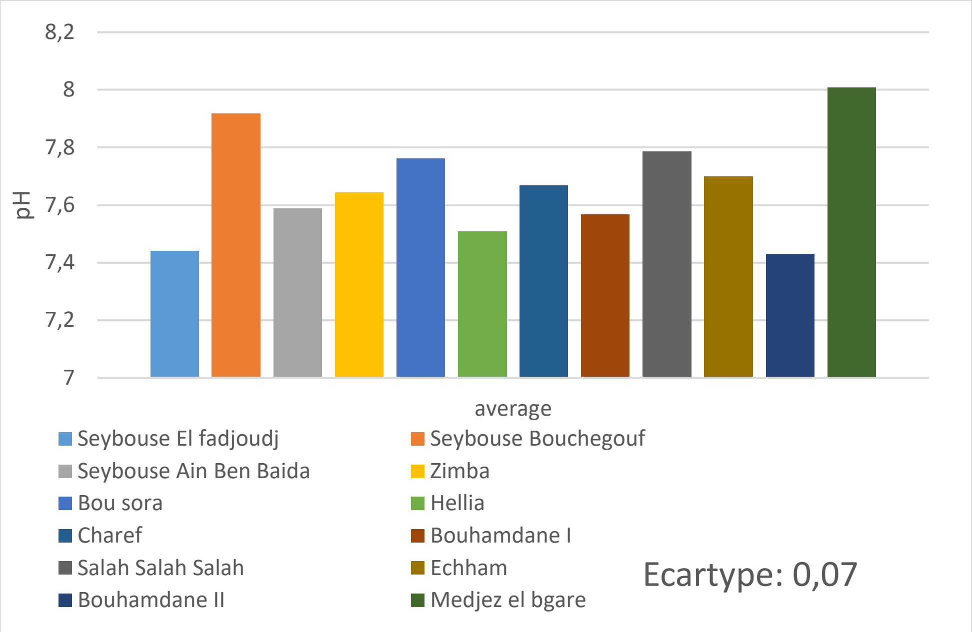


Figure 24: Histogram of average pH recorded at the study sites.

- **Dissolved Oxygen (mg/L):**

Dissolved oxygen (DO) is a key parameter for assessing freshwater quality as it is essential for the respiration of aquatic organisms. An adequate level of DO (>5 mg/L) favours the survival and development of sensitive species such as certain benthic insects (mayflies, plecopterans). On the other hand, a low concentration (<3 mg/L), often caused by organic pollution or eutrophication, can lead to hypoxic or even anoxic conditions. Dissolved oxygen is therefore an essential indicator of an ecosystem's ability to maintain a balanced biodiversity. (Diaz, 2008).

After the analysis of the oxygenation of the studied watercourses, we notice that the oxygen rate in the dam of Medjaz El bgare is extremely high with 0.85mg/L compared to the other sites, followed by another significant value of 0.61mg/L in the sites of Bouhamdane stream on the other hand the lowest value is marked in Sallah Sallah stream (Fig.25).

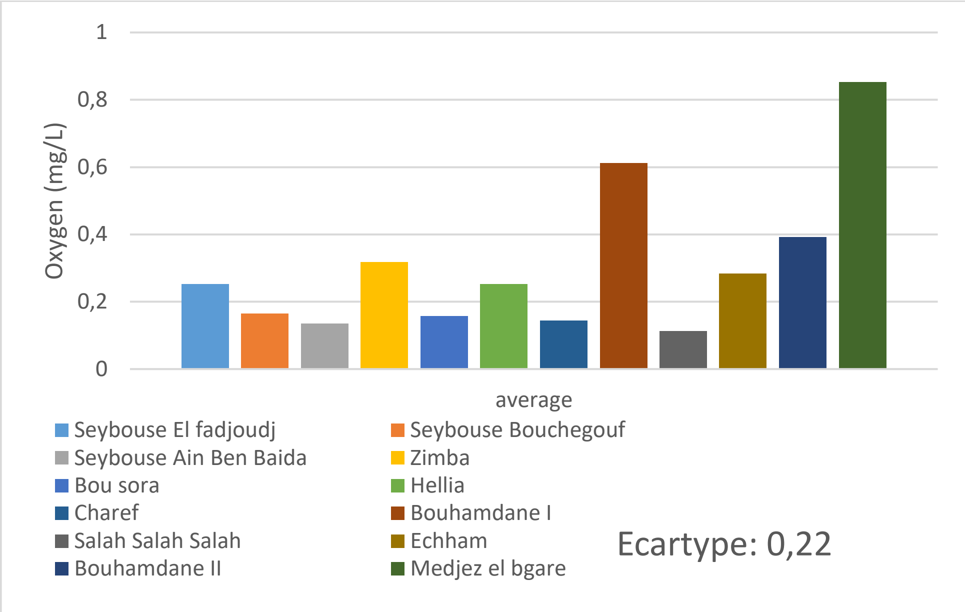


Figure 25: Histogram of dissolved Oxygen rate recorded at the study sites.

- **Depth (cm):**

The depth of watercourses influences biodiversity and the distribution of aquatic organisms. Depth also directly influences several aspects of ecological and physico-chemical quality. Depth determines thermal stratification, illumination, current speed, and exchange with sediments. Shallow areas are generally better oxygenated and more conducive to the colonisation of macrophytes and macroinvertebrates (Bennas, 2013).

During our sampling, we found that the two dams are the deeper than the other rivers, at running water or Bouhamdane dam being the deepest with an average of 90cm.

In terms of running water, Charef stream is the deepest at about 67cm, and Bou Sora stream is the shallowest at 16cm (Fig.26).

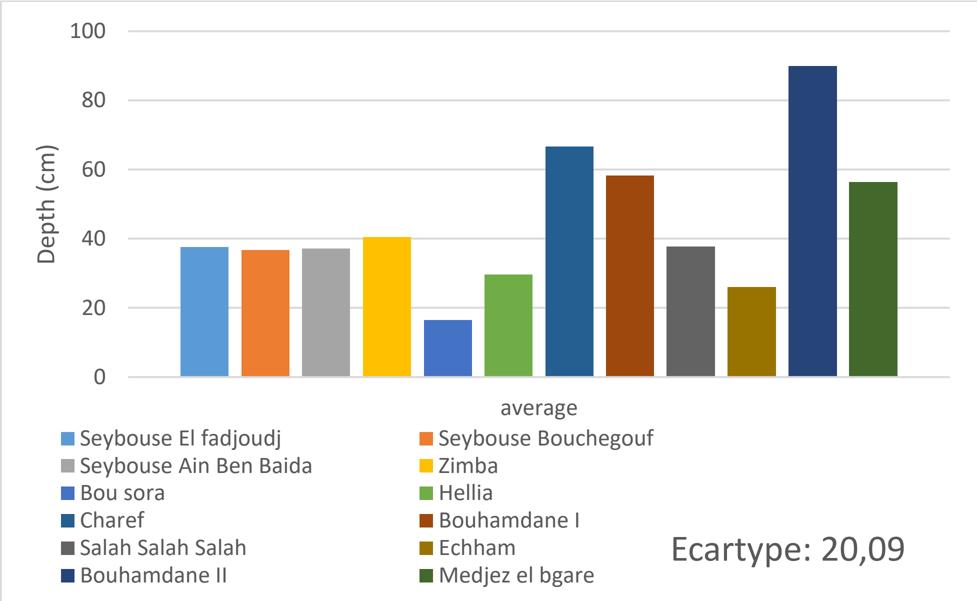


Figure 26: Histogram of the depth of the study sites.

- **Turbidity (NTU):**

Turbidity is a key parameter in assessing the impact of human pressures on aquatic ecosystems. Turbidity is an important indicator of the presence of suspended particles. High turbidity reduces light penetration, which in turn reduces photosynthesis by aquatic plants and disrupts the food chain. It can also clog the gills of aquatic organisms, disrupt fish respiration, and contaminate benthic habitats, affecting the survival of sensitive macroinvertebrates. Suspended particles can also adsorb pollutants (heavy metals, pesticides), increasing their dispersion and toxicity (Bouras, 2017).

In our results and after the turbidity analysis, we found that the Medjez el Bgare dam stands out with an extremely high value of 673 NTU in contrast of the Salah stream, which marks the lowest turbidity with 102.4 NTU (Fig.27).

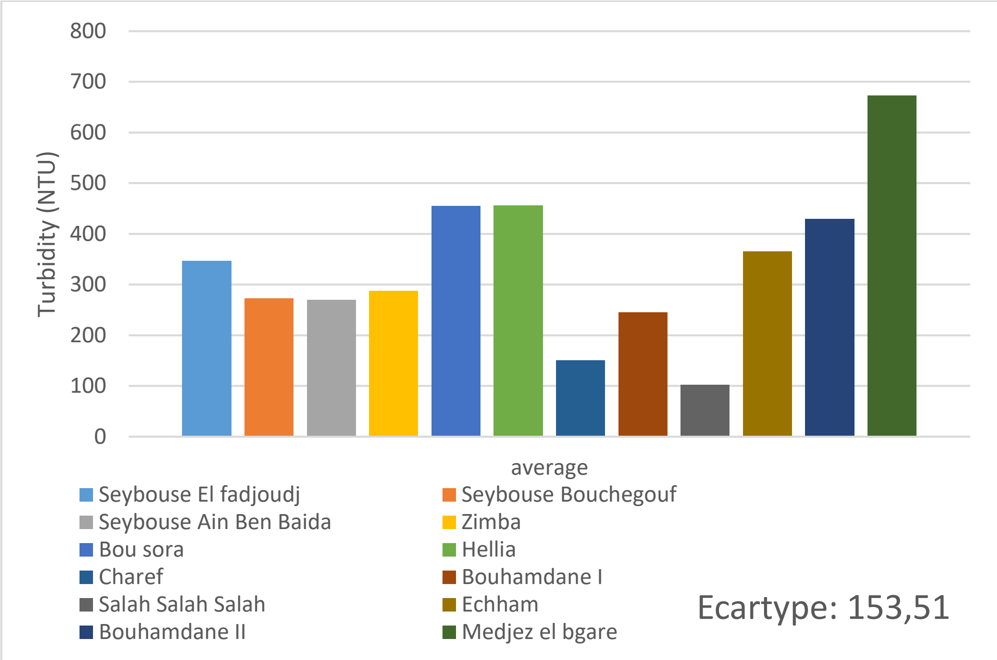


Figure 27: Histogram of the Turbidity in the study sites

- **Suspended matter (mg/L):**

Suspended matter refers to all solid particles suspended in water (of organic or mineral origin) and is a determining factor in the quality of aquatic environments. High concentrations of suspended solids can reduce water clarity and alter the living conditions of aquatic organisms as long as they are present in the environment. this accumulation also affects nutrient transport and contributes to eutrophication. Monitoring this factor is therefore crucial for assessing the impact of agricultural, urban, and industrial discharges on watercourses (Saidi, 2021).

We found that between the sites we measured, two of them stand out as the highest: Zimba stream with 713 mg/L and Echham stream with 645.5 mg/L, and on the other side, Bou Sora stream as the lowest with 160.7 mg/L (Fig.28).

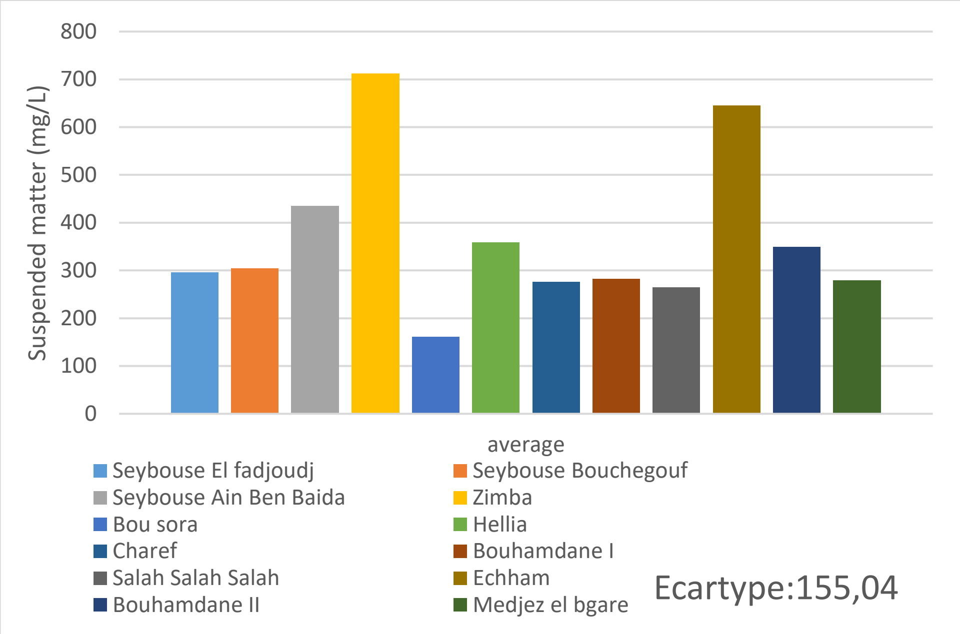


Figure 28: Histogram of the suspended matter in the study sites.

- **Nitrite (mg/L):**

Nitrites (NO_2-) are intermediate nitrogen compounds in the nitrogen cycle, generally formed by the conversion of ammonia (NH_3) to nitrates (NO_3-) by nitrifying bacteria. In aquatic environments, their presence at high levels is often a sign of recent organic pollution or an imbalance in nitrification, often caused by domestic, agricultural, or industrial discharges. Nitrites are toxic to many aquatic organisms (Benmoussa, 2021).

The results show that most sites have similar nitrite rates, except for the Salah stream, which has a very low value of 0.05 mg/L (Fig 29).

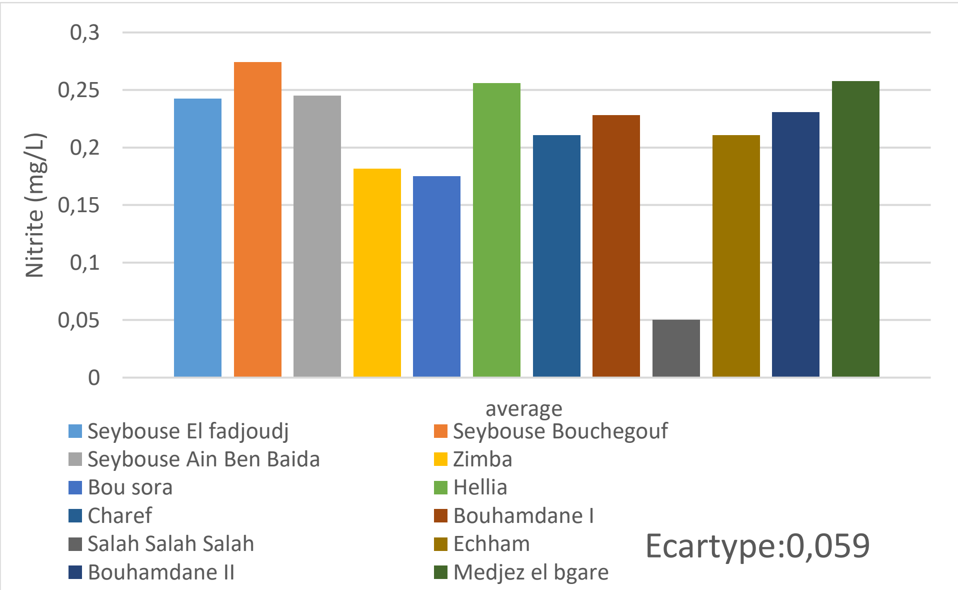


Figure 29: Histogram of the nitrite in the study sites.

- **Nitrate (mg/L):**

Nitrates (NO_3^-) are oxidised forms of nitrogen commonly found in freshwaters and are mainly derived from agricultural fertilisers, domestic wastes, and industrial effluents (Benmoussa, 2021).

Although essential for plant growth, nitrates can have serious ecotoxicological effects when present in excess in freshwaters. A review by Camargo and Alonso (2006) points out that high concentrations of nitrates can cause chronic toxicity in many aquatic organisms, particularly invertebrates and amphibians. These compounds also contribute to the eutrophication of the environment, leading to a decrease in dissolved oxygen and alteration of aquatic habitats, which affects biodiversity and the overall functioning of ecosystems.

We found that all study sites had similar nitrate levels, except Seybouse Ain Ben Baida, which had an extremely high level of 67.03 mg/L (Fig. 30).

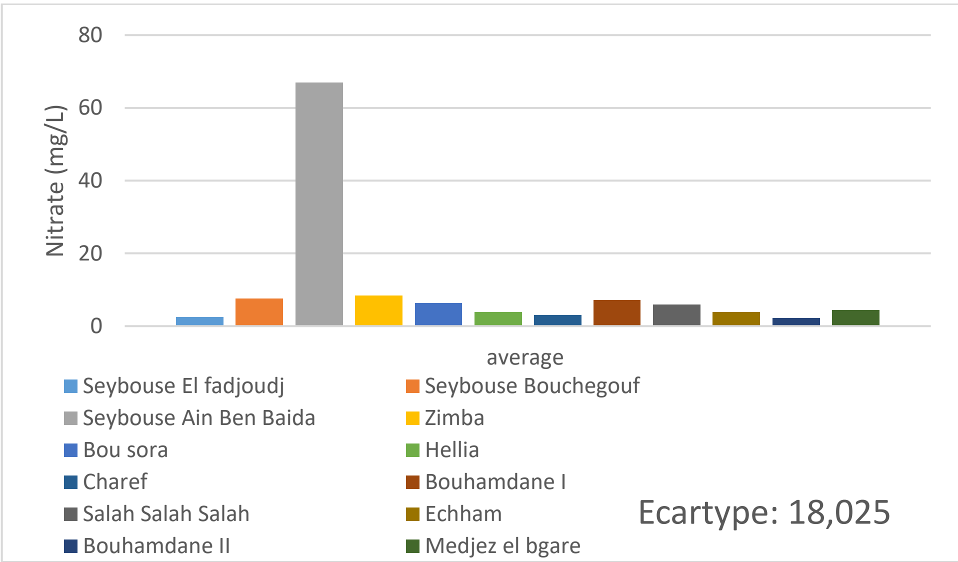


Figure 30: Histogram of the nitrate in the study sites.

- **Water speed (cm/s):**

Water speed is a fundamental hydrodynamic factor that influences the physical structure of aquatic habitats and the distribution of biological communities. A high water speed promotes the oxygenation of the water, the transport of fine sediments, and prevents excessive sedimentation, and also creates conditions favourable to a high diversity of macroinvertebrates, especially rheophilic species such as ephemerids and plecopterans. On the other hand, too low a velocity favours the accumulation of organic matter, stagnation, and eutrophication, which can reduce biodiversity and favour species tolerant of low oxygen levels (Allan, 2007).

The results show that the speed of water in the two dams is equal to 0 because they are stagnant waters on the other hand between the other course of water the site which has the speed of water the highest is Ain ben baida river with 86.6 cm/s and the weakest speed ands mark in the site of El Fadjoudj river with 39 cm/s (Fig.31).

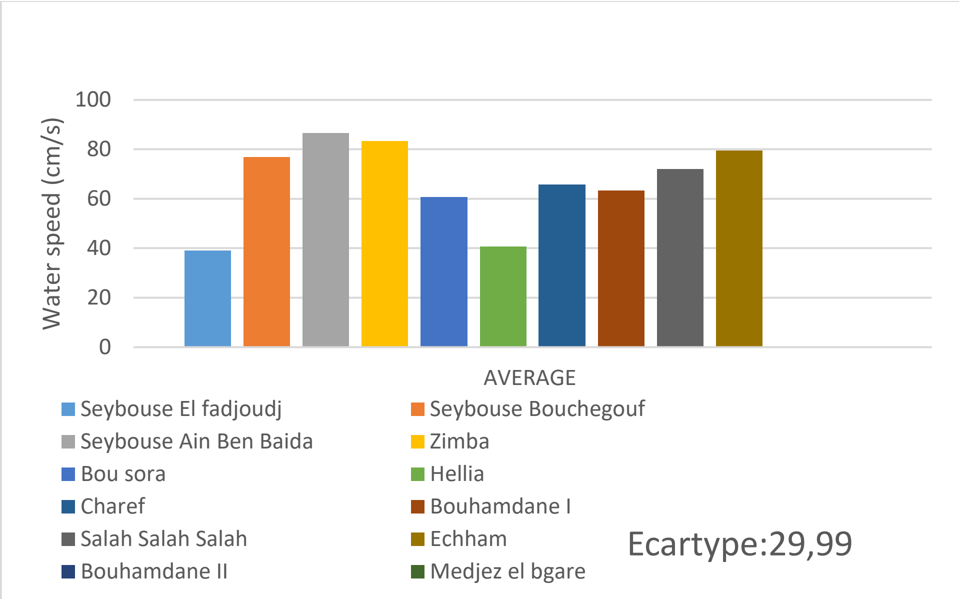


Figure 31: Histogram of the water speed evolution in the study sites**.**

Collectively, 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 [O2], pH, nitrate, nitrite, salinity,) 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 water speed and high dissolved oxygen [O2] level and conductivity, whereas the second site Salah Salah Salah stream, has high conductivity, high water speed and high nitrite levels as well as the levels of pH and salinity.

1.2. The macroinvertebrate reported:

A total of 6222 individuals were counted, belonging to 25 families, 9 orders and 3 classes. The Insecta class was the most dominant (Table 6).

Table 6: Checklist of the benthic fauna collected at the 12 study sites.

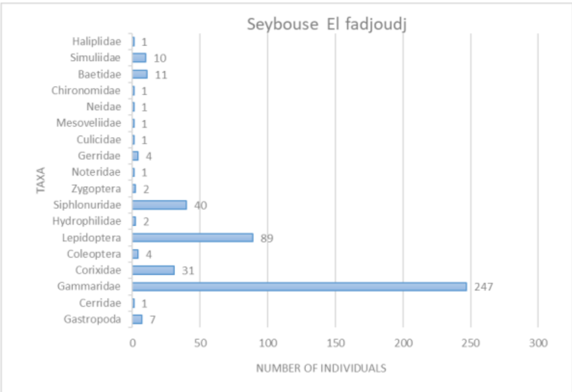
Phylum	**Class**	**Order**	**Family**	**NI**
Mollusca	Gastropoda		*Gastiropoes*	142
Aethropda	Crusacca	Amphipoda	*Gammaridae*	2009
	Insecta	Emphemeroptera	*Baetidae*	441
			Siphlonuridae	588
			Caenidae	216
		Trichoptera	*Hydropsichidae*	162
			Rotschildae	3
		Coleoptera	*Coleoptera*	79
			Noteridae	3
			Hydrophilidae	40
			Haliplidae	1
			Curculionidae	1
		Odonata	*Aeshnidae*	2
			Zygoptera	11
		Diptera	*Chironomidae*	844
			Neidae	1
			Simuliidae	49
			Culicidae	151
		Heteroptera	*Hydromitridae*	4
		Hemiptera	*Gerridae*	14
			Mesoveliidae	7
			Corixidae	1358
			Hydromitridae	4
		Lepidoptera	*Lepidoptera*	92
			cerridae	1
Total				6222

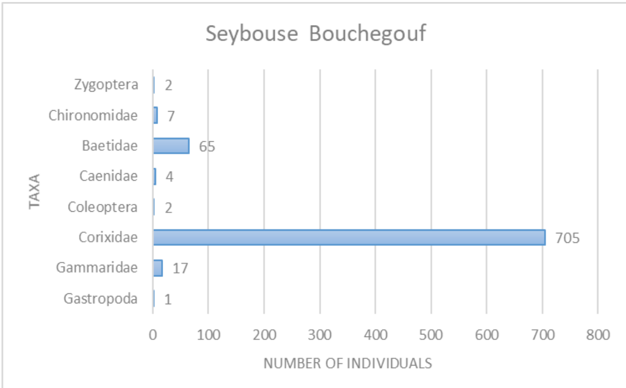
NI: Number of individuals.

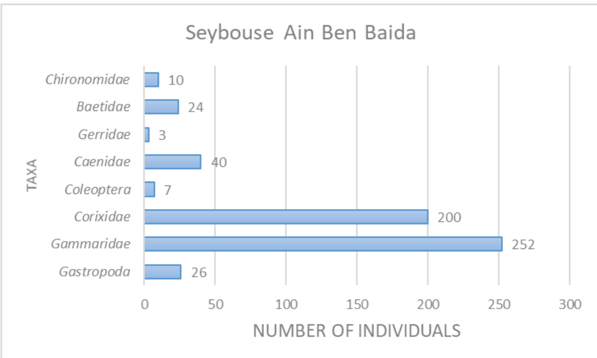
1.2.1. Abundance of the collected taxa analysis:

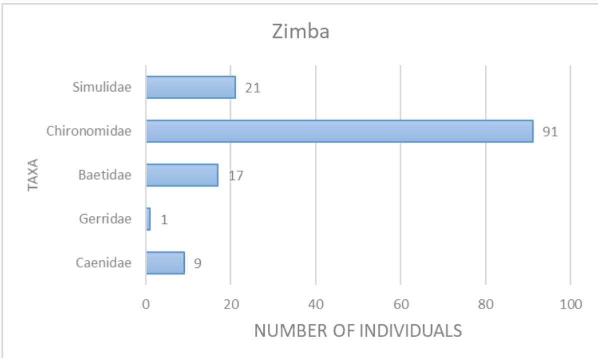
We observed a great diversity in the dominance of the different taxa from one site to another, where the family that dominates most of the sites is the *Gammaridae* which it marks 917 individuals in the Bouhamdane stream site and 252 individuals in Ain Ben Baida rever and 247 in Seybouse El Fadjoudj rever and 543 individuals in the Salah Salah Salah stream site, as well as the *Chironomidae*, which dominate. Zimba stream with 91 individuals and Bou sora stream with 79 individuals, and 145 for Hellia stream and 287 individuals recorded at Medjaz el Bgar dam, followed by the *Corixidae*, where the number of individuals collected is 705 in the site of Seybouse Bouchegouf rever and 113 at Bouhamdane dam and Charef stream with 102, and finally the *Siphlonuridae*, which dominate only Echham stream with 94 individuals (Figs 32 and 33).

