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Theme

Inventory of Aquatic Insects in Ramsar Lake (North East Algeria)

Presented by: **Miss BOUNASRI Lamis**

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In front of the jury composed of:

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- **Professor Lazli Amel**

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Lamis

Dedication

To the memory of my beloved father, who passed away when I was still a child. Although I did not have the privilege of growing up by his side, his memory has remained deeply rooted in my heart and has continuously guided my steps.

I wish he could have witnessed this achievement and shared this important moment with me. I dedicate this work to him with deep affection and immense respect.

To my dear mother, a model of devotion, courage, and selflessness. I express my sincerest gratitude for her unwavering support, patience, constant encouragement, and for all the sacrifices she made to help me reach this significant milestone in my journey. No words can truly express the depth of my gratitude and love for her.

To my dear younger brother, for his affection, his caring presence, and the joy he brings to my life. I sincerely wish him every success and fulfillment in his future endeavors.

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To my family and to all those who have supported me, directly or indirectly, I humbly dedicate this work as a token of my deepest gratitude and utmost respect.

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ABSTRACT

Aquatic macroinvertebrates are widely recognized as effective bioindicators for assessing the ecological quality of freshwater ecosystems. The present study was conducted in Lake Tonga and Oued Messida, two wetlands located within El Kala National Park, with the aim of characterizing benthic macroinvertebrate communities and evaluating the ecological status of these aquatic environments.

Sampling was carried out during the spring of 2026 at six stations distributed between the two study sites. The collected organisms were identified in the laboratory and analyzed using several ecological and biological indices.

The results revealed a total richness of 37 taxa in Oued Messida and 38 taxa in Lake Tonga, representing 2,610 and 2,329 individuals, respectively. The families Corixidae, Dytiscidae, Hydrochidae, and Pleidae were the most abundant in both ecosystems. Shannon diversity indices reached 2.816 in Oued Messida and 2.775 in Lake Tonga, indicating relatively high diversity. Pielou's evenness values (0.778 and 0.761) reflected a balanced distribution of individuals among taxa. Margalef richness indices were 4.576 and 4.772, respectively, highlighting high taxonomic richness. Similarity analyses showed a strong resemblance between the benthic communities of the two sites, with most taxa occurring in both ecosystems. The Family Biotic Index (FBI) values of 4.26 for Oued Messida and 4.56 for Lake Tonga classified both sites as having good biological water quality and low organic pollution.

This study highlights the relatively rich benthic biodiversity of the investigated wetlands and confirms the usefulness of macroinvertebrates as reliable tools for ecological assessment and monitoring of aquatic ecosystems.

Keywords: Benthic macroinvertebrates; Bioindication; Biological quality; Lake Tonga; Oued Messida.

RESUME

Les macro-invertébrés benthiques constituent d'excellents bioindicateurs permettant d'évaluer la qualité écologique des écosystèmes aquatiques. La présente étude a été réalisée au niveau du Lac Tonga et d'Oued Messida, deux zones humides du Parc National d'El Kala, afin de caractériser leurs peuplements benthiques et d'apprécier leur état écologique.

L'échantillonnage a été effectué durant le printemps 2026 dans six stations réparties entre les deux sites. Les organismes récoltés à l'aide d'un filet haveneau ont été identifiés au laboratoire puis analysés à travers plusieurs indices écologiques et biologiques.

Les résultats ont permis d'identifier 37 taxons à Oued Messida et 38 taxons au Lac Tonga, représentant respectivement 2610 et 2329 individus. Les familles des Corixidae, Dytiscidae, Hydrochidae et Pleidae ont présenté les abondances les plus élevées dans les deux milieux. Les indices de diversité de Shannon ont atteint 2,816 à Oued Messida et 2,775 au Lac Tonga, traduisant une diversité relativement importante. L'équitabilité de Pielou a montré une répartition relativement équilibrée des individus entre les taxons (0,778 et 0,761). L'indice de richesse de Margalef a révélé une richesse taxonomique élevée avec des valeurs de 4,576 et 4,772 respectivement. L'analyse de similarité a mis en évidence une forte ressemblance entre les deux communautés benthiques, avec une majorité de taxons communs aux deux sites. Les valeurs de l'Indice Biotique des Familles (FBI), estimées à 4,26 pour Oued Messida et à 4,56 pour le Lac Tonga, classent les deux milieux dans la catégorie des eaux de bonne qualité, caractérisées par une faible pollution organique.

Cette étude met en évidence une biodiversité benthique relativement riche et confirme l'intérêt des macro-invertébrés comme outils fiables pour l'évaluation et le suivi écologique des zones humides.