The results of taxa composition revealed that site El Fadjoudj of the river Seybouse has a high taxa number with 18 taxa reported, whereas the site Zimba stream has a lower taxa number with 5 taxa reported. The most abundant taxa for all sites are *Corixidae* and *Gammaridae*, and the highest abundances were reported mainly between February to June.









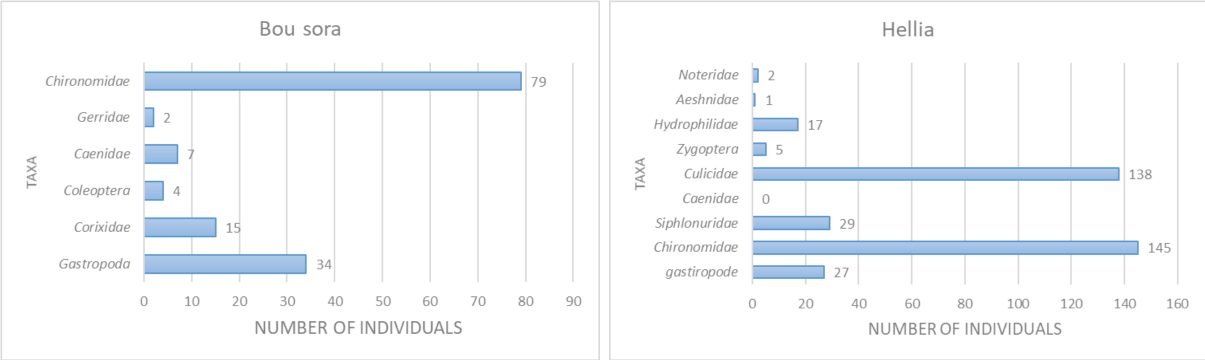
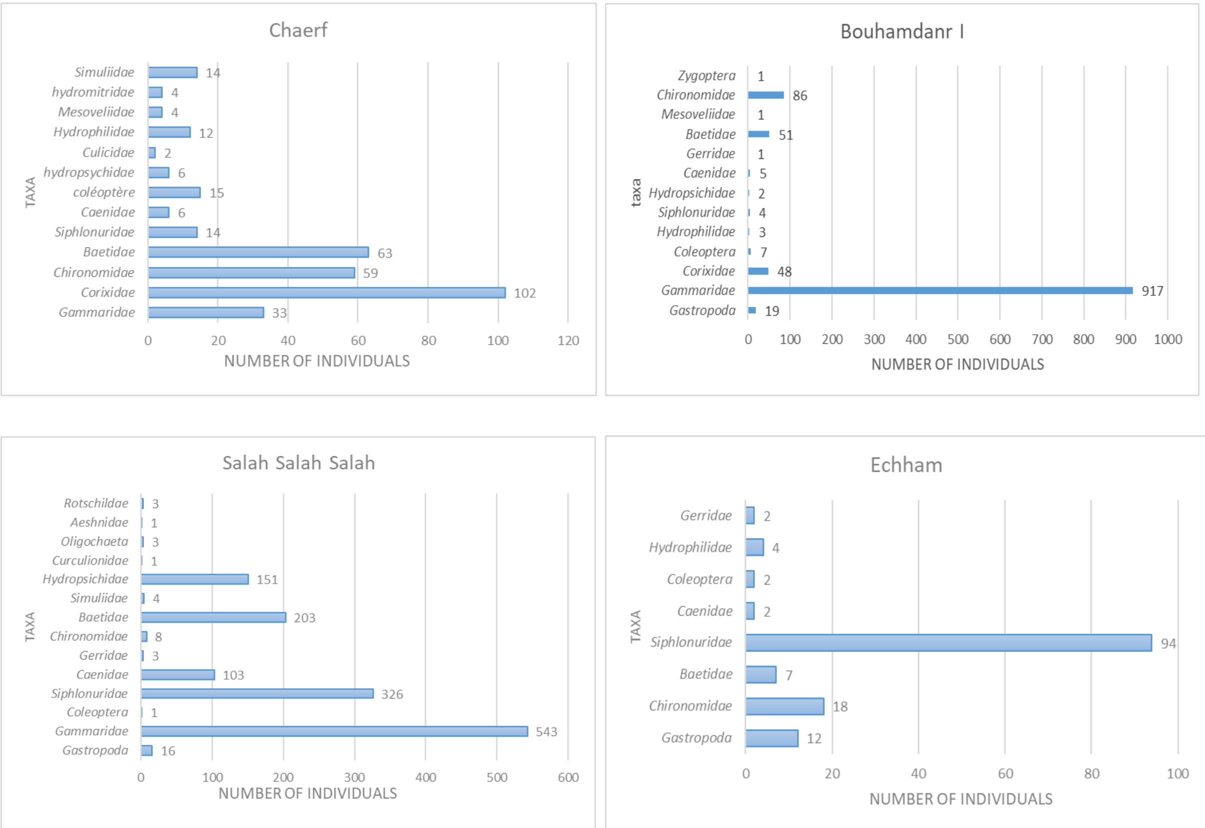


Figure 32: The abundance of macroinvertebrates collected from the sites: Seybouse El Fadjoudj river, Seybouse Bouchegouf river, Seybouse Ain Ben Baida river, Zimba stream, Bou Sora stream, and Hellia stream.



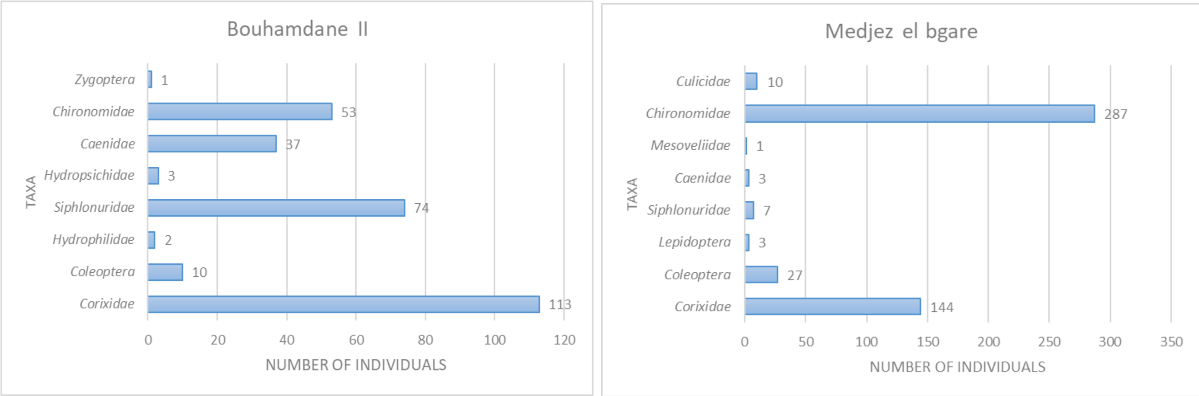


Figure 33: The abundance of macroinvertebrates collected from the sites: Charef stream, Bouhamdane stream, Salah Salah stream, Echham stream, Bouhamdane dam, Medjez el Bgare dam.

The spatial evolution of the abundance of macroinvertebrates shows a very important amount in our study sites with 6222 individuals collected during the sampling period distributed between the 12 sites where the site that contributes the highest number of fauna is Salah Salah Salah with 22% of the total fauna collected followed by 18% in the site of Bouhamdane Streem on the other hand Bou Sora and Zimba represents the lowest percentage with only 2% of the macroinvertebrates collected (Fig 33).

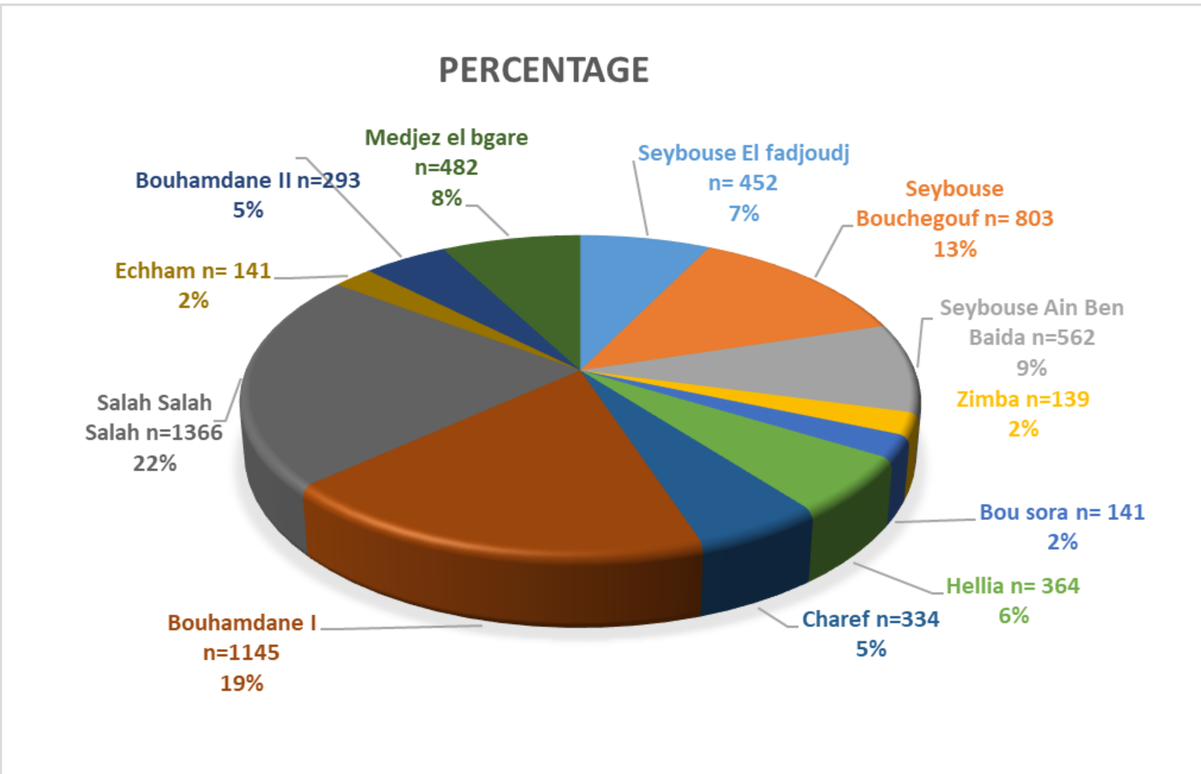


Figure 34: Percentage of macroinvertebrates by site.

2. **Community Structure:**

The results of RDA revealed for abiotic parameters that the main contributor parameters are water velocity, pH, and 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 RDA2 (Table 7). 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* (Fig 34).

Table 7: Contribution of abiotic and biotic parameters for the 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**

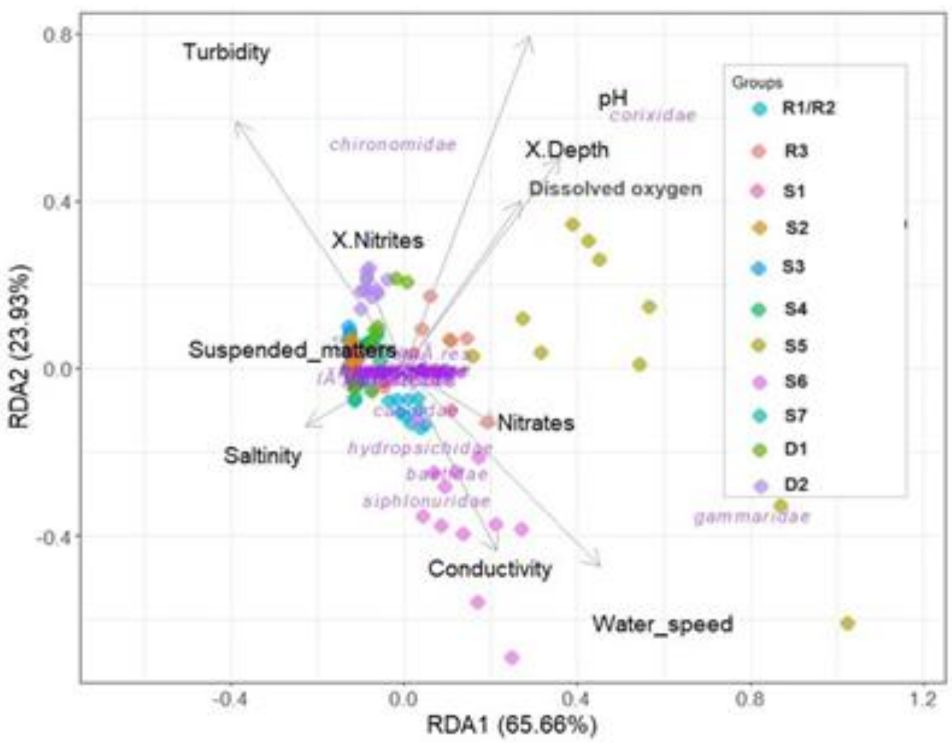


Figure 35: Redundancy analysis (RDA) of the macroinvertebrate communities of aquatic systems for the studied sites. A forward modeling procedure selected turbidity, pH, conductivity, and water speed as predictors.

To evaluate potential differences among communities (sites), we conducted a Permutational Multivariate Analysis of Variance (PERMANOVA) using the Bray-Curtis Distance (Anderson, 2017). This analysis was performed with a permutation of 10,000 times (p-values < 0.05). To visualize sites homogeneity, non-metric multidimensional scaling analysis (nMDS) was performed using the unweighted average ligation technique. Analysis was carried out using adonis function in the R package vegan (Oksanen *et al.,* 2022) and ggplot2 (Wickham, 2016) R software packages.

Permanova: PERMANOVA analysis shows a solution that the thirteen sites under study form four main biological communities ($p < 0.05$, $R = 0.86$). Specifically, Bouhamdane, Salah Salah Salah, Hellia, and Mdjaz bgar. The difference between communities was confirmed by nMDS biplot.

The main taxonomic groups that made the difference in the most different site Salah Salah Salah are *Siphonariidae, Hydropsychidae,* and *Baetidae;* however in the Bouhamdane site it's *Corixidae,* and in Mdjaz Bgar was *Culicidae* that made the difference (Fig. 36). The PERMANOVA analysis indicates that if pvalue is lower than 0.05 that means all the sites are different Our site comparison results prove that all the sites are different than each other, as a consequence of pvalue results are all equal 0.001which is considered very law (Table 8).

The Salah Salah Salah site is the biggest share with the frequency of taxonomic groups also in the biotic and abiotic factors it marks a difference with the lowest rate of dissolved oxygen with an annual average of 0.1 mg/l and in site observation shows that all of surroundings lands of the water course are covered with intensive agriculture all year long. However, the other different sites present a slight change in the physico-chemical parameters but are highly different in the environmental and biological parameters and especially the pollution factor that increases with the proximity of urban agglomerations and industrial areas, such as the site of Zimba that passes close to a sugar factory. Also, a marked tendency to a decrease of specific richness was observed from the head of the basin towards downstreams, apart from the dam where usually depth is the factor that affects the distribution the most (Fig. 36).

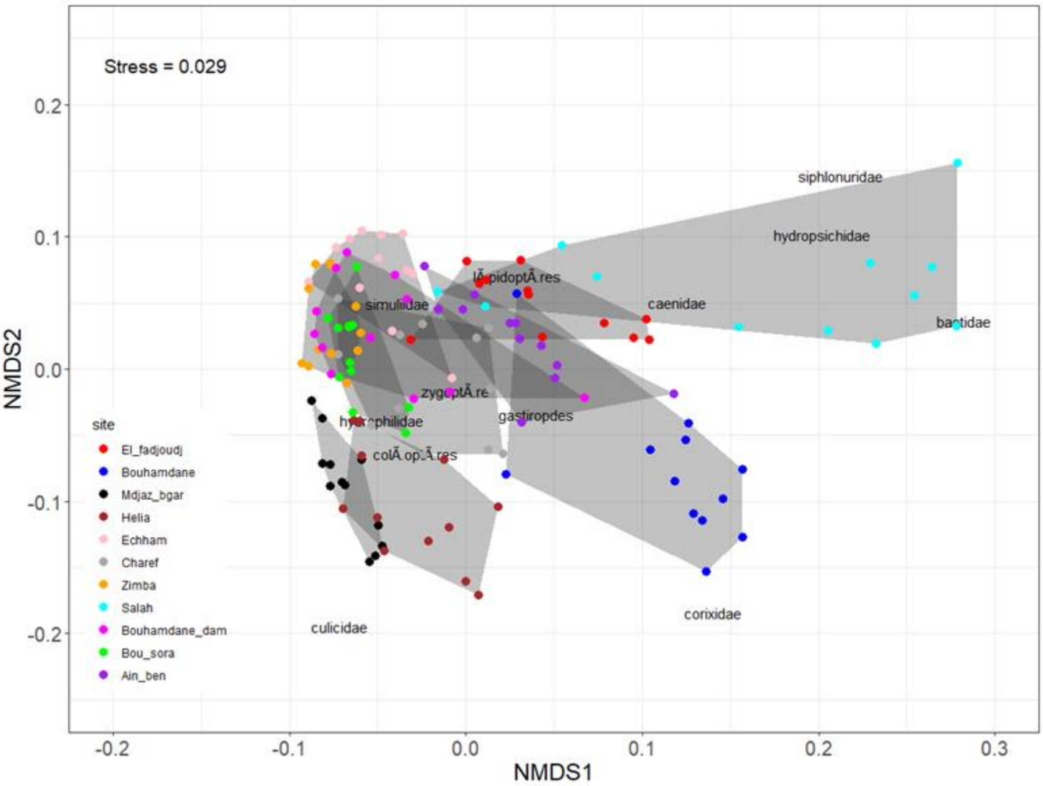


Figure 36: Non-metric multidimensional scaling (nMDS).

2.1. Null model analysis:

According to the viewpoint of null models, that means the absence of regulator factors in community structure, this means in determining the random presence or absence in community structure, on this viewpoint, it was considered two kinds of null models were considered: species cooccurrence and niche sharing (De los Rios-Escalante *et al.*,2020).

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 8). 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 9).

Table 8: Species co-occurrence null model's 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

- **"P"** values lower than 0.05 denoted structured patterns in species associations;
- **"P"** values greater than 0.05 denoted the presence of random in species associations, or not significant. **(n.s)** structured pattern.

Table 9: Niche sharing null model's 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

- **“P”** values lower than 0.05 denoted niche sharing and, in consequence, interspecific competition;
- **“P”** values upper than 0.05 denote absence of niche sharing, or not non-significant (n.s) effect.

2.2. Community distribution analysis:

2.2.1 The selected environmental variables:

First, we compiled 19 bioclimatic variables from the CHELSA database (Climatologies at High Resolution for the Earth's Land Surface Areas; Karger *et al.*, 2017) along with elevation data to efficiently capture the most important climatic factors influencing benthic macroinvertebrate community structure while minimizing redundancy. Using a threshold of $|R| \geq 0.8$, a Pearson correlation matrix was constructed to find and weed out collinear predictors. This allowed us to minimise multicollinearity and retain variables with sufficient statistical independence. After initial screening, we selected a subset of predictors with low inter-correlation that were also ecologically relevant to the life-history traits of the target macroinvertebrate taxa. These included altitude, BIO5 (maximum temperature of the warmest month), BIO6 (minimum temperature of the coldest month), BIO12 (annual precipitation), BIO15 (coefficient of variation of monthly precipitation). BIO5 and BIO6 are critical during low flow and cold seasons, reflecting thermal extremes that affect larval development, survival, diapause, and recolonisation dynamics (Bonada *et al.*, 2006; Jacobi & Vannote 1990). While BIO15 captures rainfall seasonality, an essential driver of flood-drought cycles and associated community turnover in lotic systems, BIO12 reflects general water availability, which supports base flow and habitat connectivity (Poff & Ward 1989). Elevation was retained because it affects hydrological patterns and local temperature, so determines the distribution of species. This process of variable selection ensured strong species-environment modelling and ecological relevance.

2.2.2 Variable Description and Ecological Significance:

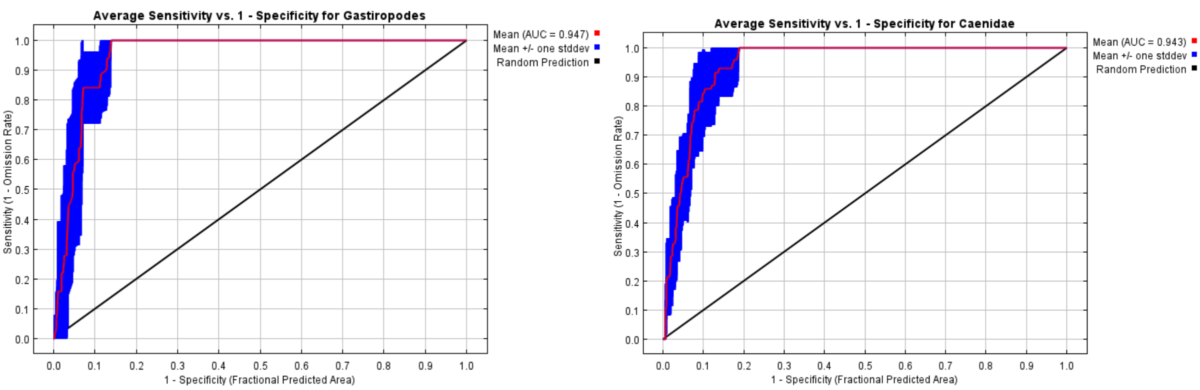
- BIO5: Maximum temperature of the warmest month. Reflects thermal stress during low-flow periods; affects larval development and survival
- BIO6: Minimum temperature of the coldest month, Index of winter thermal minima; influences diapause and recolonization dynamics
- BIO12: Annual precipitation Integrates overall water availability; sustains baseflow and habitat connectivity

- BIO15: Coefficient of variation of monthly precipitation Quantifies seasonal rainfall variability; drives flood–dry cycles and recolonization processes
- Elevation: Altitude above sea level influences temperature and hydrological regimes; shapes macroinvertebrate community structure.

2.2.3. Sensitivity taxa are to the environmental conditions analysis:

The main threshold-independent metric used to evaluate the discriminative ability of our MaxEnt taxa distribution models is the area under the curve (AUC) of the receiver operating characteristic (ROC) graph. The ROC curve graphically shows the trade-off between '1-specificity' (the false positive rate) and sensitivity (the true positive rate), which measures the proportion of known presence sites that are correctly predicted. In the MaxEnt framework, and particularly when using presence-only datasets, specificity is generally measured against a large set of background points taken from the study area. Here, the false positive rate is defined as the proportion of the background area that is incorrectly predicted to be suitable habitat.

MaxEnt systematically provides both a test area under the curve (AUC), calculated using an independent subset of presence locations retained during training, which is a more robust measure of the model's predictive performance and ability to generalise, and a training AUC, which indicates how well the model fits the environmental variables for calibration. Higher test AUC values suggest that the taxa can distinguish locations from the background environment more accurately. AUC values range from 0.5 (performance no better than chance) to 1.0 (perfect discrimination). The curves in the figure 37 show the reliability of the taxa and their non-random distribution.