Mots-clés : Macro-invertébrés benthiques ; Bioindication ; Qualité biologique ; Lac Tonga ; Oued Messida.

ملخص

تُعد اللافقاريات المائية القاعية من أهم المؤشرات الحيوية المستخدمة في تقييم الحالة البيئية للأنظمة المائية العذبة. أُنجزت هذه الدراسة على مستوى بحيرة تونغا ووادي المسيدة، وهما من المناطق الرطبة التابعة للحظيرة الوطنية للقالة، بهدف دراسة تنوع وبنية مجتمعات اللافقاريات القاعية وتقييم الجودة البيئية لهذين الوسطين المائيين.

تمت عملية أخذ العينات خلال فصل الربيع لسنة 2026 (أفريل–ماي) في ست محطات موزعة بين موقعي الدراسة. وقد تم فرز الكائنات المجمعة والتعرف عليها مخبرياً، ثم تحليل المعطيات باستخدام مجموعة من المؤشرات البيئية والحيوية.

أظهرت النتائج تسجيل 37 وحدة تصنيفية في وادي المسيدة و38 وحدة تصنيفية في بحيرة تونغا، بإجمالي 2610 و2329 فرداً على التوالي. وكانت عائلاتCorixidaeوDytiscidaeوHydrochidaeوPleidaeالأكثر وفرة في كلا الموقعين. بلغت قيم مؤشر شانون للتنوع 2.816 في وادي المسيدة و2.775 في بحيرة تونغا، مما يدل على تنوع بيولوجي معتبر. كما بينت قيم مؤشر بيلو للانتظام (0.778 و0.761) وجود توزيع متوازن نسبياً للأفراد بين الوحدات التصنيفية. أما مؤشر مارغاليف فقد سجل 4.576 و4.772 على التوالي، مما يعكس ثراءً تصنيفياً مرتفعاً. وأظهرت تحاليل التشابه وجود تقارب كبير بين المجتمعات القاعية في الموقعين. كما بينت قيم مؤشر الجودة الحيوية للعائلات (FBI) البالغة 4.26 في وادي المسيدة و4.56 في بحيرة تونغا أن المياه تتمتع بجودة بيولوجية جيدة ومستوى منخفض من التلوث العضوي.

تؤكد هذه الدراسة الأهمية البيئية للمناطق الرطبة المدروسة، كما تبرز فعالية اللافقاريات القاعية كمؤشرات حيوية موثوقة لتقييم ومتابعة الحالة البيئية للأنظمة المائية.

الكلمات المفتاحية :اللافقاريات المائية القاعية؛ المؤشرات الحيوية؛ الجودة البيولوجية؛ بحيرة تونغا؛ وادي المسيدة.