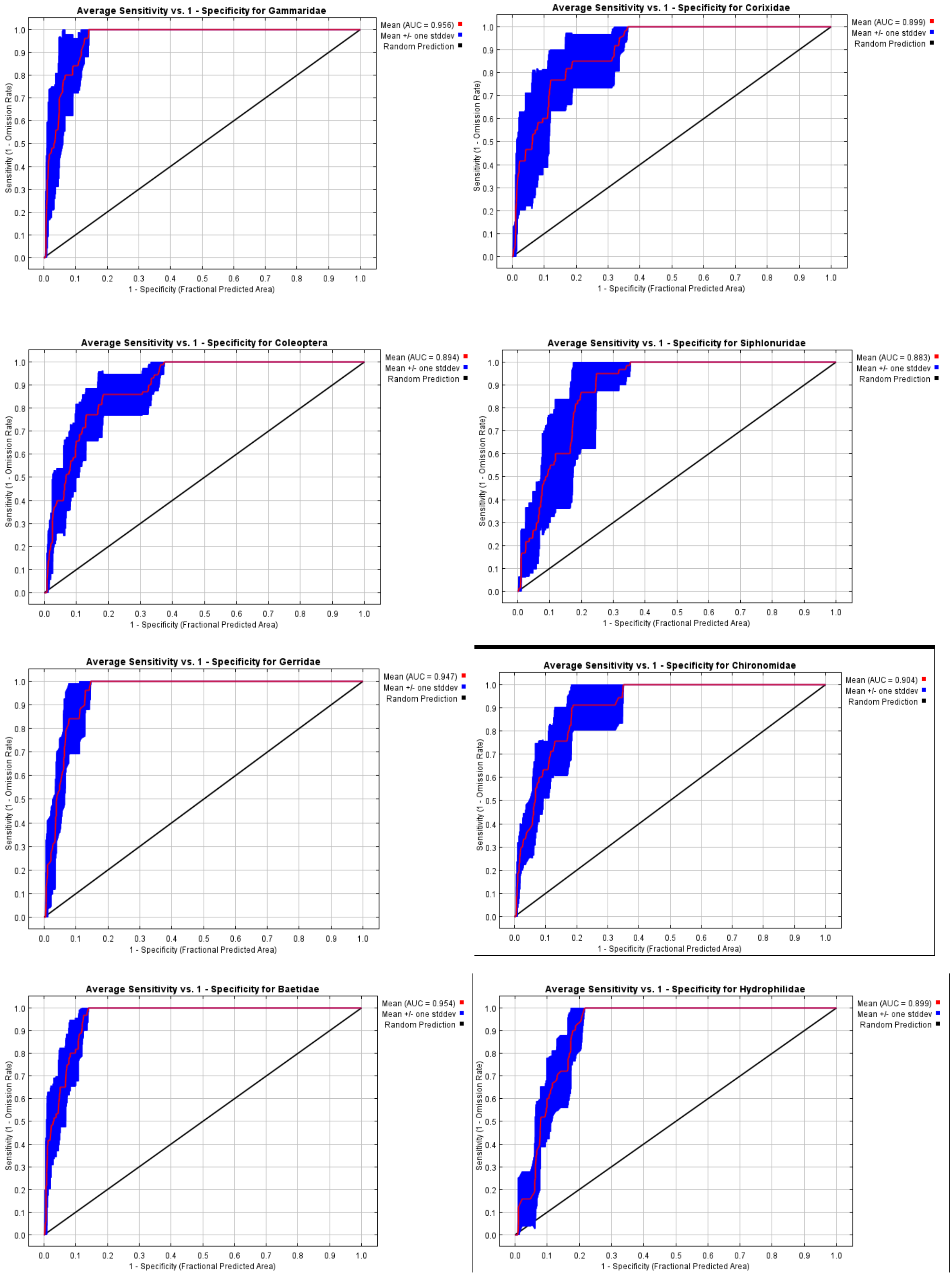


Figure 37: AUC represents the sensitivity taxa are to environmental conditions.

2.3 Distribution of collected fauna:

- ***Gastropods:***

The study region's freshwater *Gastropods*' MaxEnt species niche modeling revealed that the warmest month's maximum temperature (BIO5) was the main factor influencing habitat suitability, explaining 86.1% of regularized training gain and 86.1% of permutation importance. According to Jackknife tests (fig 38), BIO5 by itself almost replicated the full-model gain, and its absence resulted in the biggest performance drop; its marginal response showed a sharp sigmoidal rise between ~30.6 °C and ~30.9 °C, plateauing at high suitability. With the highest suitability below 200 m and a monotonic decline at higher elevations, elevation was the second most significant predictor (10.9% contribution, 7.2% permutation importance). While annual precipitation (BIO12) was insignificant (0.4 % gain, 1.1 % permutation importance) (table 10), seasonal precipitation (BIO15) and the minimum temperature of the coldest month (BIO6) each contributed only 1–1.5 % of gain (2.1–3.6 % permutation importance) and showed marginal responses that were gradually increasing (Fig 39).

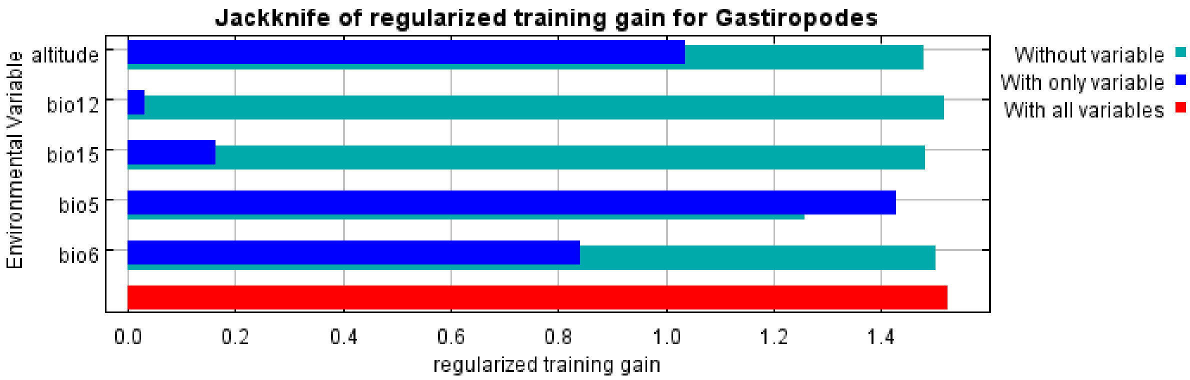


Figure 38: Jackknife test of regularized training gain for *Gastropodes*.

Table 10: The contribution of the different variables to the model gain representation of *Gastropodes.*

Variable	Percent contribution	Permutation importance
bio5	86.1	86.1
altitude	10.9	7.2
bio15	1.5	2.1
bio6	1.2	3.6
bio12	0.4	1.1

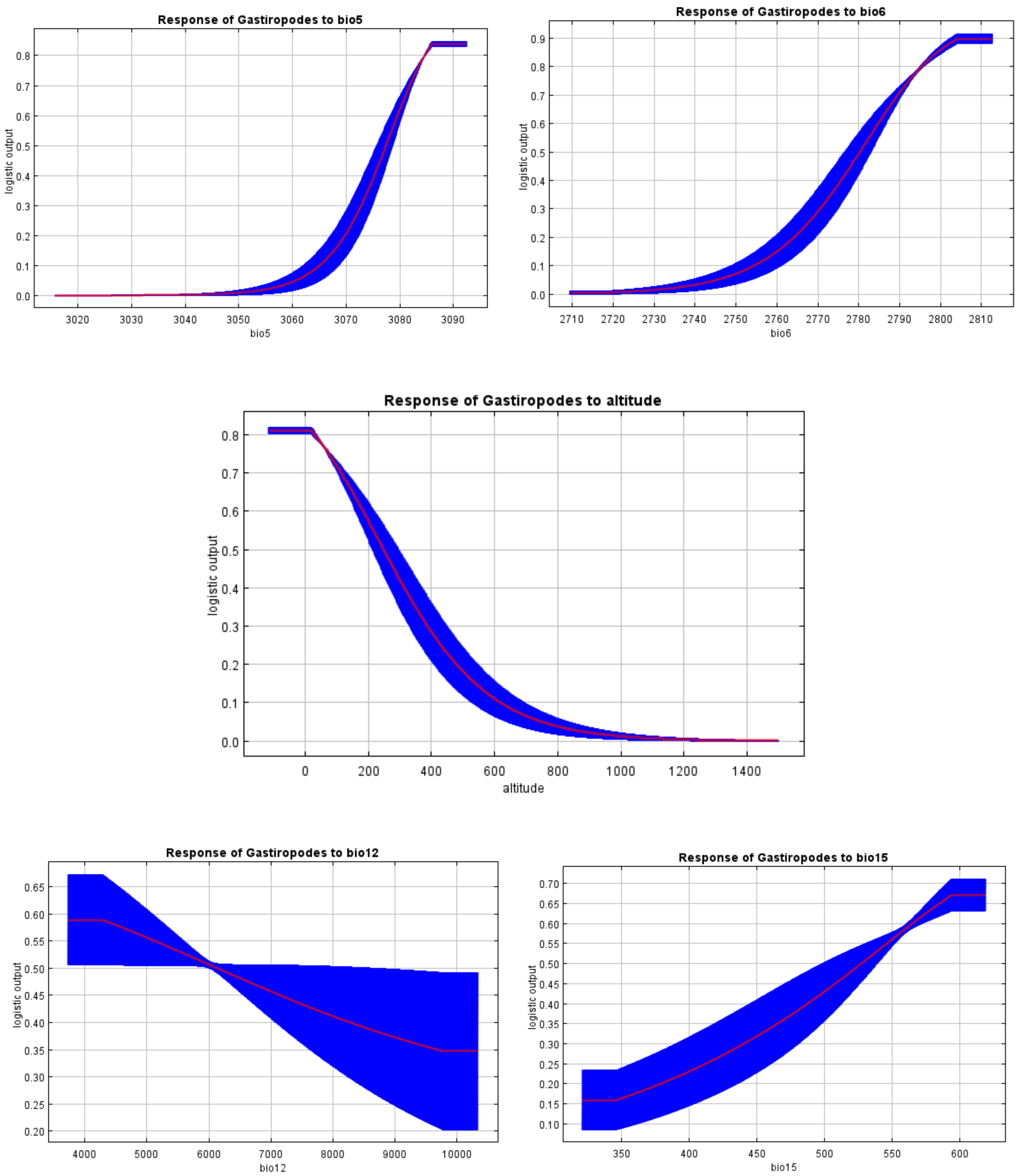


Figure 39: The ecological response of *Gastropods* to selected environmental gradients

These results show that the distribution of *Gastropods* in this region is mainly determined by summer thermal maxima, with altitude having a minor effect and precipitation measurements providing little additional explanatory power.

This distribution is represented by their presence in 8 different sites and their absence in the Zimba stream, the Bouhamdane dam, the Charef stream and Medjaz el Bgare dam, as the map in Figure 40 shows.

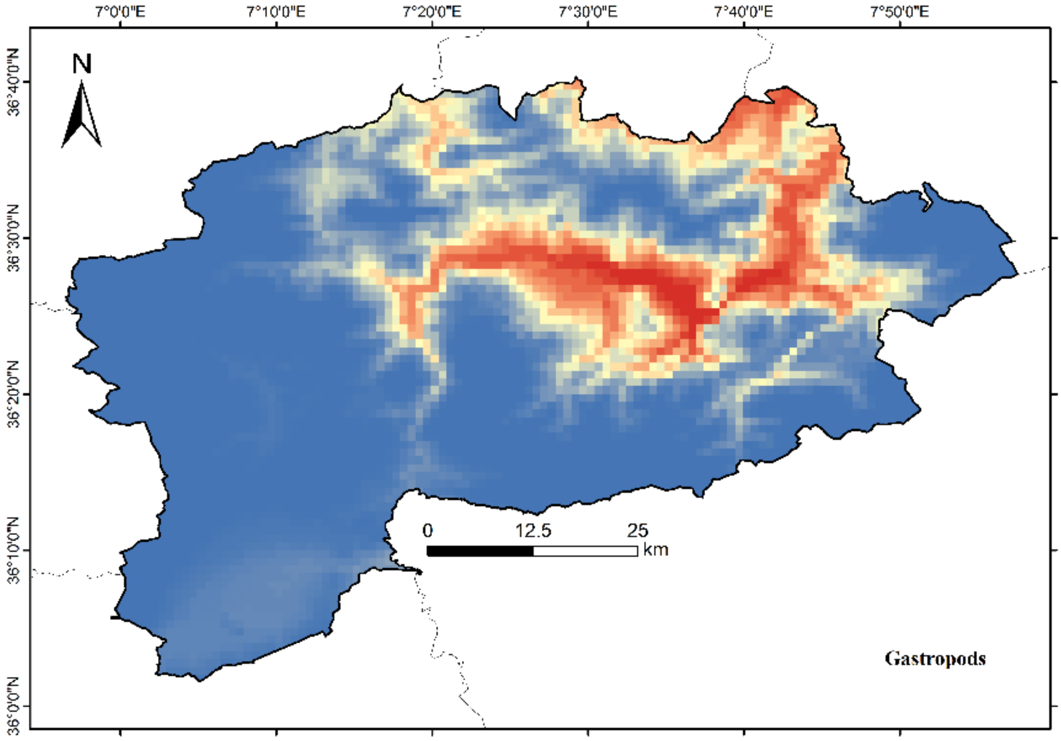


Figure 40: The geographical distribution of *Gastropodes* in northeastern Algeria.

- ***Gammaridae:***

MaxEnt modeling of *Gammaridae* in Algeria found that habitat suitability was mostly driven by the maximum temperature of the warmest month (BIO5), explaining 92.4% of regularized training gain and 84.7% of permutation importance. Jackknife tests revealed that BIO5 by itself almost exactly matched the full-model gain (Fig. 41); its removal caused the biggest performance drop; its marginal response showed a steep sigmoidal increase between ~30.7 °C and ~30.9 °C before plateauing at high suitability (Table 11).

With suitability highest at near-sea-level elevations and declining monotonically above ~200 m, altitude was the second most important predictor (3.6% contribution, 8.8% permutation importance). While precipitation seasonality (BIO15; 2.4% gain, 3.0% importance) and the minimum temperature of the coldest month (BIO6; 0.0% gain, 0.6% importance) each added minimal explanatory power and shown gradually increasing suitability trends, annual precipitation (BIO12) contributed only 1.5% of gain (2.9% importance) (Fig42).

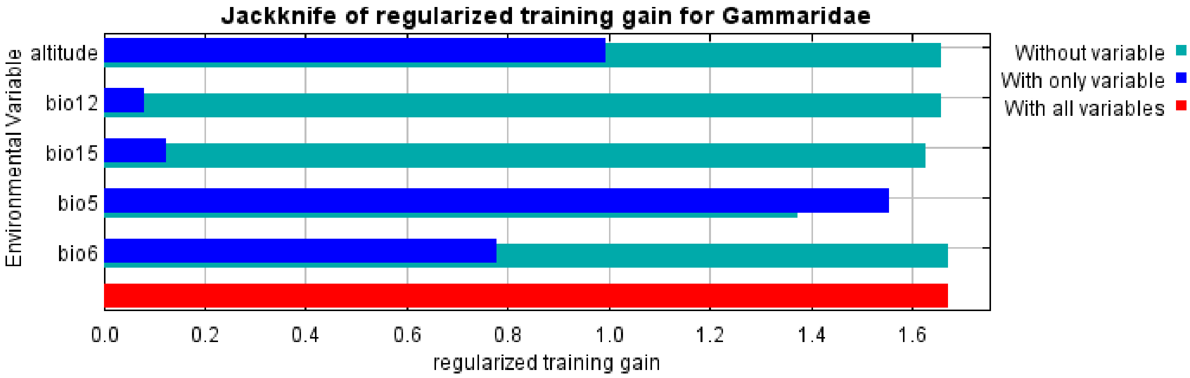
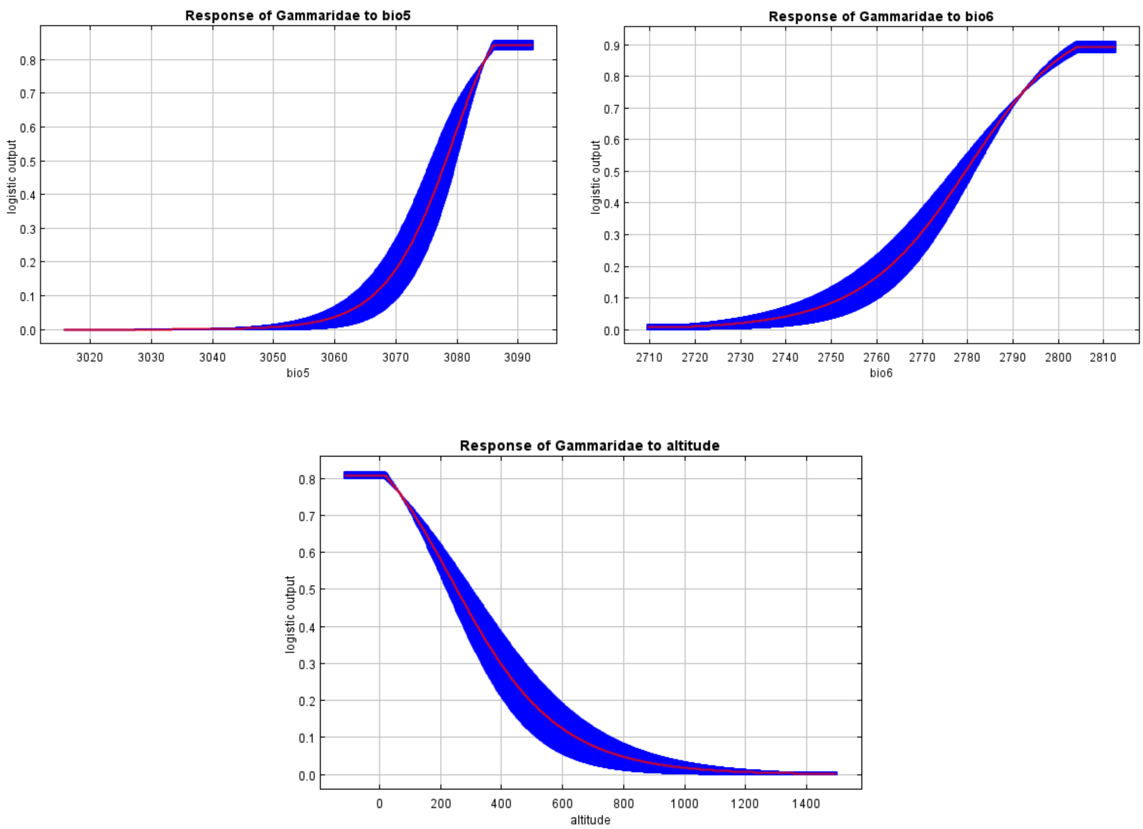


Figure 41: Jackknife test of regularized training gain for *Gammaridae*.

Table 11: The contribution of the deferent variables to the model gain representation of *Gammaridae.*

Variable	Percent contribution	Permutation importance
bio5	92.4	84.7
altitude	3.6	8.8
bio15	2.4	3
bio12	1.5	2.9
bio6	0	0.6



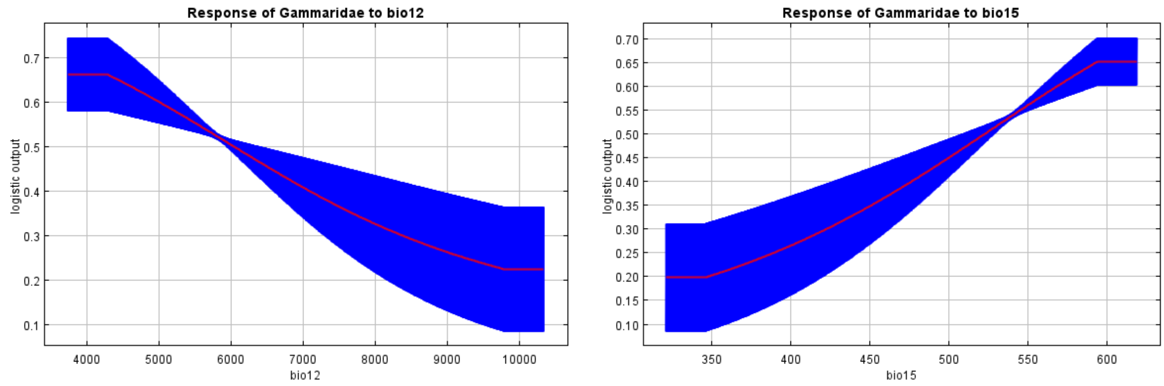


Figure 42: The ecological response of *Gammaridae* to selected environmental gradients.

These results show that summer thermal maxima shape Gammaridae distributions in Algeria mostly; elevation has a minor secondary role, and precipitation measurements provide little additional information.

While this distribution is represented by the division of 2009 *Gammaridae* individuals only in six different sites which are: the tree sites of Seyboue river, Charef stream, Salah stream and finally Bouhamdane stream, which have the biggest abundance of 917 individuals (Fig, 43).

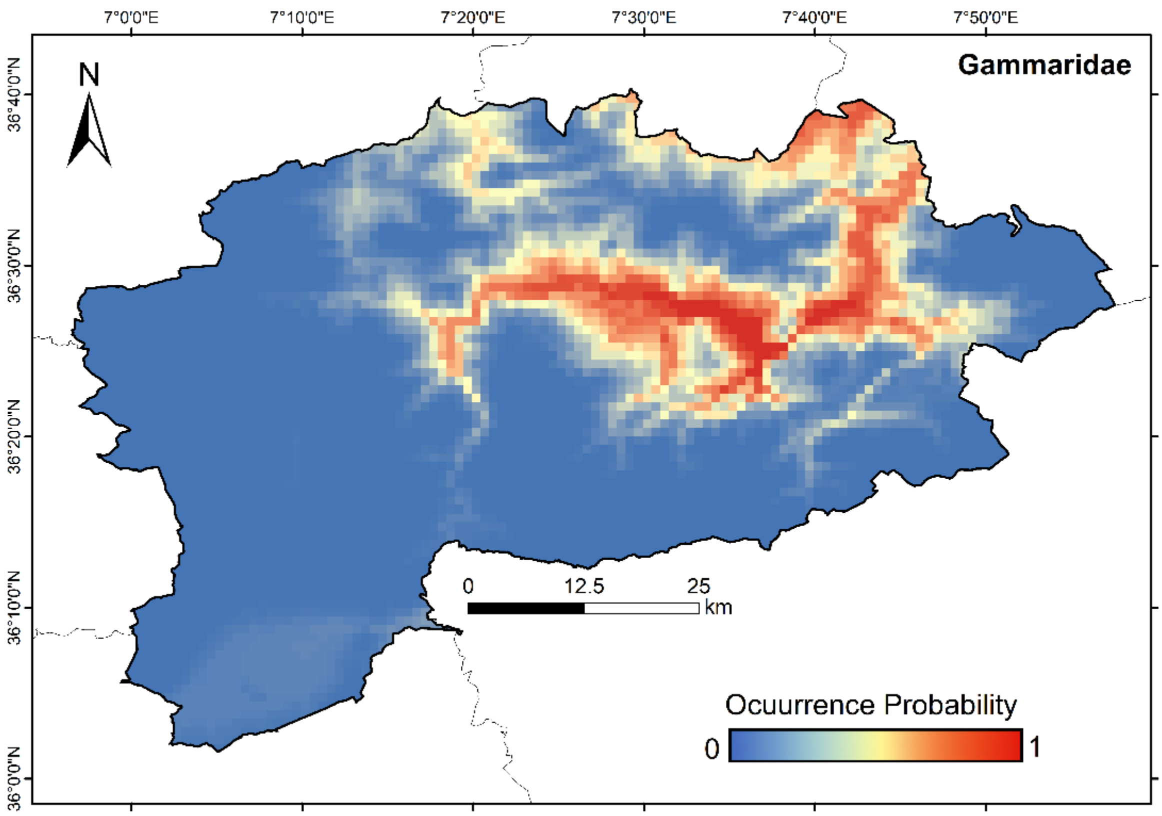


Figure 43: The geographical distribution of *Gammaridae* in northeastern Algeria.

- ***Caenidae:***

BIO5 (highest temperature of the warmest month) is identified as the most significant predictor for *Caenidae* species in the inland waterways of the Wilaya de Guelma, with a regularized training gain of 95.2% and permutation importance of 95.2% (Table 12). Its marginal response has a pronounced sigmoid curve between approximately 3060 and 3085 (≈30.6–30.9 °C), stabilizing at around 0.9 suitability.

The jackknife test demonstrates that BIO5 independently accounts for nearly the entire model improvement, and its exclusion results in the most significant decline in performance (Fig. 44). Altitude contributes merely 3.5% to the gain, exhibiting minimal permutation importance; its curve indicates optimal suitability below 200 m but provides negligible unique information beyond what BIO5 and other components already encompass.

As rainfall escalates from roughly 430 to approximately 980 mm (×10), BIO12 (annual precipitation) accounts for 1.4% of gain and 4.5% of permutation relevance, signifying diminished suitability. BIO15 (seasonal precipitation) and BIO6 (minimum temperature of the coldest month) contribute less than 0.2% to the gain; therefore their exclusion minimally impacts the model's performance (Fig. 45).

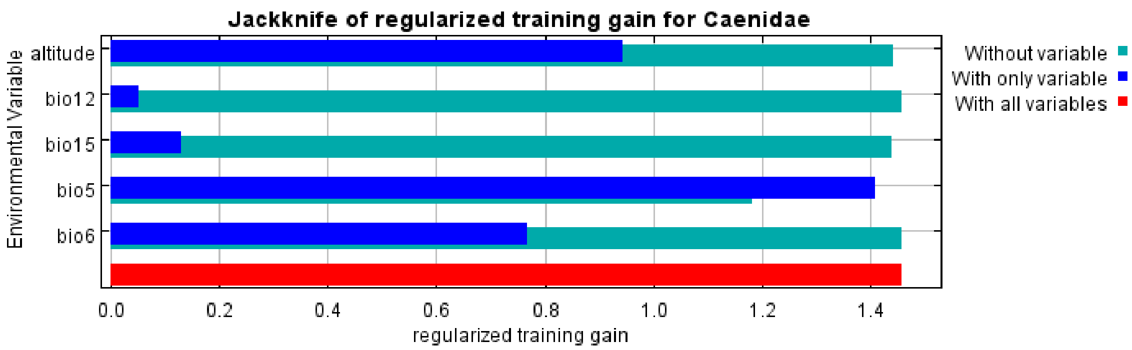


Figure 44: Jackknife test of regularized training gain for *Caenidae*.

Table 12: The contribution of the different variables to the model gain of *Caenidae*.

Variable	Percent contribution	Permutation importance
bio5	91.7	87.9
altitude	6	7.3
bio12	1.2	1.5
bio15	1.1	2.4
bio6	0.1	0.9

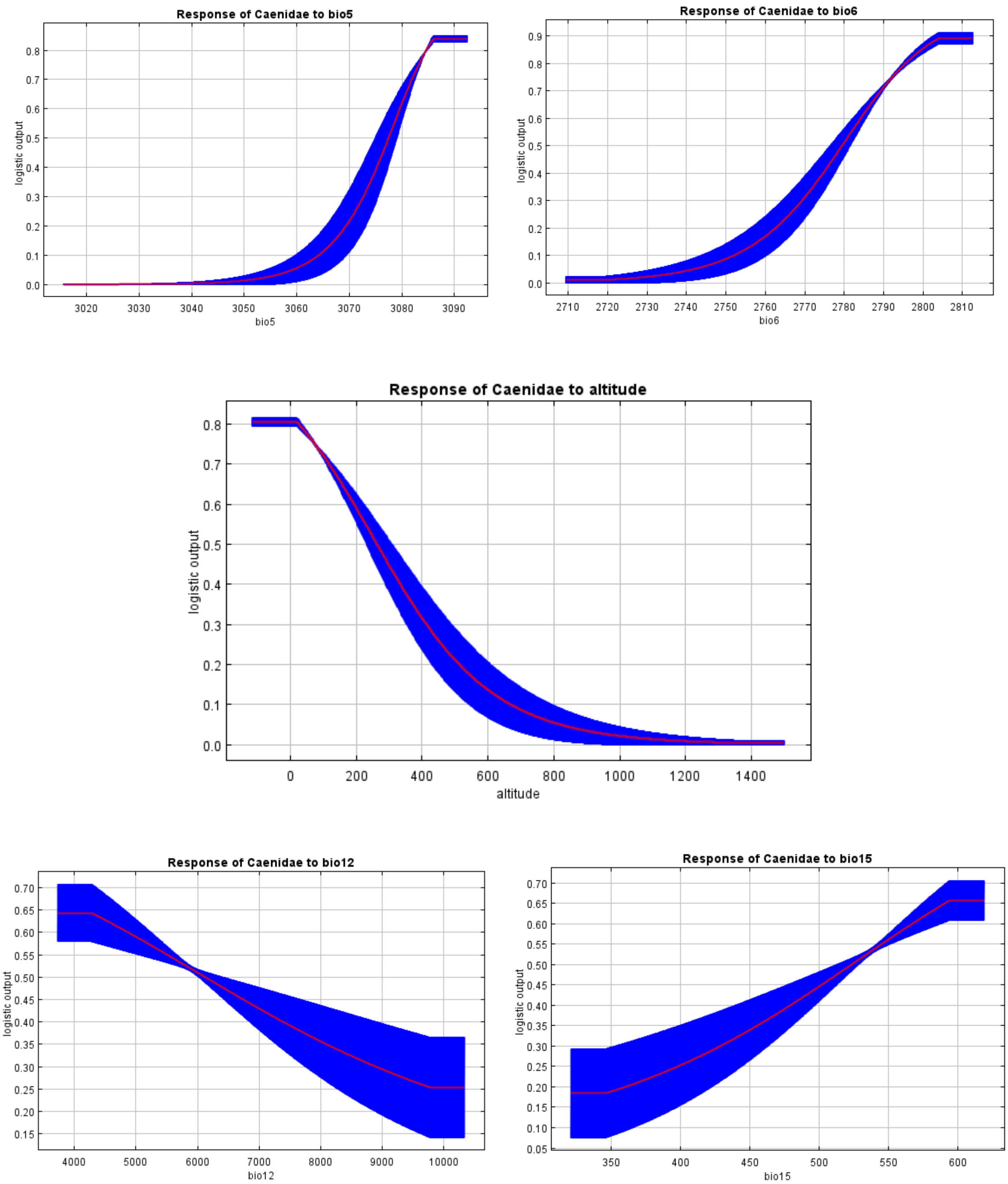


Figure 45: The ecological response of *Caenidae* to selected environmental gradients.

Collectively, these findings indicate that summer thermal maxima consistently dictate habitat suitability across *Caenidae* taxa in the region's freshwater systems, while elevation and precipitation metrics mostly serve redundant secondary roles.

As a result, *Caenidaes* showed a wide distribution throughout the region, where it occupied 10 sites, while it was absent only in Seybouse, El Fadjoudj River, and Hellia Stream (Fig. 46).

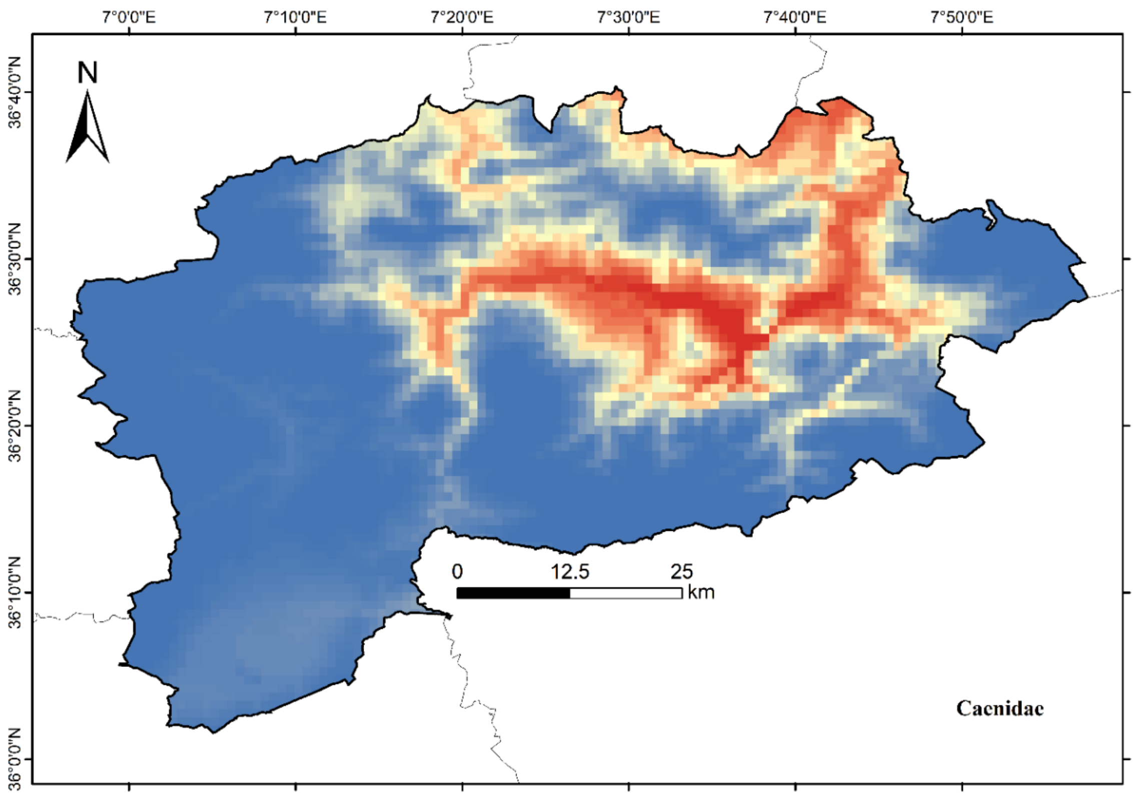


Figure 46: The geographical distribution of *Caenidae* in northeastern Algeria.

- ***Corixidae :***

MaxEnt modeling of *Corixidae* in Algeria revealed that the maximum temperature of the warmest month (BIO5) explains 89.4% of the regularized training gain and accounts for 84.5% of the permutation importance (Table 13), so determining the distribution of suitable habitats. Jackknife tests found that BIO5 by itself obtained a training gain almost equal to the whole model, and that its absence produced the most significant decline in predictive power. Between roughly 30.2.2°C and 30.9.9°C, the species responded to BIO5, showing a steep logistic increase beyond which habitat suitability plateaued, implying a thermal threshold beyond which conditions remain favorable (Fig. 48).

Second in importance, annual precipitation (BIO12) scored 6.9% contribution and 14% permutation importance. The corresponding response curve showed that habitat suitability falls drastically beyond ~6000 mm/year, with peak values in rather drier zones.

Negatively correlated with suitability, altitude accounted 3.5% of the training gain (and 0.5% permutation importance). Indicating the group's inclination for lowland freshwater habitats, predicted habitat suitability was highest at or close to sea level and dropped progressively above 200'm.

With weakly increasing suitability trends for BIO6 and a modest non-linear response for BIO15, the minimum temperature of the coldest month (BIO6) and precipitation seasonality (BIO15) made little contributions (0.1% and 0%, respectively).

With an average AUC of 0.899, the last model produced a high predictive performance and showed great model discrimination (Fig. 48).

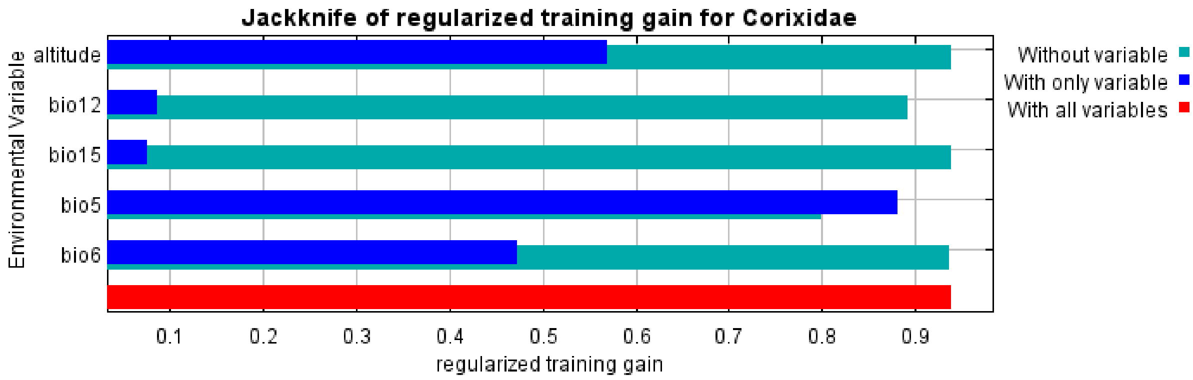


Figure 47: Jackknife test of regularized training gain for *Corixidae*.

Table 13: The contribution of the different variables to the model gain representation of *Corixidae*.

Variable	Percent contribution	Permutation importance
bio5	89.4	84.5
bio12	6.9	14
altitude	3.5	0.5
bio6	0.1	0.9
bio15	0	0

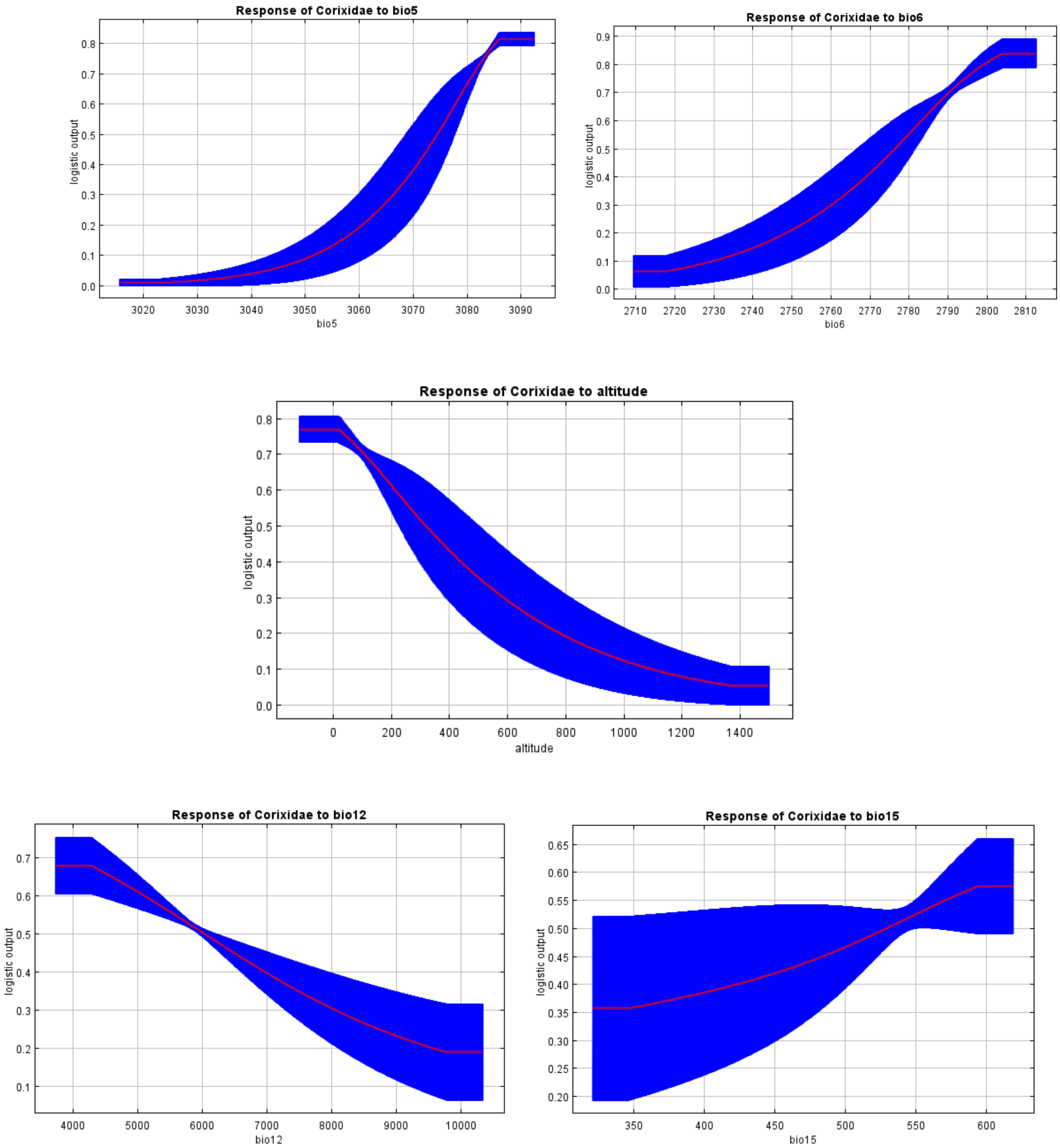


Figure 48: The ecological response of *Corixidae* to selected environmental gradients.

These results imply that thermal conditions, especially summer máxima rather than elevation and precipitation, mostly shape *Corixidae* distributions in the north-east of Algeria.

The family *Corixidae* was found to be dominant not only in terms of number of individuals (1,358) but also in its distribution in 8 sites, except Zimba, Salah Salah Salah, Echham, and Hellia stream (Fig. 49).

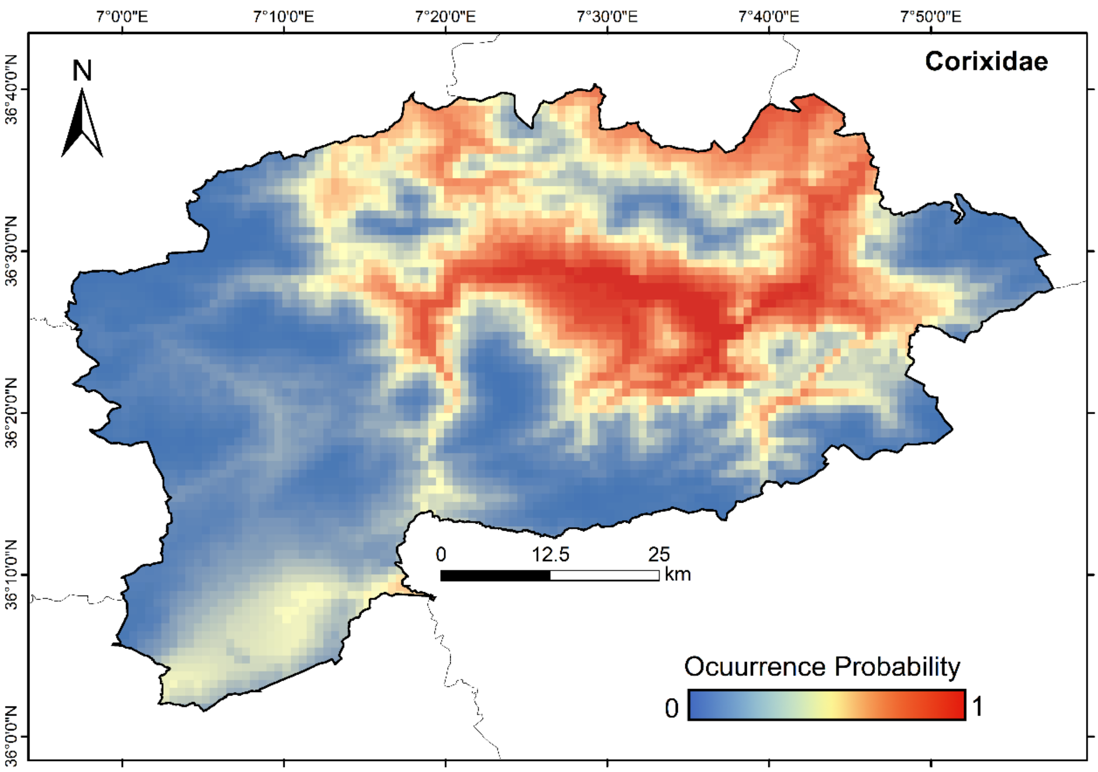


Figure 49: The geographical distribution of *Corixidae* in northeastern Algeria.

- ***Coleoptera :***

MaxEnt modeling of *Coleoptera* in the northeast of Algeria found the overwhelmingly dominant predictor of habitat suitability to be the maximum temperature of the warmest month (BIO5), so accounting for 85.7% of the permutation importance and contributing 93.9% to the regularized training gain (Table 14). Jackknife tests revealed that BIO5 by itself nearly reached the full model gain and that its absence produced the most significant performance loss. Between ~30.2.0°C and ~30.9.0°C, the species responded to BIO5, showing a steep logistic increase; after which suitability plateaued, implying a thermal optimum around this range (Fig. 50).

Contributing 6% to the gain and 14.2% to the permutation importance, annual precipitation (BIO12) was the only secondary variable of significant impact. Coleoptera in Algeria prefer rather drier conditions, as seen by a clear drop in habitat suitability beyond ~6000 mm/year in the response curve.

Training gain and permutation importance were not much influenced by other factors, including altitude, precipitation seasonality (BIO15), and the minimum temperature of the coldest month (BIO6). Their response curves displayed expected ecological patterns that is declining suitability with rising elevation but they gave the model little additional explanatory value.

Strong predictive accuracy is reflected in the high mean AUC of 0.894 of the model. These results imply that topographic and other thermal variables have little effect, while summer heat maxima mostly limits the distribution of *Coleoptera* in north-east of Algeria with minor sensitivity to precipitation levels (fig 51).

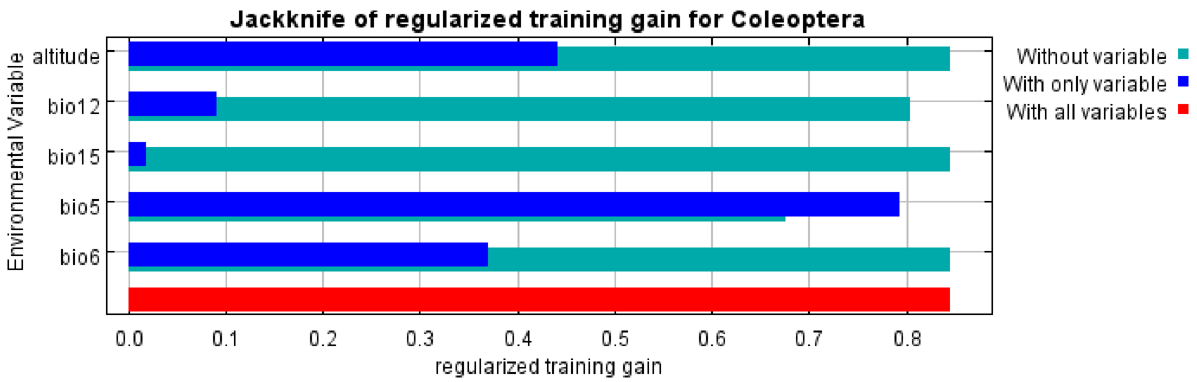


Figure 50: Jackknife test of regularized training gain for *Coleoptera*.

Table 14: The contribution of the different variables to the model gain representation of *Coleoptera*.

Variable	Percent contribution	Permutation importance
bio5	93.9	85.7
bio12	6	14.2
bio15	0.1	0.1
bio6	0	0
altitude	0	0

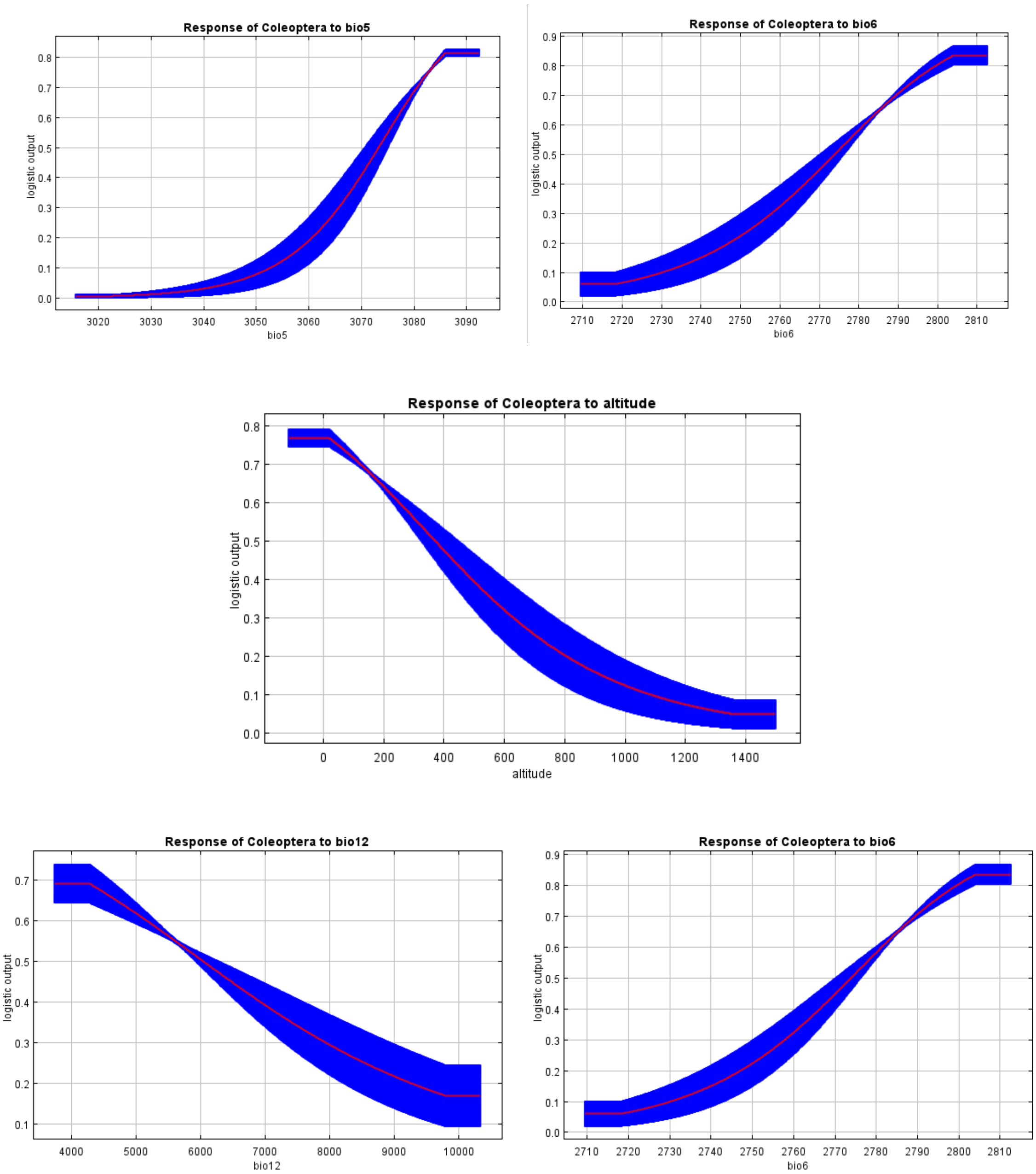


Figure 51: The ecological response of *Coleoptera* to selected environmental gradients.

The strong predictive accuracy is reflected in the high mean AUC of 0.894 of the model. These results imply that topographic and other thermal variables have little effect, while summer heat maxima mostly limit the distribution of *Coleoptera* in the north-east of Algeria with minor sensitivity to precipitation levels. which allowed the colonisation of 10 of the sampled sites to disappear only in the Zimba and Hellia streams. This wide distribution of Coleoptera is shown in the map of Figure 52.