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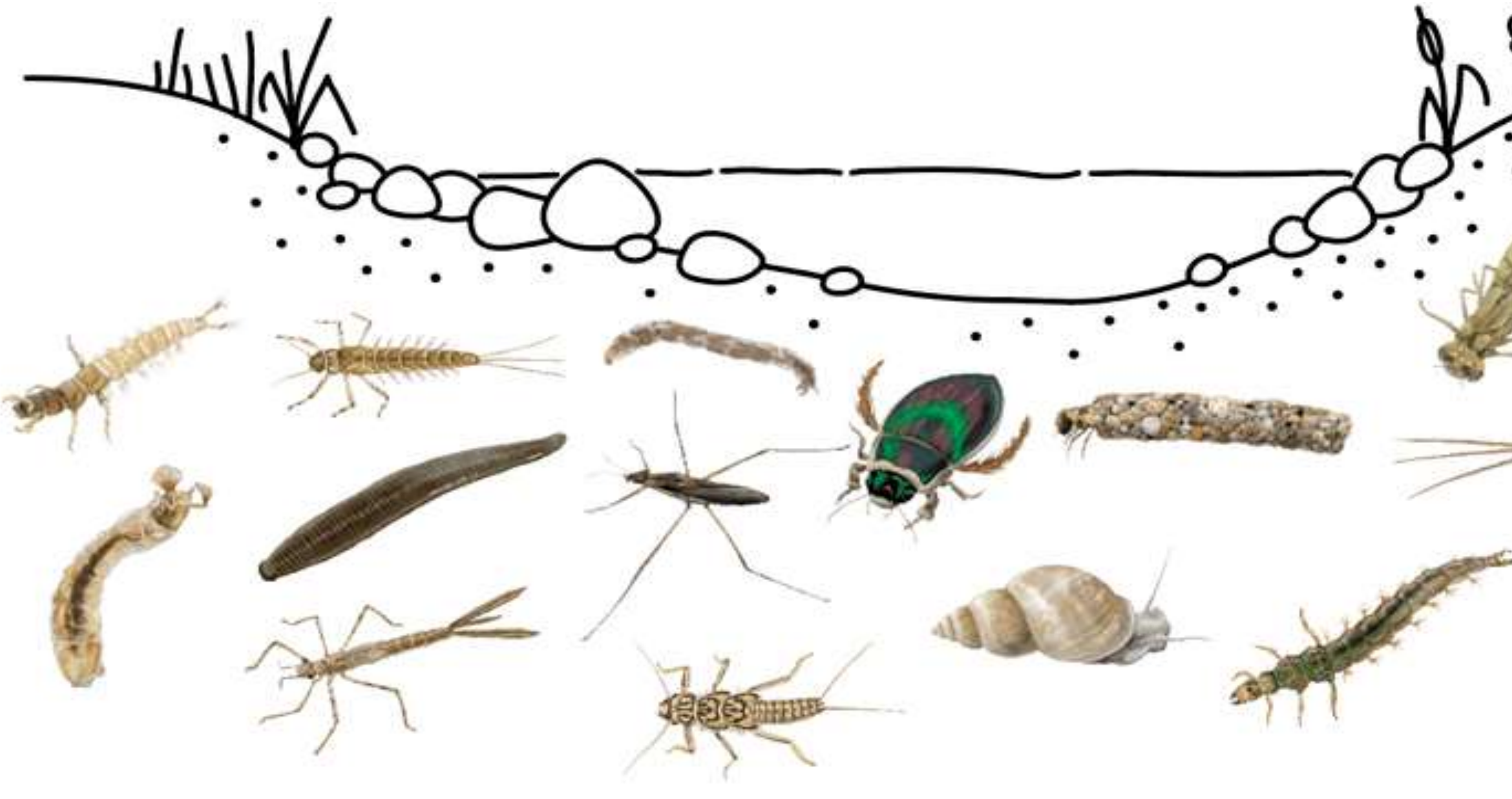
INTRODUCTION



INTRODUCTION

Aquatic ecosystems, including both freshwater and marine environments, are complex ecological systems characterized by their rich biodiversity. They host a wide range of organisms, from microorganisms to vertebrates, which interact with one another and with their physical environment. This biological diversity is essential for maintaining ecological functions such as nutrient cycling, primary production, and the balance of trophic chains **(Dudgeon *et al.,* 2006).**

According to **Sweeney et *al.,* (2004),** aquatic ecosystems are increasingly threatened by intensive exploitation, progressive pollution, and rapid population growth, all of which endanger aquatic biodiversity. Water pollution in aquatic environments has become a growing concern in Algeria, particularly in the Mediterranean region, where water is a precious and vulnerable resource. These resources are mainly affected by overexploitation (**Margat & Vallée, 1999; Mutin, 2000; Khamar *et al.,* 2000; Azzaoui et *al.,* 2002**). Furthermore, climate change is expected to exacerbate these issues through an increased frequency of droughts, reduced groundwater recharge, and greater challenges in maintaining acceptable water quality for human consumption, aquatic ecosystems, and other uses.

To preserve aquatic ecosystems, regular monitoring of their overall health has become a priority. Consequently, effective analytical chemistry and microbiological laboratory techniques remain indispensable for addressing these challenges. This relies on reliable, accurate, sensitive, and rapid measurement methods, complemented by real-time physicochemical monitoring techniques and in situ bioassays (**Belles, 2012**).

Current biomonitoring techniques are based on evaluating the taxonomic and functional composition of aquatic flora and fauna, which serve as biological indicators of river health. These indicators include diatoms (**Stevenson & Pan, 1999**), macrophytes **(Schorer *et al.,* 2001),** benthic macroinvertebrates **(Mondy *et al.,* 2012),** and fish **(Plafkin *et al.,* 1989).** Among these groups, benthic macroinvertebrates are among the most commonly used bioindicators in freshwater ecosystems **(Mason & Parr, 2003).**

Aquatic invertebrates constitute a fundamental and diverse component of freshwater ecosystems and are capable of adapting to a wide range of environmental conditions **(Odum *et al.,* 1979).** In ecological monitoring, macroinvertebrates are particularly valuable for spatial analyses and for assessing different categories of pollution. Therefore, they are widely used in studies aimed at evaluating water quality. However, human activities have caused significant impacts, leading to severe disturbances in benthic communities and biodiversity **(Nedeau *et al.,* 2003).**

Most benthic fauna found in streams are composed of macroinvertebrates. Their assemblages typically include insect larvae, mollusks, crustaceans, nematodes, and annelids, which generally inhabit areas close to the sediment. The diversity and abundance of these organisms depend on ecological conditions. Factors such as water velocity, current, temperature, and substrate type can significantly influence the distribution of macroinvertebrates within stream ecosystems **(Tenkiano, 2017).**

This variability constitutes a major advantage for their use as bioindicators. Groups such as Ephemeroptera, Plecoptera, and Trichoptera (EPT) are particularly sensitive to environmental disturbances and are generally associated with high-quality waters. In contrast, other groups such as Chironomidae and Oligochaeta are more tolerant and tend to proliferate in degraded environments **(Rosenberg & Resh, 1993; Bonada *et al.,* 2006).**

Benthic macroinvertebrates play a crucial role in maintaining the stability of aquatic ecosystems, as they represent an important component of the food web for many riverine organisms, including fish. These organisms possess characteristics that make them especially suitable for bioassessment studies (**Djamai, 2020**), while also contributing significantly to ecosystem functioning.

They actively participate in the decomposition of organic matter by fragmenting plant debris, thereby facilitating its conversion into fine particles. This process contributes to nutrient recycling and the dynamics of biogeochemical cycles. Furthermore, these organisms occupy different trophic levels within aquatic food webs and ensure the transfer of energy from primary producers to higher-level consumers such as fish, amphibians, and certain aquatic birds (**Cummins *et al.,* 2005**).

Bioindication is defined as the ability of an organism or a group of organisms to reveal environmental characteristics through their presence, absence, or biological activities (**Blandin, 1986**). Such organisms are referred to as bioindicators. In addition to chemical analyses, biological assessments provide an effective approach for evaluating environmental degradation and biodiversity loss in aquatic ecosystems resulting from anthropogenic disturbances (**Hawkes, 1979; Karr, 1991**).

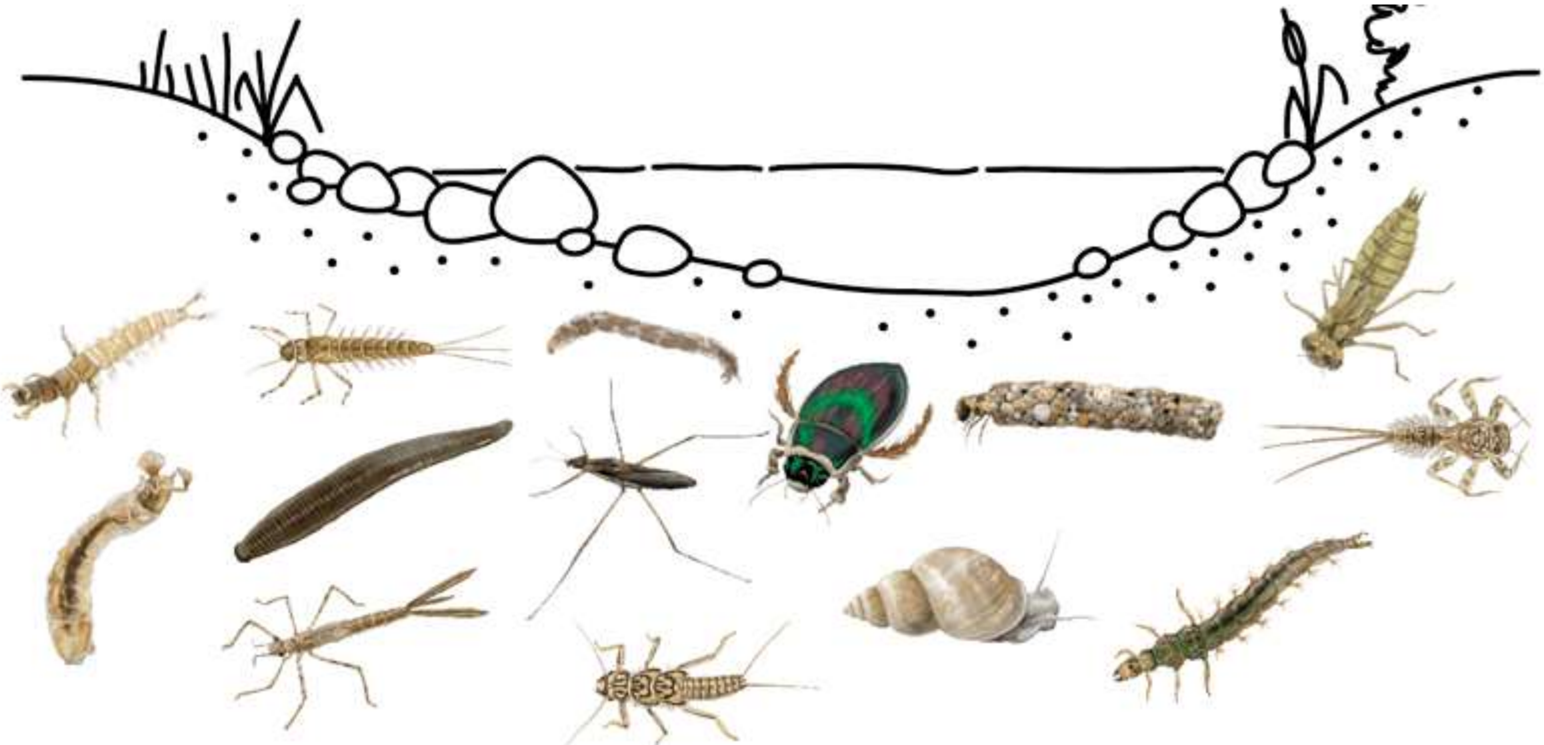
According to Boumezbeur (2003), Algeria possesses numerous wetlands that constitute valuable resources due to their biodiversity and natural productivity. More than 1,200 wetlands have been identified throughout the country, among which 52 are recognized as being of international importance (DGF, 2004). Northeastern Algeria, one of the country's wettest regions, is particularly rich in important lacustrine complexes. The El Kala wetland complex, located in this region, is one of the most significant wetland systems in North Africa and the Mediterranean Basin owing to its strategic position along migratory bird routes and its remarkable diversity of marine and lacustrine ecosystems, particularly Lake Tonga.