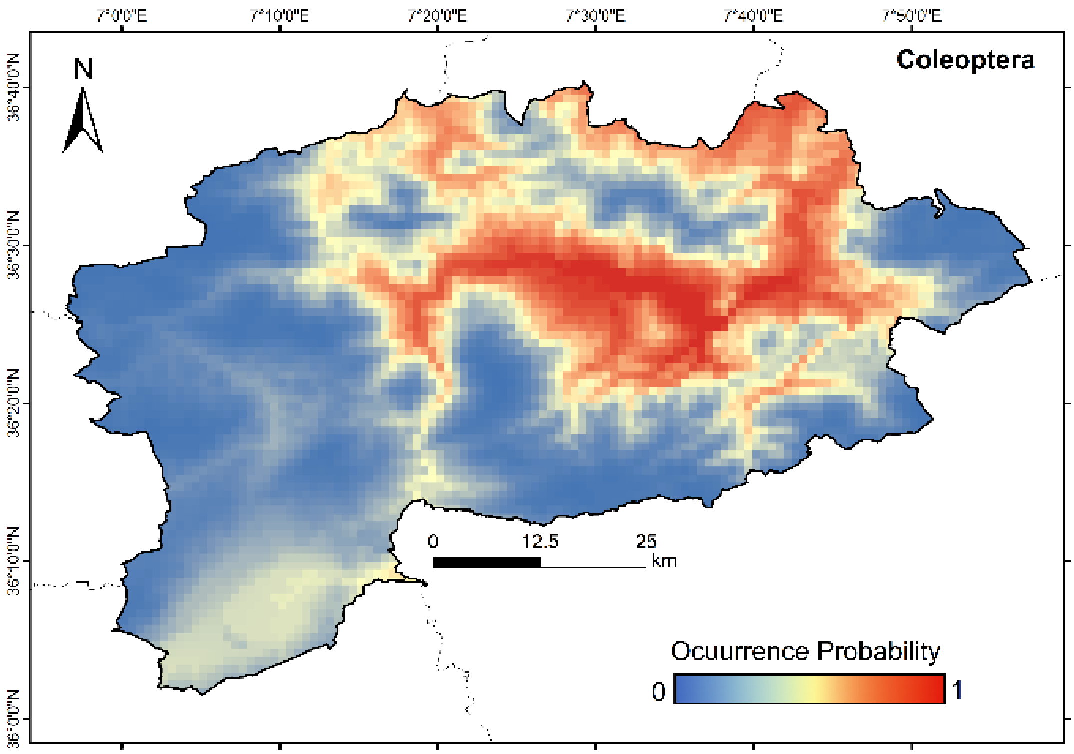


Figure 52: The geographical distribution of *Coleoptera* in northeastern Algeria.

- ***Siphlonuridae :***

The modeling of *Siphlonuridae* in the study area revealed that the primary determinant of habitat suitability was the maximum temperature of the warmest month (BIO5), explaining 84.3% of the regularized training gain and accounting for 61.4% of permutation importance (Table 15).

Jackknife studies verified BIO5's critical importance; while its absence reduced model performance, this variable alone almost matched the full-model gain (fig.53). Between ~30.2 °C and ~30.9 °C, the marginal response curve displayed a steep logistic increase in suitability, after which suitability stabilized, so defining a clear optimal thermal range. With a permutation importance of 24.6% and a contribution of 13.5%, annual precipitation (BIO12) came second most importantly. Particularly above ~6000 mm/year, the response curve showed that habitat suitability dropped significantly with increasing precipitation, implying that Siphlonuridae prefer areas with modest to low rainfall. Altitude had a modest (1.1% gain, 10.6% permutation importance) contribution; habitat suitability is highest at low elevations, then progressively above 200 m. With each ≤ 1.1% contribution, the minimum temperature of the coldest month (BIO6) and precipitation seasonality (BIO15) offered little explanatory power. Their response curves showed minor positive links with suitability but had little effect. With a mean AUC of

0.883, the model showed good predictive accuracy. With altitude playing a secondary role (Fig. 54).

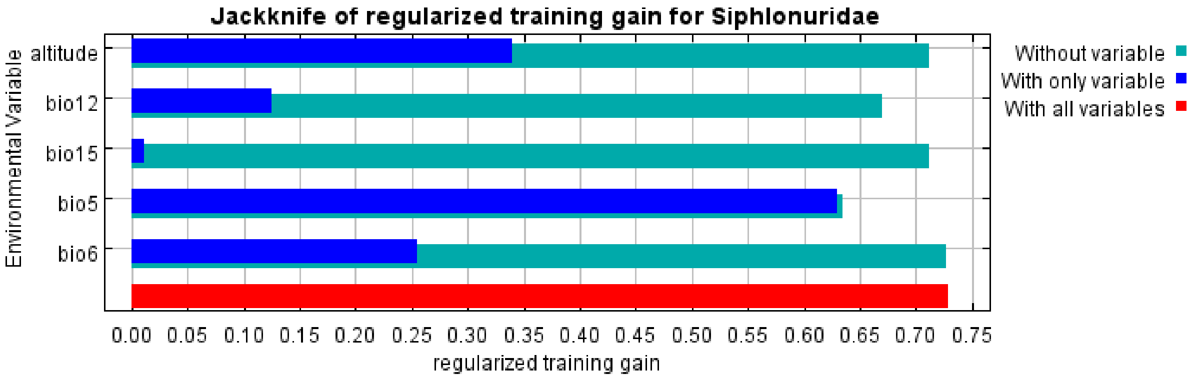


Figure 53: Jackknife test of regularized training gain for *Siphlonuridae*.

Table 15: The contribution of the different variables to the model gain representation of *Siphlonuridae*.

Variable	Percent contribution	Permutation importance
bio5	84.3	61.4
bio12	13.5	24.6
bio15	1.1	2.3
altitude	1.1	10.6
bio6	0.1	1.1

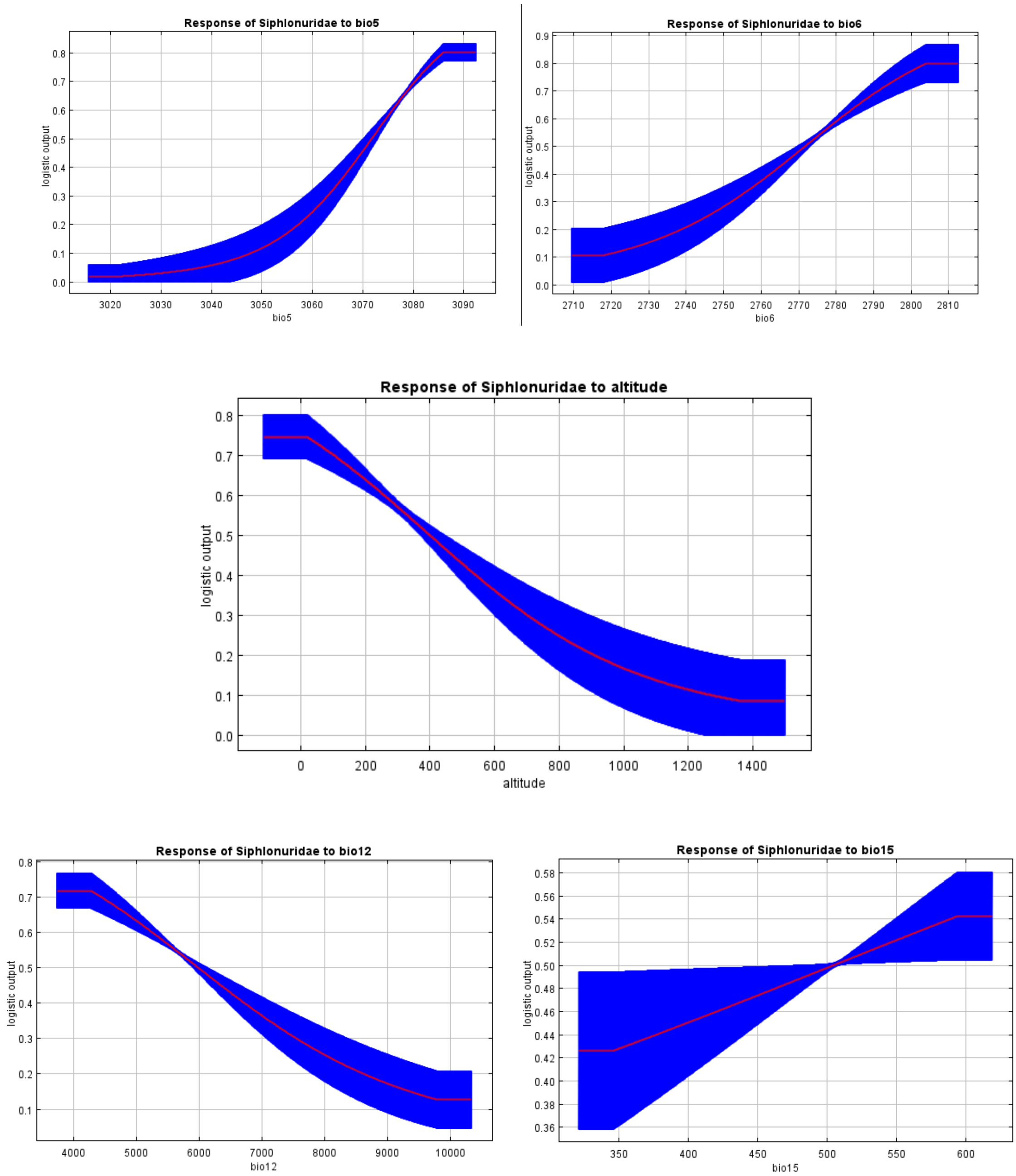


Figure 54: The ecological response of *Siphlonuridae* to selected environmental gradients.

These results highlight the main relevance of summer thermal maxima and, secondarily, annual precipitation in defining suitable habitats for *Siphlonuridae* in the north-east of Algeria.

The representation in the map (Fig.55) shows that *Siphlonuridae* has a good distribution in 8 sites and is absent in Bou Sora, Zimba streams, along with two Seybouse river sites, Bouchegouf and Ain Ben Baida, with a total of 588 individuals.

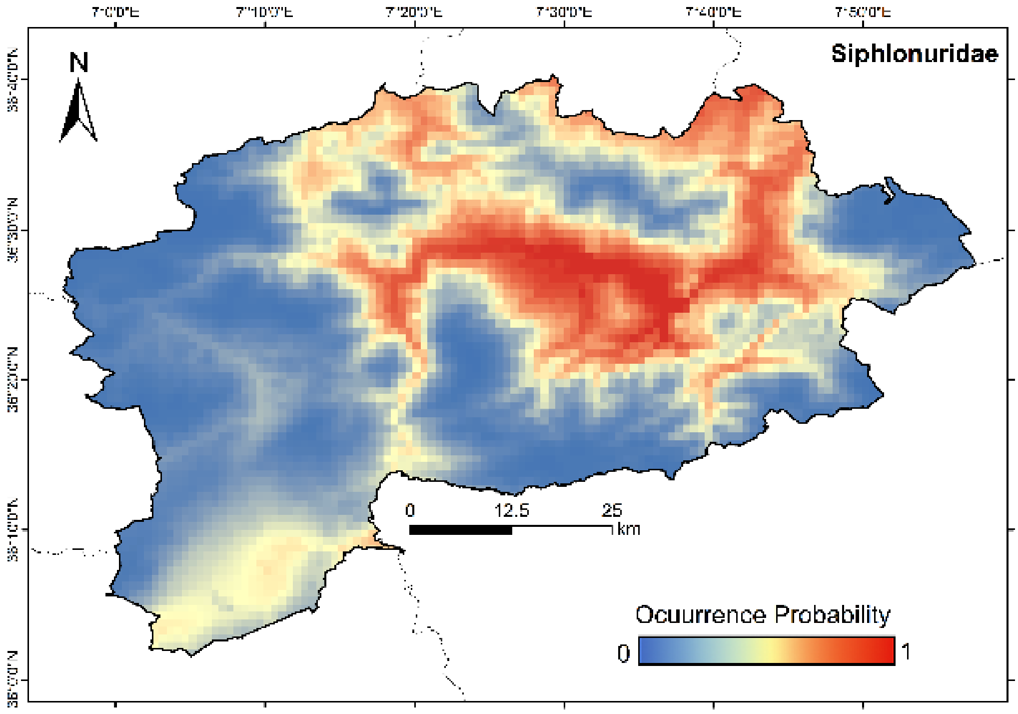


Figure 55: The geographical distribution of *Siphlonuridae* in northeastern Algeria.

- ***Gerridae :***

MaxEnt modeling of *Gerridae* revealed that the maximum temperature of the warmest month (BIO5) essentially controls habitat suitability; this accounted for 97.3% of the permutation importance and contributed 93.6% of the regularized training gain (Table 16). Jackknife tests confirmed its important function: omitting BIO5 resulted in the biggest performance drop, while BIO5 by itself attained a gain almost as high as the full model (Fig.56). indicating a thermal optimum, the response curve for BIO5 shows a sharp logistic increase between ~30.2 °C and ~30.9 °C, then suitability plateaus at high values.

The only other predictor with quantifiable impact was elevation, which accounted for 6.3% of the gain, though only 2.2% of permutation importance. Reflecting the family's inclination for lowland aquatic environments, its marginal response shows the greatest suitability at sea level, declining steeply above ~200 m and approaching zero suitability beyond ~1 000 m.

While annual precipitation (BIO12) and minimum temperature of the coldest month (BIO6) gave no explanatory value in this model, precipitation seasonality (BIO15) contributed negligibly (0.1% gain; 0.4% importance). Each showing essentially flat or undifferentiated response curves (Fig.57)

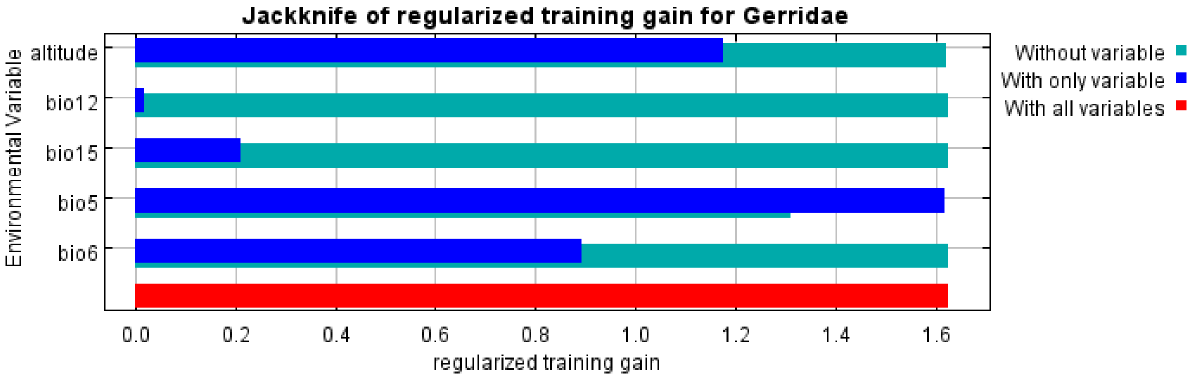


Figure 56: Jackknife test of regularized training gain for *Gerridae*.

Table 16: The contribution of the different variables to the model gain representation of *Gerridae*.

Variable	Percent contribution	Permutation importance
bio5	93.6	97.3
altitude	6.3	2.2
bio15	0.1	0.4
bio12	0	0
bio6	0	0

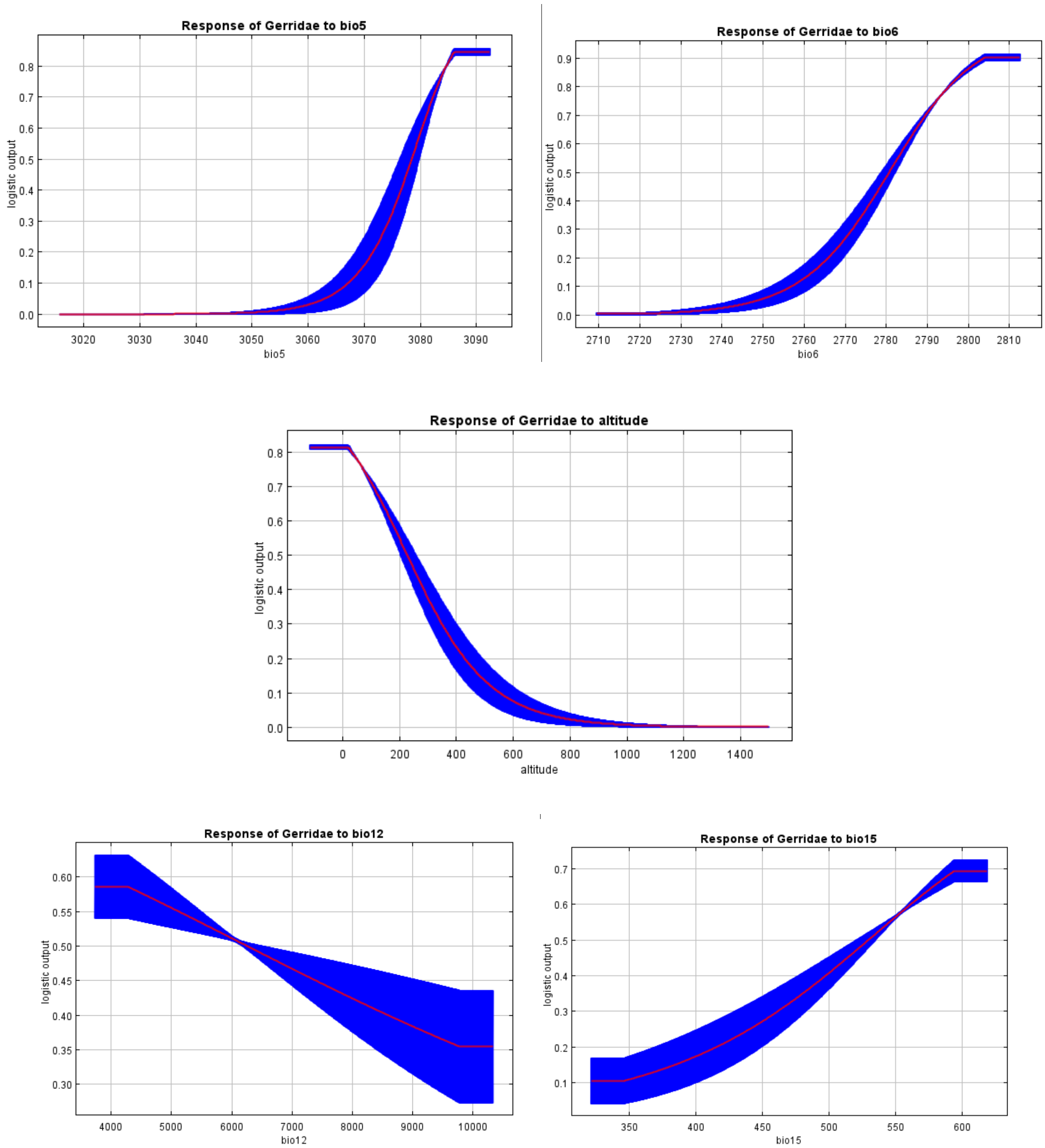


Figure 57: The ecological response of *Gerridae* to selected environmental gradients.

With a mean AUC of 0.947, the last model attained exceptional discriminating power. These findings show that the distribution of *Gerridae* in north-east Algeria is almost entirely limited by summer thermal maxima; altitude is a minor secondary factor, and precipitation variables are mainly useless.

The distribution of *Gerridae* shows that it colonises only six of the designated sites, which are Seybouse, Bouchegouf, and Ain Ben Baida river, Zimba, Bouhamdane, Salah Salah, and Echham streams, all with a small number of 14 individuals (Fig. 58).

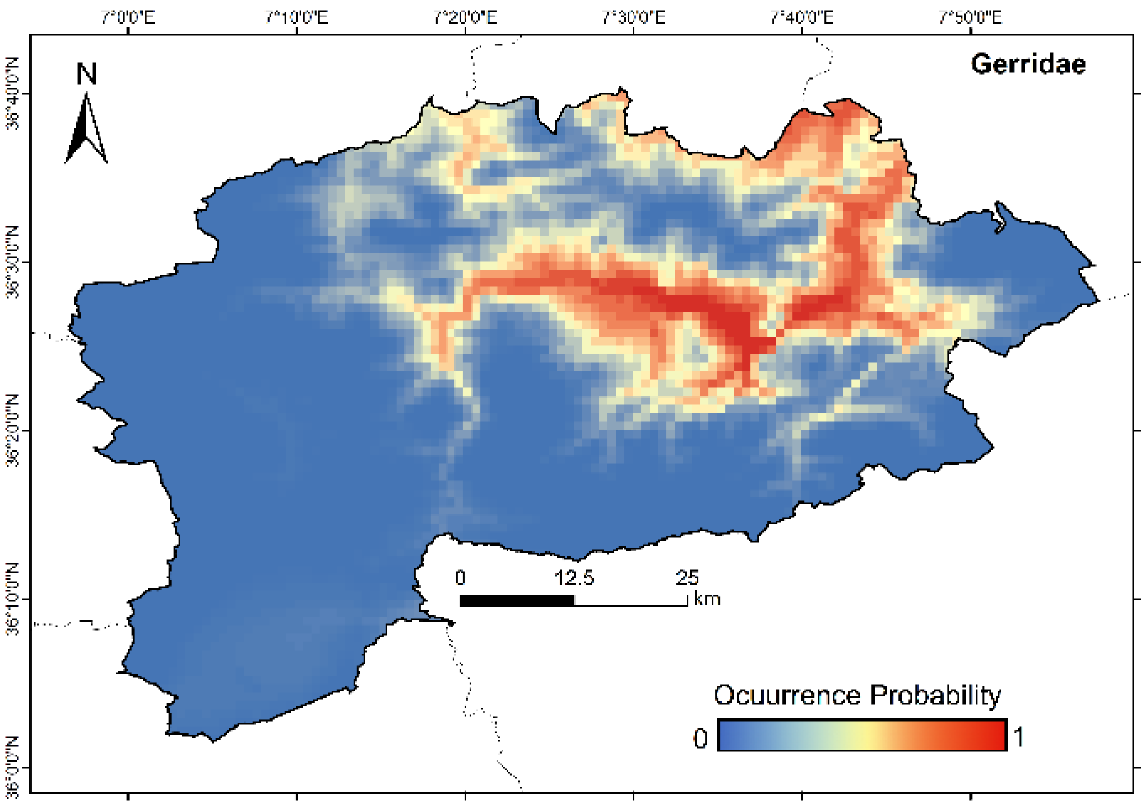


Figure 58: The geographical distribution of *Gerridae* in northeastern Algeria.

- ***Chironomidae :***

MaxEnt modeling of *Chironomidae* revealed that the maximum temperature of the warmest month (BIO5) drives habitat suitability most of the time (76.5% of permutation importance). This variable contributed 92.9% of the regularized training gain (Table 17).

Jackknife tests verified BIO5's central importance: used alone, it almost exactly replicated the full-model gain; absent, it resulted in the most performance loss. Between ~30.2 °C and ~30.9 °C, the response curve for BIO5 shows a steep logistic increase, followed by a plateauing indication of a clear thermal threshold for optimal conditions (Fig. 59).

Contributing 7.1% to gain and 20.7% of permutation importance, annual precipitation (BIO12) was the only secondary predictor of note. Its marginal response shows a consistent drop in suitability above about 6000 mm/year, implying that *Chironomidae* in Algeria prefer rather dry conditions.

Reflecting the family's lowland affinity, altitude had minimal direct influence (0.1% contribution; 2.8% permutation importance); suitability was highest near sea level and declined sharply above ~200 m. Each showing either flat or undifferentiated response curves, precipitation seasonality (BIO15) and the minimum temperature of the coldest month (BIO6) added no meaningful explanatory power (Fig. 60).

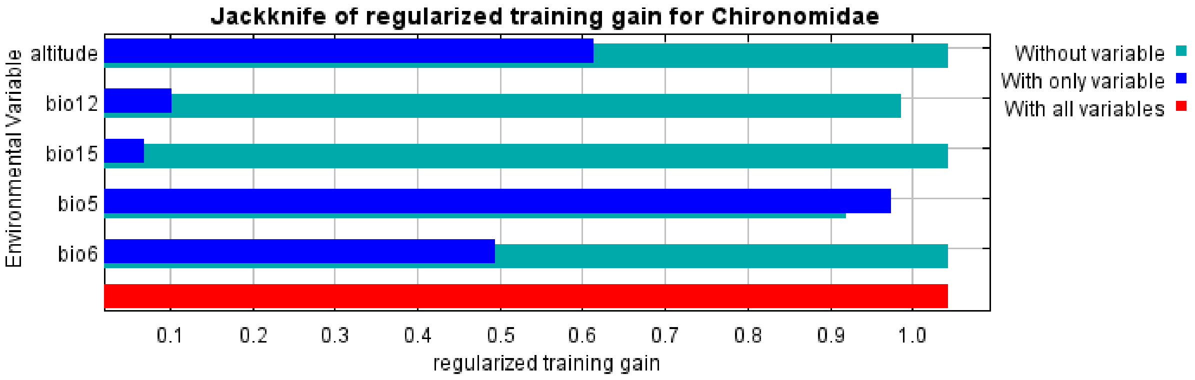


Figure 59: Jackknife test of regularized training gain for *Chironomidae*.

Table 17: The contribution of the different variables to the model gain representation of *Chironomidae*

Variable	Percent contribution	Permutation importance
bio5	92.9	76.5
bio12	7.1	20.7
altitude	0.1	2.8
bio15	0	0
bio6	0	0

.

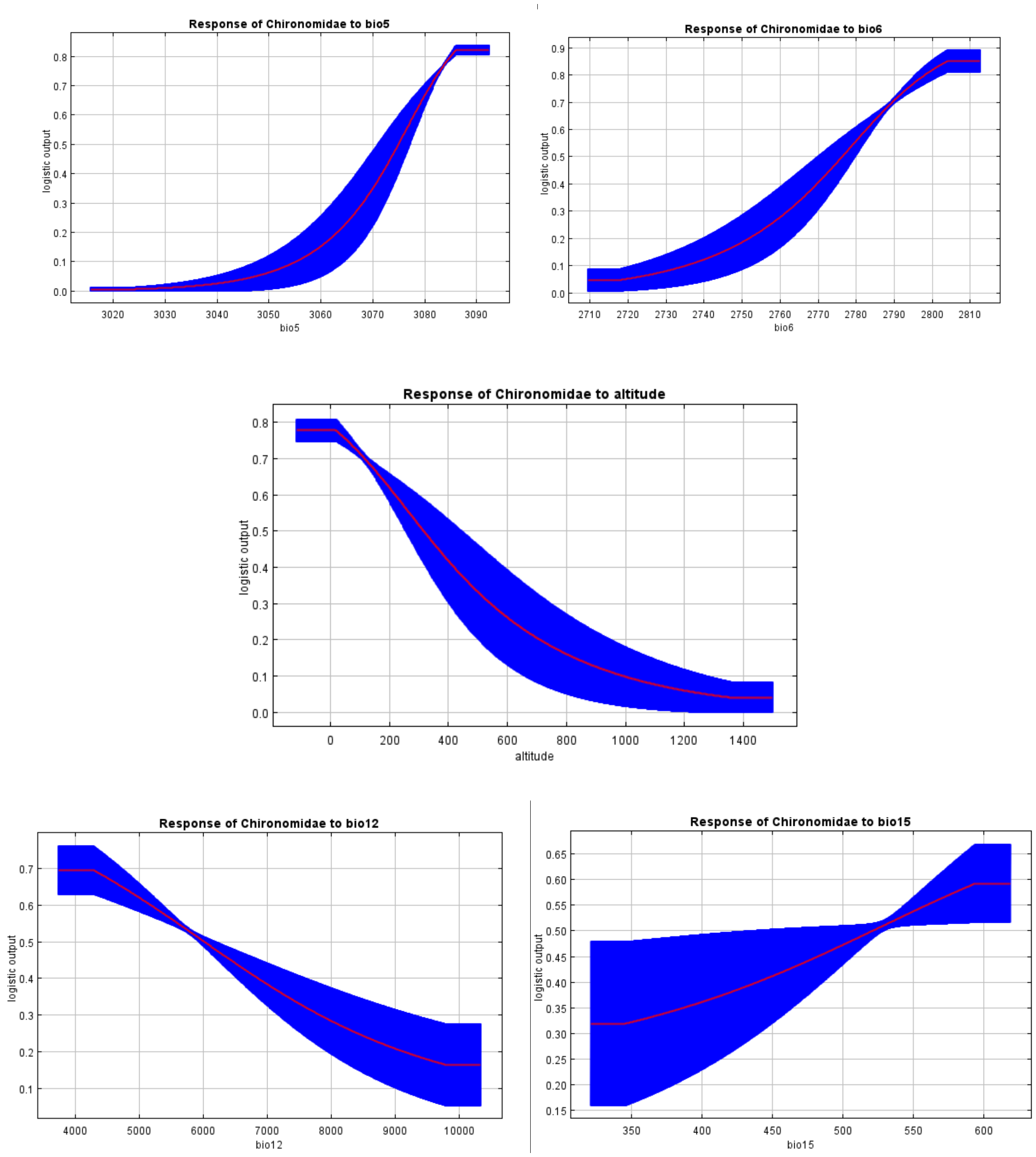


Figure 60: The ecological response of *Chironomidae* to selected environmental gradients.

With a mean AUC of 0.904, the model attained strong discriminating capability. With modest sensitivity to annual precipitation and little influence from elevation or other thermal variables, distributions in our study area are essentially limited by summer heat máxima.

This explains the presence of these taxa in all the sites we worked on, and this extremely wide distribution is illustrated by the map in (Fig.61); wich reflects its great tolerance of environmental changes and habitat disruption.

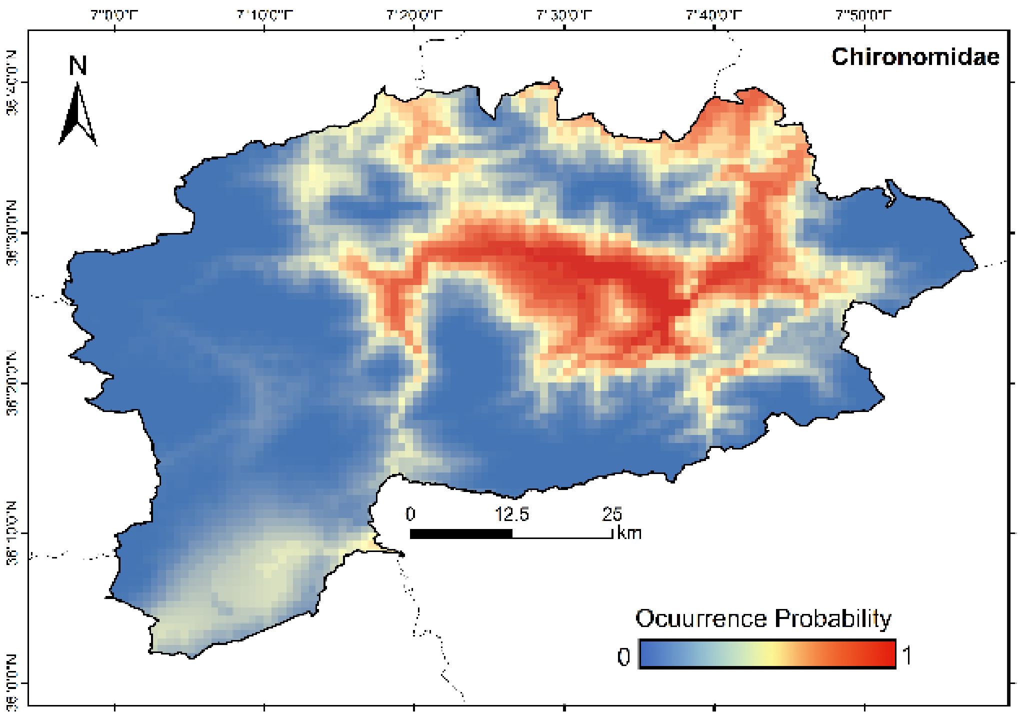


Figure 61: The geographical distribution of *Chironomidae* in northeastern Algeria.

- ***Baetidae :***

The modeling of *Baetidae* showed that habitat suitability is practically exclusively driven by the maximum temperature of the warmest month (BIO5), which contributed 95.2% of the regularized training gain and accounted for 86.2% of the permutation importance (Table 18). Jackknife studies verified BIO5's predominance: its absence resulted in the biggest performance drop, while used alone, it achieved almost the full-model gain. Between roughly 30.2 °C and 30.9 °C, the response curve for BIO5 shows a steep logistic increase, after which suitability plateaus, so indicating a clear thermal optimum (Fig. 62).

The only secondary predictor with a detectable influence (2.6% contribution; 3.3% permutation importance) was elevation. Reflecting *Baetidae*'s inclination for lowland aquatic environments, its marginal response shows the greatest fit at sea level, declining sharply above ~200 m and approaching zero at higher elevations.

Though modest permutation importances (4.7% and 4.6%), annual precipitation (BIO12) and the minimum temperature of the coldest month (BIO6) each made small contributions (1.2% and 0.9% of gain, respectively). With increasing rainfall above about 6000 mm/year, their response curves show slow declines in suitability; conversely, as winter minima rise, their suitability gently increases. With only a small upward trend in suitability at the highest seasonality values, precipitation seasonality (BIO15) was negligible (0.2% gain; 1.2% importance) (Fig. 63).

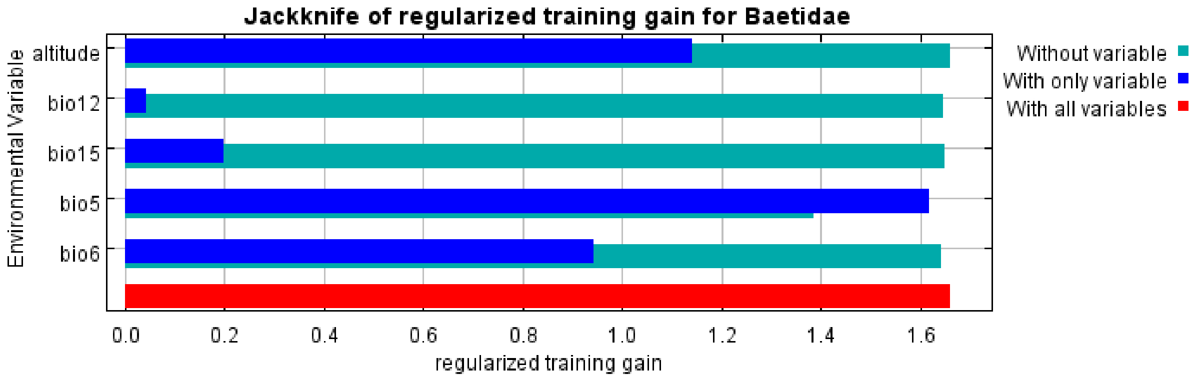


Figure 62: Jackknife test of regularized training gain for *Baetidae*.

Table 18: The contribution of the different variables to the model gain representation of *Baetidae.*

Variable	Percent contribution	Permutation importance
bio5	95.2	86.2
altitude	2.6	3.3
bio12	1.2	4.7
bio6	0.9	4.6
bio15	0.2	1.2

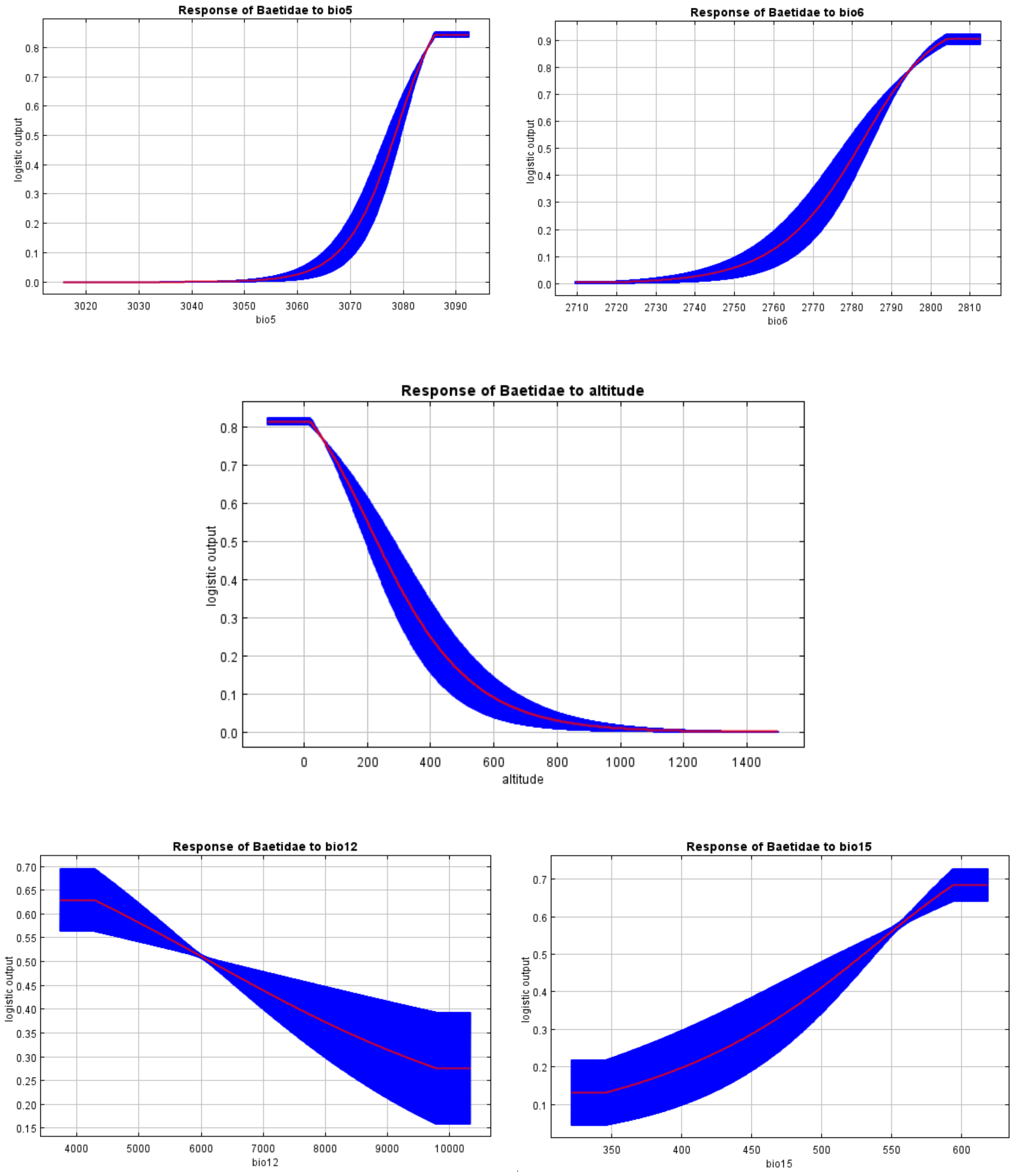


Figure 63: The ecological response of *Baetidae* to selected environmental gradients.

With a mean AUC of 0.542, the model's predictive accuracy highlights how mostly limited *Baetidae* distributions in the north-east of Algeria are by summer thermal maxima, with minor roles for elevation and precipitation variables.

As a result of this restriction, occurs in 8 different sites and disappears in the two dams in question, together with the Bou Sora and Hellia streams (Fig.64).

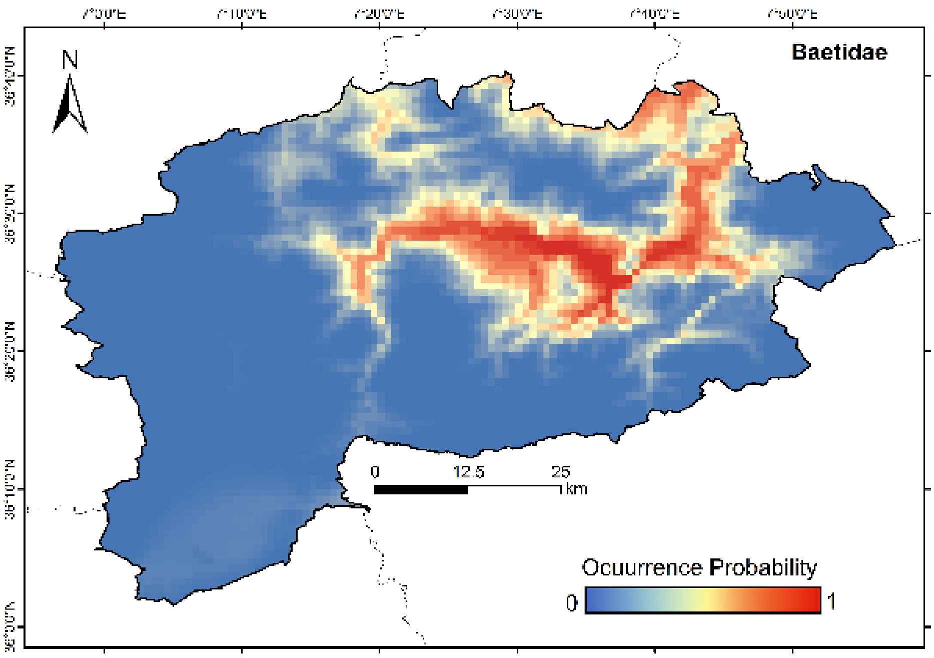


Figure 64: The geographical distribution of *Baetidae* in northeastern Algeria.

- ***Hydrophilidae:***

MaxEnt modeling of *Hydrophilidae* revealed that the maximum temperature of the warmest month (BIO5) was by far the most important predictor of habitat suitability, contributing 93.9% to the regularized training gain and accounting for 69.6% of the permutation importance (Table 19).

Jackknife tests confirmed its central role: BIO5 alone nearly matched the full model's gain, and its exclusion produced the greatest reduction in performance. The response curve displayed a steep logistic increase in suitability between ~30.2 °C and 30.9 °C, followed by a plateau, indicating a thermal optimum beyond which suitability levels off (Fig. 65).

Altitude emerged as the second most informative variable, with 2.1% contribution and 20.7% permutation importance. Its marginal response showed a clear negative relationship with suitability: habitat suitability was highest near sea level and declined consistently with increasing elevation, dropping sharply beyond 200 m. Annual precipitation (BIO12) showed moderate influence (3.5% contribution, 8.4% importance), with a response curve indicating a gradual decline in suitability as precipitation increases above ~6000 mm/year. Precipitation seasonality (BIO15) and minimum temperature of the coldest month (BIO6) contributed negligibly to model performance, despite response trends that suggested slight positive correlations with suitability (Fig. 66).

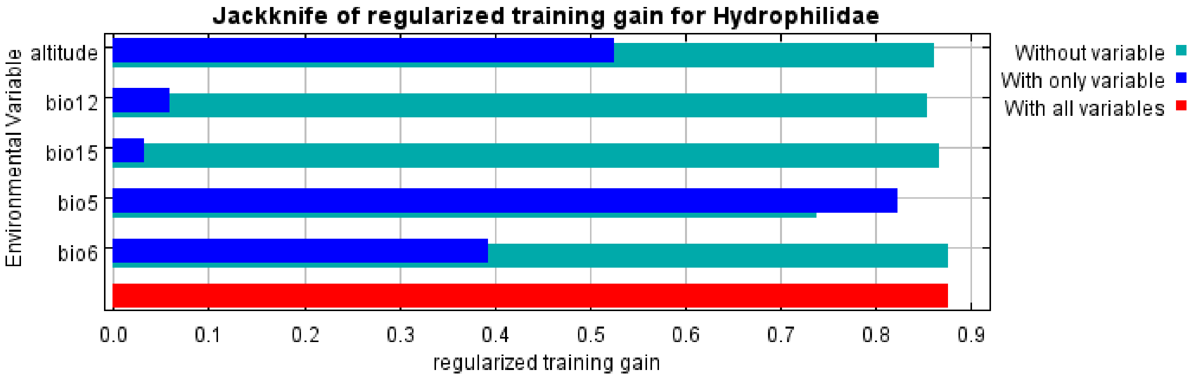
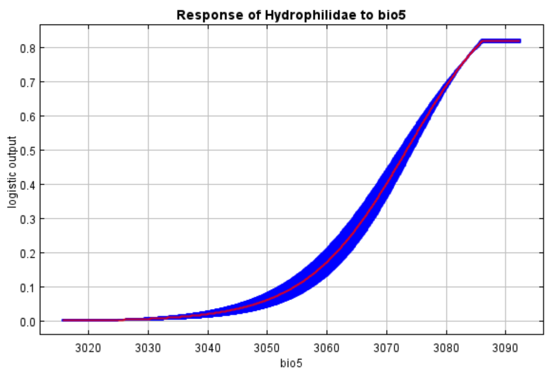
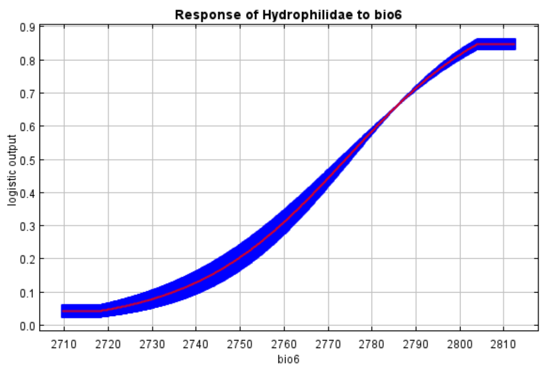


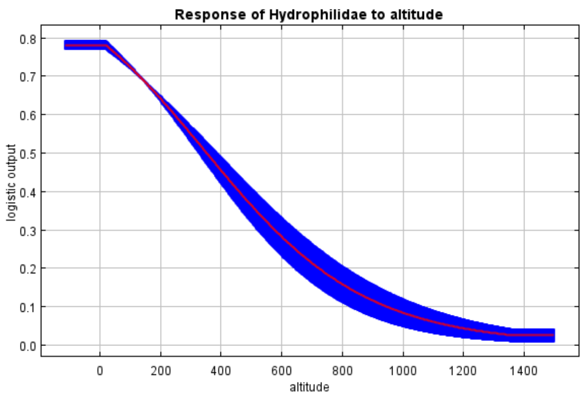
Figure 65: Jackknife test of regularized training gain for *Hydrophilidae*.

Table 19: The contribution of the different variables to the model gain representation of *Hydrophilidae*.

Variable	Percent contribution	Permutation importance
bio5	93.9	69.6
bio12	3.5	8.4
altitude	2.1	20.7
bio15	0.5	1.3
bio6	0	0







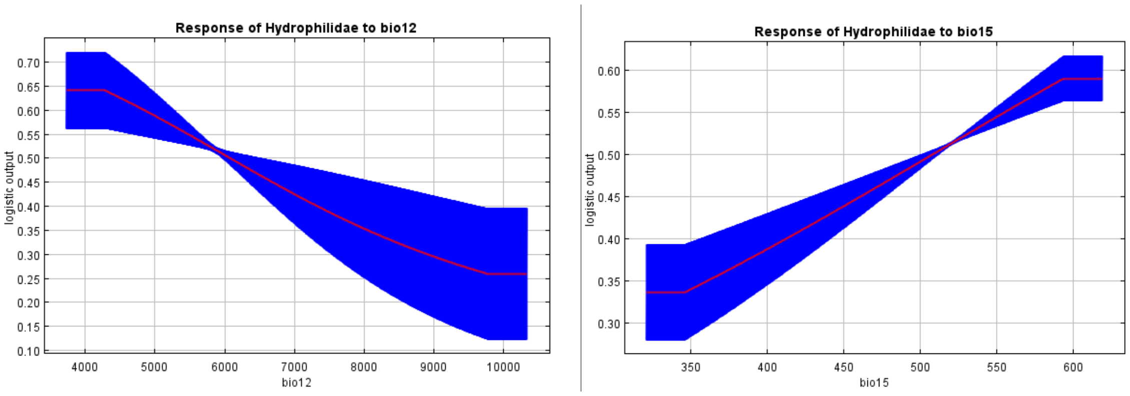


Figure 66: The ecological response of *Hydrophilidae* to selected environmental gradients.

The model's high predictive performance was supported by an AUC of 0.899, demonstrating excellent discrimination capacity. Overall, the distribution of *Hydrophilidae* in this area is primarily shaped by extreme summer temperatures and lowland topography, with minor influence from precipitation variables.

The limitation of the *Hydrophilidae* by the preceding factors leads to their distribution only in six sites and absence in the other six, which are Seybouse, El Fadjoudj and Ain Ben Baida river, Bou Sora, Zimba, Salah Salah Salah streams along with Medjaz el Bgare dam (Fig.67).

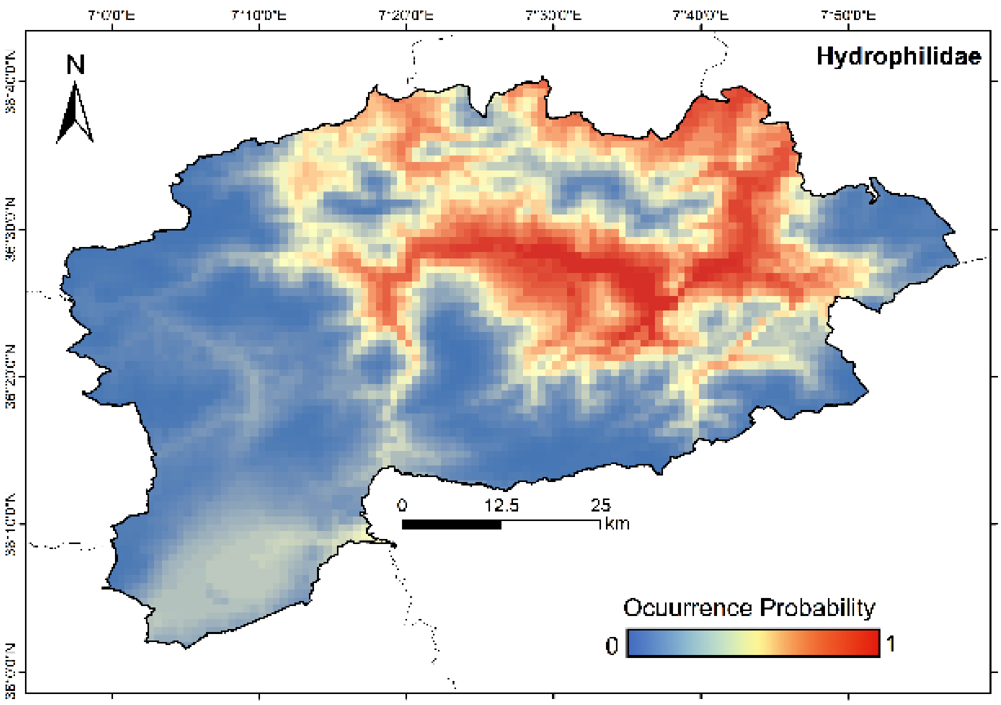


Figure 67: The geographical distribution of *Hydrophilidae* in northeastern Algeria.