More specifically, this work aims to:

- **Carry out a precise faunal and taxonomic inventory** of benthic macroinvertebrates across six stations strategically distributed between the two environments;
- **Characterize community structure and diversity** using biodiversity indices (Species richness, Shannon-Weaver, Margalef, and Pielou's evenness indices);
- **Analyze faunal similarity and spatial distribution** of assemblages between the lacustrine environment and its outlet by applying the Jaccard and Bray-Curtis indices;
- **Assess the health status and biological water quality** through the combined application of internationally recognized biotic indices, namely the Family Biotic Index (FBI), the Biological Monitoring Working Party (BMWP), and the Average Score Per Taxon (ASPT).

Following this introduction, the manuscript is organized into four main chapters. The first chapter presents general information on macroinvertebrates and their use in bioindication. The second chapter describes the study area. The third chapter outlines the materials and methods employed in this research and presents the results obtained. The fourth chapter is devoted to the discussion of the findings through comparison with previous studies reported in the literature. Finally, the work concludes with a general conclusion and future perspectives.

CHAPTER I: GENERALITIES



GENERALITIES

1. Definition

The term **"macro"** refers to invertebrates retained by a net or sieve with a mesh size of 500 µm, thus constituting the most diverse group of organisms worldwide (**Hauer and Resh, 2017**). Macroinvertebrates are organisms visible to the naked eye and mainly inhabit the bottoms of aquatic environments such as rivers, lakes, and marshes (**Moisan *et al.,* 2006**).

In general, aquatic macroinvertebrates form a heterogeneous group of organisms larger than 500 µm (Usio, 2024), or large enough to be observed without a microscope. They are mainly composed of insects but also include other taxa such as planarians, mollusks, leeches, oligochaetes, and crustaceans (**Jacobsen *et al.,* 2008**). These organisms are widely distributed throughout hydrographic networks and comprise several hundred species belonging to various phyla (**Hauer and Resh, 2017**).

From a trophic perspective, aquatic macroinvertebrates occupy different levels of the food chain. They may be classified as primary consumers, feeding on plant material, or secondary consumers, feeding on planktonic or benthic organisms. Through their activity, they play an essential role in the functioning of aquatic ecosystems, particularly by participating in nutrient recycling and the fragmentation of organic matter (**Callisto *et al.,* 2001**).

2. Habitat of Macroinvertebrates

Benthic macroinvertebrates are highly abundant and exhibit great diversity in all types of watercourses (**Chessman, 1995; Camargo *et al.,* 2004**). In lotic ecosystems, their habitat includes various elements such as mineral substrates (rocks and sediments), aquatic and riparian vegetation, leaf litter, and decomposing organic matter transported by the current. Submerged woody materials such as branches, trunks, and other debris are also part of their habitat.

In streams with active dynamics, the distribution of macroinvertebrates is closely related to physical characteristics and habitat quality, the latter directly influencing biological diversity (**Hynes, 1970; Cummins, 1975**). The spatial distribution of these organisms depends on several environmental factors, including water temperature, current velocity, and the nature and heterogeneity of the substrate (**Hynes, 1970**).