3. The specific richness:

The species richness of aquatic macroinvertebrates closely reflects the ecological condition of watercourses due to their sensitivity to physico-chemical factors and habitat structure. It is influenced by water quality (dissolved oxygen, pH, nutrients), substrate type, flow speed, riparian vegetation, and seasonality (Wallace & Webster, 1996). High levels of species richness are generally associated with environments that are little disturbed, providing a diversity of microhabitats favourable to a variety of taxa such as *Ephemeroptera, Plecoptera,* and *Trichoptera,* which are recognised as bioindicators of good quality (Hynes, 1970). On the other hand, in polluted or homogenised environments, the richness of taxa decreases in favour of tolerant species such as *Chironomidae* or *Tubificidae* (Tachet *et al*., 2010). Regional studies, such as those carried out in Algeria by Benmoussa (2018), confirm this trend in the watercourses of the Seybouse basin, where high species richness was observed upstream and a clear decrease downstream, affected by agricultural and urban discharges. In our study, we employ the Figure 68 to illustrate the spatiotemporal evolution of macroinvertebrate richness in our research area. The peak in richness is recorded at the Seybouse el Fadjoudj river station in February and April, with 18 different taxa. In contrast, Zima stream shows a serious drop in diversity and number of individuals throughout the year, with only five taxa.

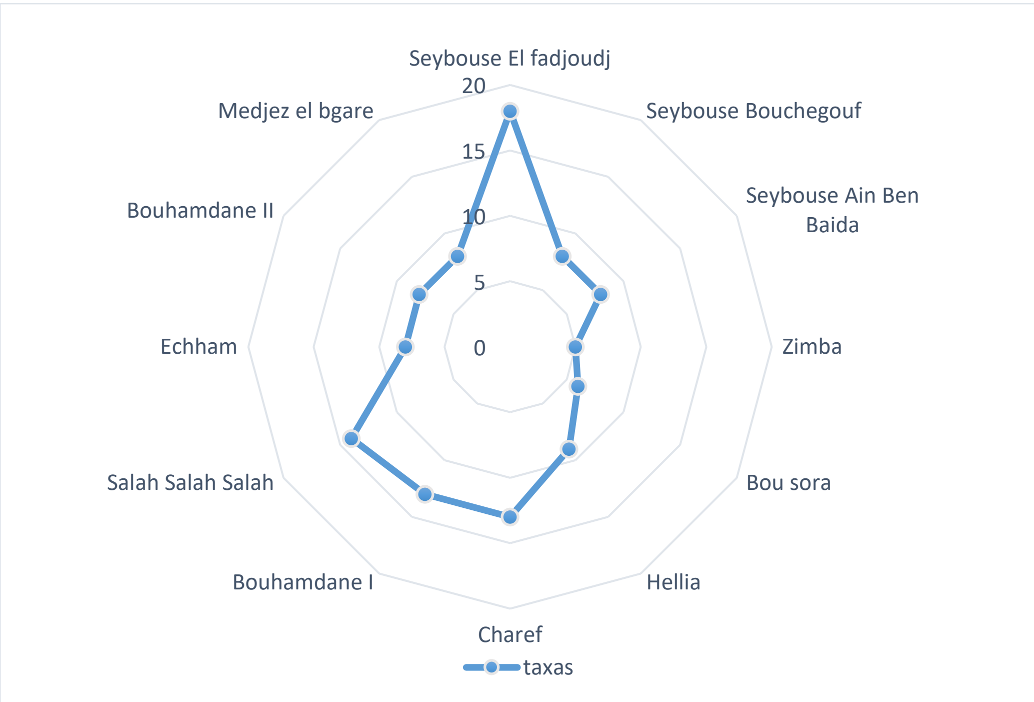


Figure 68: Evolution of species richness by location.

That summer, thermal maxima consistently dictated habitat suitability across north-eastern Algeria, with minor sensitivity to topographical conditions, reflected by elevation in our study, along with the previous results of the physicochemical parameter analysis. This led to the identification of hotspots around the suitable areas (**Seybouse El Fadjoudj River, Salah Salah stream, Charef stream, and Bouhamdane stream**).

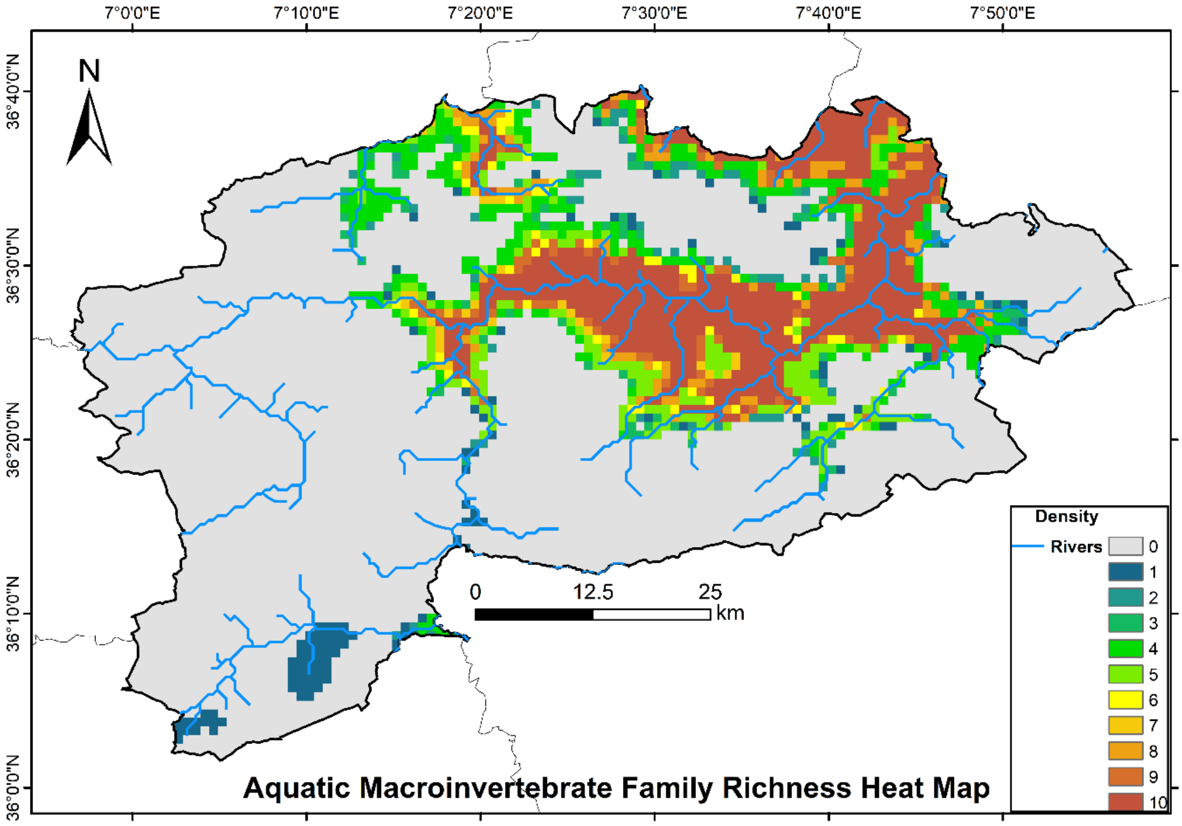


Figure 69: A heat map representing the distribution of specific richness in the study area.

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 [O2] 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 doesn´t allow the assessment of benthic invertebrates (De los Ríos-Escalante *et al*., 2020a). Whereas sites with low pH, low oxygen level [O2], 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 highest abundances were reported mainly between February to June, would corresponds to the Northern Hemisphere spring, would corresponds to the end of the 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, were reported for two sites of the 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 the river course, due to topographical conditions, whereas the conductivity varies along the river course due to variations in nutrients and mineral inputs from the 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).

The following of aquatic organisms that populate this region have different preferences and requirements with regard to various biotic and abiotic factors. When an environmental change occurs, it disturbs the communities that inhabit it, as demonstrated in the following studies: About the distribution of the fauna collected, there is very heterogeneous variability in the frequency of the collected macroinvertebrates, with *Chironomidae* occupying all the study sites, but with a wide distribution range and low abundance as a result of the constant change in the freshwater aquatic ecosystem (see the studies by Ferguani & Arab, 2013; Sellam *et al*., 2017; Pinder & Reiss, 1983; Jacobsen & Perry, 2007). However, other studies show that species respond to both natural and anthropogenic factors also influence the fauna. Hot, dry summers have a profound influence on the fauna's composition, with only a few species being tolerant, as demonstrated by Chaib *et al.,* 2011).

Moreover, the distribution of benthic macroinvertebrates is strongly determined by physico-chemical parameters, such as oxygen concentration and water depth (Rouibi *et al.,* 2021). (Kalogianni, 2017) states that pollution and water stress have a significant impact on species richness, abundance, and community structure (composition and organization) of macroinvertebrates. Furthermore, (Sabater *et al*.,2016), in their study, concluded that variations in physico-chemical stressors such as high levels of dissolved organic matter and nutrients, as well as changes in water flow exert a much stronger influence on the structure of macroinvertebrate communities than pollutants alone. However, in the presence of pollution, the effects of low flow are amplified. Freshwater ecosystems in northeastern Algeria are threatened by habitat degradation and pollution (Khedidja & Boudoukha, 2013; Foufou *et al.,*2017; Baaloudj *et al.,*2021).

Also the study reveals after the follow of relationship between the environmental conditions specialy the altitude and the distribution of the spicific richness along with the abundance of macroinvertebrates. That they classicly decreases from the high gound to the lew ones as it is mentioned in Ricardo *et al*., 2003; Rouibi *et al.,*2021. This effect that biotic and abiotic facors has on our colected fauna is close the the one in the spanish and Chilean (Boix *et al.,*2009; Ríos-Escalante *et al.,*2020; Vega *et al.,*2020; Barile *et al.,*2021). Also, The differens proved by the Permanova analysis and Niche sharing null models in our sites comparison is similar to the results marked by De los Ríos-Escalante *et al.,*2020 and Baaloudj *et al.,*2021.

The results on the analysis of benthic structure of macroinvertebrates community and there sensitivity to the pollution as well their reaction to the anthropogenic action specialy the *Hydropsychidae, Corixidae* and *Culicidae.* are close to those reported by Haouchine. 2011, Baaloudj *et al.,*2020, Rouibi *et al.,*2021, Khelifa *et al*.,2016, Khelifa *et al*.,2019, Zebsa *et al,* 2014, the general composition of the most specific richness in the est Algerian benthics is similar to many other Algerian and Moroccan rivers (Bagella *et al*.,2010; Baaloudj *et al.,*2020; Zouggaghe 2020; Rouibi *et al.,*2021).

Conclusion

Conclusion

Conclusion:

This study focused on the analysis of aquatic macroinvertebrates in northeastern Algeria, conducted between October 2020 and September 2021. A total of 12 sites were investigated, selected based on various criteria such as altitude, surrounding land use (ranging from agricultural to industrial zones), and proximity to urban areas. Throughout the study, we collected 6,222 individuals belonging to 25 taxa. The distribution of individuals varied considerably across sites, with the highest abundance recorded at Salah Salah (1,366 individuals; 22%) and the lowest at Zimba Stream (139 individuals; 2%).

The analysis of abiotic parameters revealed relatively moderate values for most environmental variables across ten sites (including three along the Seybouse River, five streams, and two reservoirs). However, two sites exhibited distinct characteristics: Boudhame Stream, with high water depth, flow velocity, dissolved oxygen, and conductivity; and Salah Salah Stream, with elevated conductivity, flow velocity, nitrite concentration, pH, and salinity.

The temporal evolution of macroinvertebrate abundance showed a significant presence at the study sites. Corixidae emerged as the most abundant taxon (1,358 individuals), followed by Gammaridae (2,009 individuals), with peak abundance observed from February to June. Chironomidae were present at all sites, highlighting their high tolerance to environmental variation and habitat disturbance.

The results also revealed pronounced differences in community structure across the sites, both in terms of species diversity and dominance. These differences are likely attributed to strong geographical isolation, environmental heterogeneity, and spatial variation within the same water body for example, along the course of the same river (Boix *et al.*, 2009; Figueroa *et al.*, 2003, 2007, 2013; De los Ríos-Escalante *et al.*, 2020a; Vega *et al.*, 2020; Baaloudj *et al.*, 2020; Barile *et al.*, 2021; Figueroa & De los Ríos-Escalante, 2021; Chaib *et al.*, 2023).

Species richness across aquatic ecosystems in northeastern Algeria showed considerable variability from one site to another, with notable heterogeneity observed. The study allowed us to identify biodiversity hotspots in the region, particularly the El Fadjoudj River (18 taxa), Salah Salah (14 taxa), and Bouhamdane and Charef (13 taxa each).

Conclusion

Overall, this research highlights the spatial and temporal dynamics of aquatic macroinvertebrate communities in relation to abiotic factors in northeastern Algerian water bodies. It also provides a valuable assessment of the ecological quality of the region's freshwater ecosystems. Nevertheless, further ecological investigations are recommended to better understand the functional roles of these ecosystems within the Algerian context.

References

REFERENCES

1. ALLAN, J. D., & CASTILLO, M. M. (2007). Stream Ecology: Structure and Function of Running Waters (2nd ed.). Springer.and future challenges. Journal of the North American Benthological Society, 29(1), 344-358.
2. BAALOUDJ, A., (2019). Emergence ecology of the critically endangered Urothemis edwardsii in a new colonized site in El Kala National Park (Algeria): conservation implications. Zoology and Ecology, vol. 29, no. 2, pp. 137-142.
3. BAALOUDJ, A., DE LOS RÍOS-ESCALANTE, P.R. and ESSE, C., (2022.) Benthic community ecology for Algerian river Seybouse. Brazilian Journal of Biology = Revista Brasileira de Biologia, vol. 84, e251566. http://dx.doi.org/10.1590/1519-6984.251566. PMid:35019090.
4. BAALOUDj, A., (2019) Emergence ecology of the critically endangered Urothemis edwardsii in a new colonized site in El Kala National Park (Algeria): conservation implications, https://doi.org/10.35513/21658005.2019.2.10 .
5. BAALOUDJ, A., OUARAB, S., KERFOUF, A., BOURIACH, M., HUSSEIN, A., HAMMANA, A.C. and DJENEBA, H.N., (2020). Use of macroinvertebrates to assess the quality of Seybouse River (North-East of Algeria). Ukrainian Journal of Ecology, vol. 10, no. 4, pp. 60-66. http://dx.doi.org/10.15421/2020_168.
6. BAGELLA, S., CARIA, M.C. and ZUCCARELLO, V., (2010). Patterns of emblematic habitat types in Mediterranean temporary wetlands. Comptes Rendus Biology, vol. 333, no. 9, pp. 694-700. http://dx.doi.org/10.1016/j.crvi.2010.06.006. PMid:20816650.
7. BARBOUR, M. T., GERRITSEN, J., SNYDER, B. D., & STRIBLING, J. B. (1999). Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers. U.S. EPA.
8. BARILE, J., VEGA, R. and DE LOS RIOS-ESCALANTE, P., (2021). First report the role of benthic macroinvertebrates as preys for native fish in Toltén river (38° S, Araucania region Chile). Brazilian Journal of Biology = Revista Brasileira de Biologia, vol. 81, no. 3, pp. 845-853. http://dx.doi.org/10.1590/1519-6984.232661. PMid:32965340.
9. BEAK, W. T., GRIFFING, C. T. and AMP; A. G. APPLEBY., (1973) Use ofartificial substrate samplers to assess water pollution. Biological Methods for the assessment of water quality, ATSM STP 528, American Society for testing and materials, pp. 227-241.
10. BEBBA, N. (2017). Impact des paramètres environnementaux et distribution spatio-temporelle des éphéméroptères dans les oueds de biskra et batna. doctoral Thesis, University of Ferhat Abbas, setif 1. 198p.
11. BECHAA T., DAHMANI K., ALKAMA D., DECHAICHA A., (2024) The Role and Impact of Vegetation on the Urban Fabric. Case of Guelma City. International Journal of Innovative Technologies in Social Science.

12. BEKHOUCHE, N., F. MARNICHE, and A. OULDJAOUI, (2017). Contribution to the study of the biodiversity of benthic invertebrates and the biological quality of some rivers in the watershed Boumerzoug (east of Algeria). Journal of Fundamental and Applied Sciences 9 (1): 234–260. http://dx.doi.org/10.4314/jfas.v9i1.16.

13. BELALA S. ,(2022), Recherches hydrobiologiques sur l'Oued Youkous (Tébessa Est d'Algérie) « Bioécologiedes macro-invertébrés et distribution spatiale des peuplements » ; doctoral Thesis; Oum El bouaghi.
14. BELHADJ TAHAR, K., BAALOUDJ, A., KERFOUF, A., BENALLAL, M.A., & DENIS, F., (2017). Macrobenthic fauna of the coastal seabeds of Oran's Gulf (Western Algeria). Ukrainia Journal of Ecology, 11(4), 1–4.
15. BELHADJ, M. (2017). Évaluation de la qualité écologique de l'oued Bou Sora à l'aide des macroinvertébrés benthiques., University of Frères Mentouri Constantine 1. university Thesis
16. BELMAR, O., BRUNO, D., MARTINEZ-CAPEL, F., BARQUIN, J. & VELASCO, J. (2013). Effects of flow regime alteration on fluvial habitats and riparian quality in a semiarid Mediterranean basin. Ecological Indicators, 30, 52-64.
17. BENMOUSSA, H., DERRADJI, F., & KEBICHE-SENHADJI, O. (2021). Assessment of physico-chemical and bacteriological water quality in the Bounamoussa River, northeastern Algeria. Applied Water Science, 11, DOI: 10.1007/s13201-020-01331-4.
18. BENNAS, N., DAKKI, M., & TAYBI, A. F. (2013). L'influence des facteurs environnementaux sur la distribution des macroinvertébrés benthiques dans les zones humides du nord du Maroc. Bulletin of the Scientific Institute, Rabat, life Sciences section de la Vie, 35, 1–9.
19. BLAYAC J., (1912). Esquisse Géologique du Bassin de la Seybouse et de quelques régionsvoisines.- Géological maps and cross-sections . 491pages.
20. BLAYAC J., (1912), Esquisse Géologique du Bassin de la Seybouse et de quelques régions voisines. Géological maps and cross-sections, 491.
21. BOIX, D., SALA, J., GASCON, S., RUHI, A. and QUINTANA, X.D., 2009. Structure of invertebrate assemblages' contribution to the ecological functioning of the Mediterranean temporary ponds. In: P. FRAGA and I. ARGUIMBAU, eds. International Conference on Mediterranean Temporary Ponds. Maó, Menorca, Spain: Consell Insular de Menorca, pp. 153-189.
22. BONADA, N., PRAT, N., RESH, V. H., & STATZNER, B. (2006). Developments in aquatic insect biomonitoring: a comparative analysis of recent approaches. Annual Review of Entomology, 51, 495–523.
23. BONADA, N., PRAT, N., RESH, V. H., & STATZNER, B. (2006). Developments in aquatic insect biomonitoring: A comparative analysis of recent approaches. Annual Review of Entomology, 51, 495–523. https://doi.org/10.1146/annurev.ento.51.110104.151124
24. BORJA, Á., DAUER, D. M., ELLIOTT, M. & SIMENSTAD, C. A. (2010). Medium- and long-term recovery of estuarine and coastal ecosystems: patterns, rates and restoration effectiveness. Estuaries and Coasts, 33(6), 1249-1260.
25. BOUALI, N., BAALOUDJ, A., TOUARFIA, M., HOUHAMDI, I., MAAZI, M. C., HOUHAMDI, M., (2021). Ecology, phenology and wintering behavior of Anatidae in the wetlands of Souk–Ahras (north–eastern Algeria). Arxius de Miscel·lània Zoològica, 19: 135–149, Doi: https://doi.org/10.32800/amz.2021.19.0135 .
26. BOUALI, N., BAALOUDJ, A., TOUARFIA, M., HOUHAMDI, I., MAAZI, M.C. and HOUHAMDI, M., 2021. Ecology, phenology and wintering behavior of Anatidae in the wetlands of Souk-Ahras (north- eastern Algeria). Arxius de Miscel.Lania Zoologica, vol. 19, no. 2, pp. 135-149. http://dx.doi.org/10.32800/amz.2021.19.0135.

REFERENCES

27. BOUCENNA H.(2023). Les macroinvertébrés benthiques de la région de Collo. doctoral Thesis, University of 8 Mai 1945, Guelma.
28. BOUCHARD, R. W. (2004). Guide to aquatic macroinvertebrates of the Upper Midwest. Water Resources Center, University of Minnesota.
29. BOUHALA, Z. (2020). Contribution à l´ étude des macroinvertébrés de Oued Charef (Oued Seybousse). doctoral Thesis, University of Badji Mokhtar, Annaba. 167p.
30. BOURAS, D., & BOUTIBA, Z. (2017). Impact de la turbidité sur la qualité des eaux du littoral ouest-algérien et ses effets sur la faune aquatique. African Journal of Environmental Science and Technology, 11(8), 410–418.
31. CAIRNS, J., & J., R PRATT., (1993). A history of biological monitoring using benthic macroinvertebrates. Dans: Rosenberg, D.M. et V.H.Resh., (1993) Freshwater Biomonitoring and benthic Macroinvertebrates. Kluwer Academic Publishers.
32. CALLISTO, M., MORENO, P. ET BARBOSA, F. 2001. Habitat diversity and benthic functional trophic groups at Serra do Cipó, Southeast Brazil. Revista Brasileira de Biologia, 61, 259-266.
33. CAMARGO, J. A., & ALONSO, Á. (2006). Ecological and toxicological effects of inorganic nitrogen pollution in aquatic ecosystems: A global assessment. Environment International, 32(6), 831–849. https://doi.org/10.1016/j.envint.2006.05.002
34. CAMARGO, J.A, ALONSO, A ET DE LA PUENTE, M, (2004): Multimetric assessment of nutrient enrichment in impounded rivers based on benthic macroinvertebrates. Environmental Monitoring and Publishers, 96 :233-249.
35. CARVAJAL-QUINTERO, J.D., ESCOBAR, F., ALVARADO, F., VILLA-NAVARRO, F.A., JARAMILLO-VILLA, U. and MALDONADO- OCAMPO, J.A., (2015). Variation in freshwater fish assemblages along a regional elevation gradient in the northern Andes, Colombia. Ecology and Evolution, vol. 5, no. 13, pp. 2608-2620. http://dx.doi.org/10.1002/ece3.1539. PMid:26257874.
36. CHAIB, N. B. SAMRAOUI, MARZIALI, L. ET ROSSARO, B. (2011). «Chironomid taxocenosis in a South Mediterranean wadi, the Kebir-East (Algeria) ». studi trentini di scienze naturali. 88:61-75.
37. CHAIB, S., BAALOUDJ, A., DE LOS RÍOS-ESCALANTE, P., ESSE, C., GHARBI, M. and HOUHAMDI, M., 2023. Ecological structure of aquatic macroinvertebrate communities in the Hauts Plateaux of Northeast Algeria. Brazilian Journal of Biology = Revista Brasileira de Biologia, vol. 83, e273010. http://dx.doi. org/10.1590/1519-6984.273010. PMid:37585930.
38. CHERAIRIA M., (2015), Contribution à l'Etude des Simuliidae de l'Est Algérien: Systématique, Ecologie et Caryologie, doctoral Thesis, GUELMA.
39. CHESSMAN, B.C, (1995): Rapid assessment of rivers using macroinvertebrates: A procedure based on habitat-specific sampling, family level identification and biotic index Australian journal of ecology.20:122-129.
40. CHIROUF MED AMINE, MOUMENE MADANI, (2015), étude écologique des macros invertébrés d'oued Hellia, University of 8 Mai 1945, Guelma.
41. CUMMINS, K. W. & KLUG, M. J. (1979). Feeding ecology of stream invertebrates. Annual review of ecology and systematics, 10(1), 147-172.
42. CUMMINS, K. W., & KLUG, M. J. (1979). Feeding ecology of stream invertebrates. Annual Review of Ecology and Systematics, 10, 147–172. (Scientific article)
43. DAJOZ R., (1985). Précis d'écologie Ed. Dunod, Paris : 489 p
44. DAJOZ, R. (2000). Précis d'écologie. Dunod: Paris. 165p.