In rivers, where water is in constant motion and organized along a longitudinal gradient, three main habitat types are generally distinguished:

- **Riffles**: characterized by fast-flowing water, shallow depth, and coarse substrates, corresponding to erosion zones;
- **Runs and pools**: characterized by slower currents, greater depth, and finer substrates such as sand and gravel, associated with sedimentation zones;
- **Deep pools**: deep areas with slow currents, dominated by fine substrates such as silt and mud (Tachet et al., 2010).

Within these habitats, several types of microhabitats can be distinguished:

- **Mineral microhabitats**: include inorganic substrates ranging from bedrock to fine particles such as sand, silt, and clay.
- **Organic microhabitats**: correspond to substrates dominated by organic matter. These include plant debris such as submerged branches and logs, accumulations of leaves on the streambed (litter), and organic-rich sediments such as mud.
- **Vegetal microhabitats**: encompass all living plants, mainly hydrophytes, which provide support and shelter for numerous species.

Thus, in the monitoring of benthic macroinvertebrates, the assessment of the surrounding habitat constitutes an essential complementary source of information, allowing a better interpretation of biological data.

3. Life Cycles of Benthic Macroinvertebrates

Benthic macroinvertebrates are abundant and highly diverse organisms that play an essential role in maintaining the balance of aquatic ecosystems and, indirectly, terrestrial ecosystems, since some species emerge from the water to reach their adult stage.

Certain groups, such as worms, leeches, and mollusks, spend their entire lives in aquatic environments, whereas others, particularly insects, inhabit aquatic ecosystems only during specific stages of their development, mainly during the larval stage.

The duration of the life cycle of macroinvertebrates is highly variable, ranging from a few weeks, as observed in some Diptera (Simuliidae), to several decades, as in bivalves of the genus *Margaritifera*. According to their relationship with the aquatic environment, species can be classified into holobiotic species, whose entire life cycle occurs in water, and **amphibiotic species**, which occupy aquatic habitats only during certain developmental stages (**Tachet *et al.,* 2010).**

In aquatic insects, development begins with egg hatching and continues through a series of transformations leading to the adult stage, known as the imago. This process is referred to as metamorphosis.

Holometabolous insects undergo complete metamorphosis consisting of the following stages: egg, larva, pupa (or chrysalis), and adult. In this case, larvae differ considerably from adults and are primarily adapted for growth, whereas the adult stage is specialized for dispersal and reproduction (**Loeschcke and Krebs, 1996**).

In contrast, hemimetabolous insects undergo incomplete metamorphosis characterized by gradual development without a pupal stage. The larva (or nymph) generally resembles the adult, although it is smaller and lacks fully developed wings.

4. Taxonomic Composition

Aquatic macroinvertebrates constitute a faunal group characterized by great diversity and wide distribution in inland waters (**Neveu, 2001**). They occupy a wide variety of habitats and microhabitats. This group includes larvae and adult forms of aquatic insects, as well as crustaceans, water mites, mollusks, and annelids (**Gagnon and Pedneau, 2006**).

4.1. Insects

Insects are divided into two groups according to their type of metamorphosis.

Insects with incomplete metamorphosis (hemimetabolous insects) include Hemiptera, Odonata, Plecoptera, and Ephemeroptera, whose wing buds develop progressively during successive molts.

Insects with complete metamorphosis (holometabolous insects) include Diptera, Trichoptera, Megaloptera, Coleoptera, and certain Lepidoptera (Pyralidae) (**Gullan *et al.,* 2014**).

4.2. Mollusks

These organisms are distinguished by the presence of a calcareous shell. This shell consists of a single piece in Gastropoda and two articulated valves in Lamellibranchia, also known as Bivalvia or Pelecypoda **(Lévêque, 1980).** Their identification relies mainly on shell morphology (**Macan, 1960; Ellis, 1978**).

4.3. Nematodes

These are unsegmented worms covered by a thick cuticle. They may be free-living or parasitic on plant and animal organisms (**Touzin, 2008**). They are found throughout aquatic ecosystems, including ponds, streams, rivers, and lakes.

4.4. Annelids

Hirudinea (leeches) are characterized by a body lacking bristles and by the presence of two suckers, an anterior sucker containing the mouth and a posterior sucker (**Touzin, 2008**).

Oligochaetes are segmented worms, generally hermaphroditic, living either on the surface or within the substrates of aquatic environments, whether lotic or lentic **(Touzin, 2008)**.

4.5. Crustaceans

Ostracods are small crustaceans whose bodies are protected by a bivalve carapace. Their larvae, known as nauplii, exhibit a lifestyle similar to that of adults.

Amphipods and isopods are distinguished by their body shape: laterally compressed in amphipods and dorsoventrally flattened in isopods. Amphipods are common in lakes and streams, with some species inhabiting specific environments such as peat bogs and springs. Isopods mainly occur in running waters, although certain species colonize the littoral zones of stagnant waters (**Martin and Davis, 2001**).

4.6. Arachnids

Water mites (Hydracarina) are invertebrates belonging to the class Arachnida and adapted to freshwater environments. They are poorly represented in brackish and marine ecosystems. They are mainly found on rooted aquatic vegetation along the margins of lakes and ponds, as well as in certain flowing waters (**Peyrusse and Bertrand, 2001**).

5. Identification and Classification of Macroinvertebrates

The identification of benthic macroinvertebrates generally presents several difficulties. These are often related to the lack of previous studies, insufficient available data, or the absence of precise morphological criteria, particularly for juvenile stages.

Consequently, the taxonomic level at which organisms can be identified may vary according to these constraints and often remains heterogeneous, both among different faunal groups and within the same taxon (**Forcellini, 2012**).

In some cases, genetic analyses are used to confirm species-level identification and overcome the limitations of morphological determination.

The identification of macroinvertebrates therefore relies on numerous specialized reference works, including those of **Grassé and Doumenc (1995**), **Beaumont and Cassier (2004), Merritt et *al.,* (2008), and Tachet et *al.,* (2010).**

6. Classification of Macroinvertebrates into Functional Feeding Groups

Benthic macroinvertebrates constitute a key component of lotic aquatic food webs, occupying an intermediate position between primary producers (I) and top consumers in the food chain (III).

On the one hand, they accelerate the decomposition processes of allochthonous organic matter (dead leaves and plant debris) by breaking it down into finer particles, thereby enhancing the activity of microorganisms such as bacteria and aquatic fungi (hyphomycetes) **(Floury, 2013).**

Cummins (1973) proposed a classification of benthic macrofauna into functional feeding groups. These groups describe the feeding strategies of macroinvertebrates and represent a compromise between the morphological adaptations of invertebrates and the type and size of available food resources.

Six trophic groups have been identified:

6.1. Predators

Predators are carnivorous organisms that feed on live prey larger than 103 µm, including other invertebrates and sometimes small vertebrates. Members of this group possess specialized adaptations that enable them to hunt, pierce, suck, or grasp their prey.

Odonata larvae are formidable predators equipped with an extendable lower jaw that can rapidly project forward to capture prey **(Corbet, 1980**). Nepidae and Gerridae possess specialized forelegs that facilitate prey capture **(Fig. 1**).

6.2. Scrapers (Grazers)

Scrapers feed on autochthonous organic matter in the form of epilithic or epiphytic biofilms. They scrape or brush mineral and organic surfaces, ingesting particles generally smaller than 1 mm.

Gastropods, for example, graze on algae covering rocks using a rough tongue-like structure called the radula.

6.3. Collectors (Filter Feeders)

Collectors feed on fine organic matter suspended in the water column. Larvae of *Hydropsyche* capture this material using filtering structures, while blackfly larvae (Simuliidae) deploy fan-shaped premandibular appendages into the current to trap food particles (**Fig. 2**) **(Wallace and Merritt, 1980).**

6.4. Collector–Scrapers (Mixed Feeders)

These organisms exhibit a mixed feeding strategy combining collecting and scraping behaviors. Examples include members of the families Baetidae and Caenidae.

6.5. Shredders

Shredders possess specialized mouthparts that enable them to cut and fragment living vascular plants (macrophytes and bryophytes) as well as coarse particulate organic matter larger than 103 µm.

6.6. Generalists (Undifferentiated Feeders)

These are invertebrates for which it is difficult to assign a specific trophic group. This category includes families whose feeding habits vary according to subfamily or tribe, such as the Chironomidae **(Ivol-Rigaut, 1998).**