45. DAJOZ, R. 1975. Précis d'écologie Ed. Bordas, Paris : 549 p.
46. DAMBRI B.; (2021) ; macroinvertebrates of the western Aures massif : Taxonomy ; ecology and conservation ; doctoral Thesis; Guelma.
47. DE LOS RIOS-ESCALANTE, P., ESSE, C., SANTANDER-MASSA, R., SAAVEDRA, P. and ENCINA-MONTOYA, F., 2020a. Benthic macroinvertebrate communities in sites with native forest presence and absence in north Patagonia. Iheringia. Série Zoologia, vol. 110, e2020014. http://dx.doi.org/10.1590/1678-4766e2020014.
48. DE LOS RÍOS-ESCALANTE, P.R., CONTRERAS, A., LARA, G., LATSAGUE, M. and ESSE, C., (2020)b. First reports of associations between spectral properties, chlorophyll, bacterial and zooplankton in two Chilean north Patagonian lakes (Villarrica and Caburgua, 38 S, Araucania region, Chile). Journal of King Saud University. Science, vol. 32, no. 7, pp. 3167-3173. http://dx.doi.org/10.1016/j.jksus.2020.09.003.
49. DEBEICHE, T-H. (2002). Evolution de la qualité des eaux (salinité, azote et métaux lourds) sous l'effet de la pollution saline, agricole et industrielle. Application a la basse plaine de la Seybouse – Nord-est Algérien. Thesis Doctoral. University of Constantine.
50. DESCROIX L., VIRAMONTES D., VAUCLIN M., BARRIOS J.G., & ESTEVES M. (2001). Influence of soil surface features and vegetation on runoff and erosion in the Western Sierra Madre (Durango, Northwest Mexico). Catena, 43(2): 115-35.
51. DIAZ, R. J., & ROSENBERG, R. (2008). Spreading dead zones and consequences for marine ecosystems. Science, 321(5891), 926–929. https://doi.org/10.1126/science.1156401
52. DUDGEON, D., ARTHINGTON, A. H., GESSNER, M. O., KAWABATA, Z.-I., KNOWLER, D. J., Lévêque, C. & Stiassny, M. L. (2006). Freshwater biodiversity: importance, threats, status and conservation challenges. Biological reviews, 81(2), 163-182.
53. FERGANI, H. ET A. ARAB.(2013). « Utilisation des macro-invertébrés benthiques comme bio indicateurs de pollution d'oued El Harrach ». in USTHB-FBS-4th international Congress of the populations & Animal communities.«CIPCA4» TACHIT (Bechar)- ALGERIA.
54. FERGUANI, H. and ARAB, A., (2013). Utilisation des macroinvertébrés benthiques comme bioindicateurs de pollution d'Oued El Harrach [Use of macroinvertebrates as bioindicators of water pollution in El Harrach Stream]. In: 4th International Congress on Animal Populations and Communities , 2013, Taghit, Algeria. Taghit: International Communications, pp. 205-212.
55. FIGUEROA, D. and DE LOS RIOS-ESCALANTE, P., 2021. Macrozoobenthos in an altitudinal gradient in North Patagonian Cautin river (Araucania Region, Chile). Brazilian Journal of Biology = Revista Brasileira de Biologia, vol. 82, e240484. http://dx.doi. org/10.1590/1519-6984.240484. PMid:34105648.
56. FIGUEROA, R., BONADA, N., GUEVARA, M., PEDREROS, P., CORREA-ARANEDA, F., DIAZ, M.E. and RUIZ, V.H., 2013. Freshwater biodiversity and conservation in Mediterranean climate streams of Chile. Hydrobiologia, vol. 719, no. 1, pp. 269-289. http://dx.doi.org/10.1007/s10750-013-1685-4.
57. FIGUEROA, R., PALMA, A., RUIZ, V. and NIELL, X., 2007. Análisis comparativo de índices bióticos utilizados en la evaluación de la calidad de aguas en un río

mediterráneo de Chile, río Chillán, VIII región. Revista Chilena de Historia Natural, vol. 80, no. 2, pp. 225-242. http://dx.doi.org/10.4067/S0716- 078X2007000200008.

58. FIGUEROA, R., VALDOVINOS, C., ARAYA, E. and PARRA, O., 2003.Macroinvertebrados bentónicos como indicadores de calidad de agua de ríos del sur de Chile. Revista Chilena de Historia Natural, vol. 76, no. 2, pp. 275-285. http://dx.doi.org/10.4067/ S0716-078X2003000200012.
59. FLORIAN A. HARVEY, E., (2019). Regulation of the functional structure of aquatic communities across spatial scales in a major river network. Ecology, 100(2), e02590.https://doi.org/10.1002/ecy.2590.
60. FLORIAN V., (2019), Fonctionnement et structure des écosystèmes aquatiques en réponse aux perturbations anthropiques de type bottom-up et top-down. Ecologie, Environnement. Sorbonne University. Français. NNT : https://theses.hal.science/tel-03004766.
61. FOUFOU, A., DJORFI, S., HAIED, N., KECHICHED, R., AZLAOUI, M., & HANI, A. (2017). Water pollution diagnosis and risk assessment of Wadi Zied plain aquifer caused by the leachates of Annaba landfill (NE Algeria). Energy Procedia, 119, 393-406.
62. GAGNON E. ET PEDNEAU J.,(2006) .Sur Vol Benthose, guide du volontaire, programme de surveillance volontaire des petits cours d'eau. Edition CVRB. Québec. Canada.
63. GHACHI A., (1986). Hydrologie et utilisation de la ressource en eau en Algérie : le bassin de la Seybouse, Algiers, O.P.U,
64. GOTELLI, N.J. and ELLISON, A.M., (2013)[viewed 6 January 2022]. EcoSimR 1.00 [online]. Available from: http://www.uvm. edu/~ngotelli/EcoSim/EcoSim.html
65. GOTELLI, N.J. and ENTSMINGER, G.L.,(2007)([viewed 6 January 2022]. EcoSim: null models software for ecology (version 7) [online]. Available from: http://www.garyentsminger.com/ecosim
66. GOTELLI, N.J.,(2000). Null model analysis of species co-occurrence patterns. Ecology, vol. 81, no. 9, pp. 2606-2621. http://dx.doi. org/10.1890/0012-9658(2000)081[2606:NMAOSC]2.0.CO;2.
67. GREENHLG, M. and OVENDEN, D., (2009)(. Guide de la vie des eaux douces: les plakntes, les animaux, les empreintes. Paris: Delachaux et Niestié. (in French).
68. Hamzaoui, D. (2015). Étude de la répartition des macroinvertébrés benthiques de l'oued Saoura (Béchar). doctoral Thesis, University of USTHB, Algiers.117p.
69. HAOUCHINE, S., 2011. Recherches sur la faunistique et l'écologie des macroinvertébrés descours d'eau de Kabylie [Research on the faunistic quality and the ecology of benthic macroinvertebrates of Kabylie rivers]. Algeria : University of Mouloud Maameri de Tizi Ouzou. Doctoral thesis in Biological Sciences. http://dx.doi.org/10.3390/insects12040353. PMid:33920977
70. Hershey, E. A. & G, A. Lamberti., (2001) Aquatic insect ecology. Dans: Ecology and classification of North America freshwater invertebrates, second edition. Academic Press. Thorp, H.I & A.P. Covish, Ed.
71. HOUHAMDI, M., 2014b. Emergence pattern, site selection, and seasonal regulation of Onychogomphus costae Selys, 1885 (Odonata: Gomphidae) in northeastern Algeria. Aquatic Insects, vol. 36, no. 3-4, pp. 257-265. http://dx.doi.org/10.1080/01650424.2015.1087574

72. HUSSAIN, Q. A., & PANDIT, A. K. (2012). Macroinvertebrates in streams: A review of some ecological factors. International Journal of Fisheries and Aquaculture, 4(7), 114-123.
73. HYNES, H. B. N. (1970). The Ecology of Running Waters. University of Toronto Press.
74. JACOBI, C. M., & VANNOTE, R. L. (1990). Temperature-mediated life histories in aquatic insects: implications for community structure. Journal of the North American Benthological Society, 9(4), 217–229.
75. JACOBSEN, R. E. ET SUE A. PERRY. 2007. « Polypedilum nubifer, a chironomid midge (Diptera: Chironomidae) new to Florida that has nuisance potential ». Florida Entomologist 90(1):264–267.
76. KABORE, I., OUEDRAOGO, I., TAMPO, L., OUEDA, A., MOOG, O., GUENDA, W. ET MELCHER, A. H. 2016. Composition and dynamic of benthic macroinvertebrates community in semiarid area rivers of Burkina Faso (West Africa). International Journal of Biological and Chemical Sciences, 10, 1542-1561.
77. KALOGIANNI, E., VOURKA, A., KARAOUZAS, I., VARDAKAS, L., LASCHOU, S., & SKOULIKIDIS, N. T. (2017). Combined effects of water stress and pollution on macroinvertebrate and fish assemblages in a Mediterranean intermittent river. Science of the Total Environment, 603, 639-650.
78. KARGER, D. N., CONRAD, O., BÖHNER, J., KAWOHL, T., KREFT, H., SORIA-AUZA, R. W., ... & ZIMMERMANN, N. E. (2017). Climatologies at high resolution for the earth's land surface areas. Scientific Data, 4, 170122. https://doi.org/10.1038/sdata.2017.122
79. KEFFORD, B. J., PAPAS, P. J., METZELING, L., & NUGEGODA, D. (2004). Do laboratory salinity tolerances of freshwater animals correspond with their field salinity?. Environmental Pollution, 129(3), 355–362. https://doi.org/10.1016/j.envpol.2003.10.010.
80. KHEDIDJA, A., & BOUDOUKHA, A. (2013). Anthropogenic impact conditions on water quality in the alluvial aquifer of the region tadjenanet-chelghoum laid (eastern algeria). European Scientific Journal, 9(21).
81. KHELIFA, R. (2016). A hotspot for threatened Mediterranean odonates in the Seybouse River (Northeast Algeria): Are IUCN population sizes drastically underestimated?. Int. J. Odonatol. 19, 1–11. https://doi.org/10.1080/13887890.2015.1133331.
82. KHELIFA, R., MAHDJOUB, H., BAALOUDJ, A., CANNINGS, R.A. and SAMWAYS, M.J.,(2021)a. Remarkable population resilience in a North African endemic damselfly in the face of rapid agricultural transformation. Insects, vol. 12, no. 4, pp. 353. http://dx.doi. org/10.3390/insects12040353. PMid:33920977.
83. KHELIFA, R., MAHDJOUB, H., BAALOUDJ, A., CANNINGS, R.A. and SAMWAYS, M.J., 2021b. Effects of both climate change and human water demand on a highly threatened damselfly. Scientific Reports, vol. 11, no. 1, pp. 7725. http://dx.doi.org/10.1038/ s41598-021-86383-z. PMid:33833264.
84. KHELIFA, R., ZEBSA, R., AMARI, H., MELLAL, M.K., MAHDJOUB, H. and KAHALERRAS, A.,(2016). A hotspot for threatened Mediterranean odonates in the Seybouse River (Northeast Algeria): are IUCN population sizes drastically underestimated? International Journal of Odonatology, vol. 19, no. 1-2, pp. 1-11. http://dx.doi.org/10.1080/13887890.2015.1133331.

85. LAKE, P. S. (2003). Ecological effects of perturbation by drought in flowing waters. Freshwater Biology, 48(7), 1161–1172.
86. LAZRI M., AMEUR S., & HADDAD B. (2007). Analyse de données de précipitations par approche markovienne. LARHYSS Journal, 9782(6): 7-20.
87. LEGENDRE, P. and LEGENDRE, L., 1998. Numerical ecology. 2nd ed. Amsterdam: Elsevier, 990p.
88. LERAUT, P. (2003). Le Guide entomologique. Plus de 1 000 espèces européennes. Editions Delachaux et Niestlé. 44- Satour Abdellatif (2025), Les macroinvertébrés des Hauts Plateaux du nord-est algérien, doctoral thesis, university 8 mai 45, Guelma.
89. LIN, Y., CHEN, K., CHEN, Q. ET CHEN, B. (2016). Effect of disturbance on the hydro-environmental factors and macroinvertebrate community in the Lijiang River. Procedia Engineering, 154, 247-251.
90. LOUNACI, A. (2005). Recherches sur la faunistique;écologie et la biogéographie des macroinvertebres des cours d'eau de Kabylie (Tizi-Ouzou, Algéria). Tizi-Ouzou.
91. MERNIZ N. ; (2021) ; Etude de la variation spatiotemporelle des précipitations dans le Nord-Est algérien ; doctoral Thesis ; Constantine.
92. MERRITT, R. W.; WALLACE, J. B. (2009). Chapter 12 - Aquatic Habitats. In V. H. Resh & R. T. Cardé (Eds.), Encyclopedia of Insects (Second Edition). San Diego: Academic Press, 38-48 p.
93. MERRITT, R. W., CUMMINS, K. W. ET BERG, M. B. 2017. Trophic relationships of macroinvertebrates. Methods in Stream Ecology, Volume 1. Elsevier.
94. MOONEY, H., PEJCHAR, L., A. (2009). Invasive species, ecosystem services and human well-being. Trends in Ecology & Evolution, 24(9), 497–504.
95. MOUASSA, S., CHAAB, S., MOULLA, A.S., ZAAGANE, M. AND BRAHMIA, N. (2018), Chemical characterization and assessment of surface waters' suitability for irrigation in the mid- Seybouse wadi plain (North-Eastern Algeria)"
96. MUSY A., & HIGY C, (2004). Hydrologie : une science de la nature. Polytechnc and University Presses of romandy. Italy. 314 p.

97. OFFICE NATIONAL DE LA METEOROLOGIE (ONM), (2024), Station météorologique de Guelma. Données climatiques annuelles. Alger, Algérie.
98. OKSANEN, J., BLANCHET, F.G., FRIENDLY, M., KINDT, R., LEGENDRE, P., MCGLINN, D., O'HARA, R.B., SIMPSON, G.L., SOLYMOS, P., STEVENS, M.H.H., SZOECS, E. and WAGNER, H., (2019) [viewed 6 January 2022]. Package "Vegan" [online]. Vienna: R Foundation for Statistical Computing. Available from: https://cran.r-project. org/web/packages/vegan/vegan.pdf
99. OKUDE, G. ET FUTAHASHI, R. (2021). Pigmentation and color pattern diversity in Odonata. Current Opinion in Genetics et Development, 69, 14-20.
100. PINDER, LCV. REISSI, F. (1983). The larvae of Chironominae (Diptera: Chironomidae) of the Holarctic region-Keys and diagnoses . Chironomidae of the Holarctic Region. Keys and Diagnoses, 1. Larvae; Entomol. Scand. Suppl. 19:149–294.
101. POFF, N. L., & WARD, J. V. (1989). Implications of streamflow variability and predictability for lotic community structure: a regional analysis of streamflow patterns. Canadian Journal of Fisheries and Aquatic Sciences, 46(10), 1805–1818.
102. PYRON, M. NEUMANN, K. (2008). Hydrologic alterations in the Wabash River watershed, USA. River Research and Applications, 24(8), 1175-1184.

103. R DEVELOPMENT CORE TEAM, (2021). R: a language and environment for statistical computing. Vienna: R Foundation for Statistical Computing.
104. REGGAM ASMA, (2015), Contribution à l'étude de la qualité microbiologique et physico-chimique des eaux d'Oued Seybouse, university 8 mai 45, Guelma.
105. RICHARDSON, E. A., KAISER, M. J., EDWARDS-JONES, G., & POSSINGHAM, H. P. (2006). Sensitivity of marine-reserve design to the spatial resolution of socioeconomic data.Conservation Biology, 20(4), 1191-1202.
106. RICHTER, B. D., BAUMGARTNER, J. V., POWELL, J. & BRAUN, D. P. (1996). A method for assessing hydrologic alteration within ecosystems. Conservation biology, 10(4), 1163-1174.
107. RONCHAIL J. & GALLAIRE R. (2006). ENSO and rainfall along the Zongo valley (Bolivia) from the Altiplano to the Amazon basin. International Journal of Climatology: A Journal of the Royal Meteorological Society, 26(9), 1223-1236.
108. ROSENBERG, D. M. & RESH, V. H. (2009). Chapter 207 - Pollution, Insect Response to. In V. H. Resh & R. T. Cardé (Eds.), Encyclopedia of Insects (Second Edition). San Diego: Academic Press, (pp. 819-821).
109. ROSENBERG, D. M., & RESH, V. H. (1993). Freshwater biomonitoring and benthic macroinvertebrates. Chapman & Hall, New York.
110. ROUIBI, A., BAALOUDJ, A., CHAHROUR, F., KERFOUF, A., RIZI, H., BERDJA, R., BELKHIRIA, W., CHAIB, S. and GHARBI, M.(2021). Characterization and diversity of macroinvertebrates of the Bouhamdane stream (Northeast of Algeria). Zoology and Ecology, vol. 31, no. 1, pp. 45-52 http://dx.doi.org/10.35513/21658005.2021.1.8
111. SAIDI, N., DJEBBAR, M. A., & TALEB, M. Z. (2021). Impact des matières en suspension sur la qualité de l'eau du bassin versant de l'oued Rhumel (Algérie). Larhyss Journal, 45, 99–113.
112. SANDIN, L., & JOHNSON, R. K. (2004). Local, landscape and regional factors structuring benthic macroinvertebrate assemblages in Swedish streams. Landscape Ecology, 19, 501-514.
113.
114. SAMRAOUI, F. and SAMRAOUI, B., (2008). The reproductive ecology of the Common Coot (Fulica atra) in the Hauts Plateaux, northeast Algeria. Waterbirds, vol. 30, no. 1, pp. 133-139. http://dx.doi.org/10.1675/15244695(2007)030[0133:TREOTC]2.0.CO;2
115. SAUNDERS, D. L., MEEUWIG, J. J. & VINCENT, A. C. (2002). Freshwater protected areas: strategies for conservation. Conservation biology, 16(1), 30-41.
116. SELLAM, N. A. VIÑOLAS, R. ZOUGGAGHE, ET R. MOULAI. (2017). « L'utilisation des Coleoptera, Ephemeroptera et Diptera comme bioindicateurs de la qualite des eaux de quelques Oueds en Algérie ». Butlletí de la Institució Catalana d'Història Natural 47–56.
117. SOGETHA et SOGREAH : (1969 et 1976), A. GHACHI (1986) in A.B.H.-C.S.M.
118. STRAYER, D. L. & DUDGEON, D. (2010). Freshwater biodiversity conservation: recent progress
119. SUAREZ, B., BARRIOS, M. and TEIXEIRA DE MELLO, F., (2022), .Macroinvertebrates' response to different land use in lowland streams from Uruguay:

use of artificial substrates for biomonitoring. Neotropical Biodiversity, vol. 8, no. 1, pp. 136-146. http://dx.doi.org/10.1080/23766808.2022.2049178.

120. TACHET, H. P., R., MICHEL, B. & PHILIPPE, U. (2010). Invertébrés d'eau douce: Systématique, biologie, écologie. CNRS, Paris, 70-529.2

121. TACHET, H., RICHOUX, P., BOURNAUD, M. and USSEGLIO-POLATERA, P.,(2012). Invertébrés d'eau douce: systématique, biologie, écologie. Paris: Editions CNRS. (in French).

122. TANSLEY, A. G. (1935). The Use and Abuse of Vegetational Concepts and Terms. Ecology 16:284–307.

123. TIHO, S. and JOSENS, G., (2007). Co-occurrence of earthworms in urban surroundings: a null model analysis of community structure. European Journal of Soil Biology, vol. 43, no. 2, pp. 84-90. http://dx.doi.org/10.1016/j.ejsobi.2006.10.004.

124. TOCKNER, K., & STANFORD, J. A. (2002). Riverine flood plains: present state and future trends. Environmental Conservation, 29(3), 308–330.

125. TOFT, C.A., (1985). Resource partitioning in amphibians and reptiles. Copeia, vol. 1, no. 1, pp. 1-21. http://dx.doi.org/10.2307/1444785.

126. TONDOH, J.E., (2006). Seasonal changes in earthworm diversity and community structure in Central Côte d'Ivoire. European Journal of Soil Biology, vol. 42, suppl. 1, pp. 334-340. http://dx.doi.org/10.1016/j.ejsobi.2006.09.003.

127. TOUATI A. S., GUEROUI Y., MAOUI A., (2016), Etude de la Qualité Hydrochimique et Bactériologique des Eaux Superficielles et de l'Aquifère Superficielle du Sous-bassin de Bouhamdane (North-East of Algeria), University of Ouargla, Faculty of Hydrocarbons, Renewable Energy, Earth and Universe Sciences.

128. TOUZIN, D. & ROY, M. (2008). Utilisation des macroinvertébrés benthiques pour évaluer la dégradation de la qualité de l'eau des rivières au Québec. Faculty of agricultural and food sciences University of Laval. Quebec, Canada. 40p.

129. VEGA, R., DE LOS RÍOS-ESCALANTE, P., ENCINA, F., NORAMBUENA, J.A., BARILE, J. and MARDONES, A., (2020). First reports of inventory and role of macroinvertebrate and fish in Cautín River (38°S, Araucania region, Chile). Brazilian Journal of Biology = Revista Brasileira de Biologia, vol. 80, no. 1, pp. 215-228. http://dx.doi. org/10.1590/1519-6984.203511. PMid:31066767.

130. WALLACE, J. B., & WEBSTER, J. R. (1996). The role of macroinvertebrates in stream ecosystem function. Annual Review of Entomology, 41(1), 115–139. https://doi.org/10.1146/annurev.en.41.010196.000555

131. WICKHAM, H., 2009. ggplot2: elegant graphics for data analysis. New York: Springer-Verlag.

132. ZEBSA, R., KHELIFA, R. and KAHALERRAS, A., (2014)a. Emergence pattern, microhabitat choice, and population structure of the Maghribian endemic Gomphus lucasii Selys, 1849 (Odonata: Gomphidae) in northeastern Algeria. Aquatic Insects, vol. 36, no. 3-4, pp. 245-255. http://dx.doi.org/10.1080/01650424.2015.1083587 .

133. ZOUGGAGHE, F., (2020). Structure et distribution des macro- invertébrés aquatiques e la kabylie de la Soummam (north of Algéria). Bulletin of the Zoological Society of France, vol. 145, no. 3, pp. 295-310.

Annexes

Annexe 01: The abiotic variables:

- **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):**

Sites	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept
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:**

Sites	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept
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

- **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):**

Sites	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept
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):**

Sites	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept
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

- **Nitrite (mg/L):**

Sites	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**
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):**

Sites	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**
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

Annexe 02: The abundance of taxa per station.

- Seybouse El Fadjoudj River:

Taxa	Number of individuals
Gastropoda	7
Cerridae	1
Gammaridae	247
Corixidae	31
Coleoptera	4
Lepidoptera	89
Hydrophilidae	2
Siphlonuridae	40
Zygoptera	2
Noteridae	1
Gerridae	4
Culicidae	1
Mesoveliidae	1
Neidae	1
Chironomidae	1
Baetidae	11
Simuliidae	10
Haliplidae	1
	454

- Seybouse Bouchegouf :

Taxa	number of individuals
Gastropoda	1
Gammaridae	17
Corixidae	705
Coleoptera	2
Caenidae	4
Baetidae	65
Chironomidae	7
Zygoptera	2
	803

- Seybouse Ain Ben Baida :

Taxa	Number of individuals
Gastropoda	26
Gammaridae	252
Corixidae	200
Coleoptera	7
Caenidae	40
Gerridae	3
Baetidae	24
Chironomidae	10
	562

- Zimba

Taxa	Number of individuals
Caenidae	9
Gerridae	1
Baetidae	17
Chironomidae	91
Simulidae	21
	139

- Bou Sora :

Taxa	Number of individuals
Gastropoda	34
Corixidae	15
Coleoptera	4
Caenidae	7
Gerridae	2
Chironomidae	79
	141

- Hellia :

Taxa	Number of individuals
gastiropode	27
Chironomidae	145
Siphlonuridae	29
Caenidae	0
Culicidae	138
Zygoptera	5

Hydrophilidae	17
Aeshnidae	1
Noteridae	2
	364

- Charef :

Taxa	Number of individuals
Gammaridae	33
Corixidae	102
Chironomidae	59
Baetidae	63
Siphlonuridae	14
Caenidae	6
coléoptère	15
hydropsychidae	6
Culicidae	2
Hydrophilidae	12
Mesoveliidae	4
hydromitridae	4
Simuliidae	14
	334

- Bouhamdane I :

Taxa	Number of individuals
Gastropoda	19
Gammaridae	917
Corixidae	48
Coleoptera	7
Hydrophilidae	3
Siphlonuridae	4

Hydropsichidae	2
Caenidae	5
Gerridae	1
Baetidae	51
Mesoveliidae	1
Chironomidae	86
Zygoptera	1
	1145

- Salah salah salah :

Taxa	**Number of individuals**
Gastropoda	16
Gammaridae	543
Coleoptera	1
Siphlonuridae	326
Caenidae	103
Gerridae	3
Chironomidae	8
Baetidae	203
Simuliidae	4
Hydropsichidae	151
Curculionidae	1
Oligochaeta	3
Aeshnidae	1
Rotschildae	3
	1366

- Echham :

Taxa	**Number of individuals**
Gastropoda	12
Chironomidae	18

Baetidae	7
Siphlonuridae	94
Caenidae	2
Coleoptera	2
Hydrophilidae	4
Gerridae	2
	141

- Bouhamdane Dam :

Taxa	**Number of individuals**
Corixidae	113
Coleoptera	10
Hydrophilidae	2
Siphlonuridae	74
Hydropsichidae	3
Caenidae	37
Chironomidae	53
Zygoptera	1
	293

- Medjez el Bgare Dam :

Taxa	**Number of individuals**
Corixidae	144
Coleoptera	27
Lepidoptera	3
Siphlonuridae	7
Caenidae	3
Mesoveliidae	1
Chironomidae	287
Culicidae	10
	482

Annexe 03: The percentage of taxa per site.

Sites	Abundance	percentage
Seybouse El fadjoudj	452	7,26454516
Seybouse Bouchegouf	803	12,9058181
Seybouse Ain Ben Baida	562	9,03246545
Zimba	139	2,23400836
Bou sora	141	2,26615236
Hellia	364	5,85020894
Charef	334	5,36804886
Bouhamdane I	1145	18,4024429
Salah Salah Salah	1366	21,9543555
Echham	141	2,26615236
Bouhamdane II	293	4,70909675
Medjez el bgare	482	7,74670524

Annexes