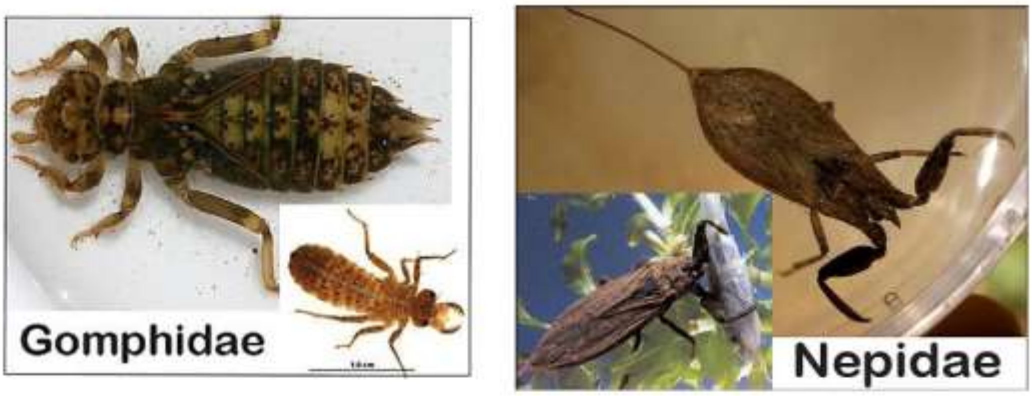


Figure 1: Predatory macroinvertebrates (Odonata: Gomphidae; Heteroptera: Nepa) **(Flickriver, 2008; Flickr, 2010)**

Figure 2: Macro-invertebrate filter feeders (Caddisflies [Hydropsyche], Black flies [Simuliidae]) **(Troutnut, 2007)**

7. Factors Influencing Macroinvertebrates

7.1. Abiotic Factors

The abundance and taxonomic richness of benthic macroinvertebrate communities are strongly influenced by variations in the physical and chemical properties of their habitat. Physical modifications, such as the construction of hydroelectric dams or riverbank erosion, as well as chemical alterations related to pollution, can have significant impacts on these organisms.

Aquatic macroinvertebrates have specific ecological requirements regarding several environmental parameters, including water temperature, dissolved oxygen concentration, and pH. Any disturbance of these factors may lead to changes in community structure, affecting species abundance, dominance, and diversity.

An excessive increase in pollutants within the aquatic environment may cause the disappearance of sensitive species, thereby favoring species that are tolerant of degraded conditions. Consequently, pollution contributes to a reduction in macroinvertebrate species diversity and to the simplification of biological communities (**Rosenberg and Resh, 1993; Bonada *et al.,* 2006; Tachet *et al.,* 2010**).

7.2. Biotic Factors

Interactions among species, such as competition for food resources, play a key role in the disappearance of certain species. Furthermore, habitat degradation may lead to declines in predator populations, consequently affecting all levels of the food chain (**Cassier *et al.,* 1998**).

Voelz and McArthur (2000) found that the abundance of species within a population is independent of its specific composition. It is influenced by a large number of environmental and interspecific factors, including environmental stability, competition, and predation (**Boudrari, 2022).**

8. Bioindication

Bioindication refers to the use of living organisms to assess environmental quality. Certain organisms that are sensitive to pollutants serve as biological indicators through their presence, absence, or behavioral changes **(Blandin, 1986; Hart *et al.,* 1999).**

Compared with chemical analyses, biological monitoring constitutes an effective and economically advantageous method for assessing the degradation of aquatic habitats and the loss of biodiversity resulting from anthropogenic disturbances (**Hynes, 1960; Hawkes, 1979; Karr, 1991; Rosenberg and Resh, 1993**).

The conventional assessment of water quality is based on the measurement of physicochemical parameters, which are compared with reference standards. However, this approach presents certain limitations, as it may sometimes detect non-existent effects or, conversely, fail to reveal actual impacts (**Thomas, 1993).**

In contrast, biomonitoring makes it possible to integrate the combined effects of pollutants as well as the consequences of environmental disturbances such as eutrophication, excessive plant growth, and habitat degradation (**Bellan, 1984**).

According to Blandin (1986), bioindicators are animal or plant organisms whose physical, behavioral, or ecological characteristics make it possible to assess the degree of environmental disturbance. They therefore provide information on both natural and anthropogenic variations in environmental conditions.

A good biological indicator must possess specific ecological requirements, allowing a direct relationship to be established between its presence or absence and environmental conditions **(Touzin, 2008).**

Various groups of organisms can be used in bioindication, including diatoms, macrophytes, benthic macroinvertebrates, and fish, all of which respond sensitively to factors such as oxygen depletion and heavy metal pollution **(Touzin, 2008).**

8.1. Aquatic Macroinvertebrates and Bioindication

Aquatic macroinvertebrates can be used to detect different types of pollution, including organic pollution, heavy metal contamination, the impacts of human activities, and environmental acidification (**Woodcock and Huryn, 2007; Moisan and Pelletier, 2014**).

Certain taxa, such as Plecoptera, Trichoptera, and some Ephemeroptera, require highly oxygenated water and are therefore among the most sensitive organisms to pollution.

In contrast, Tubificidae, Syrphidae, Chironomidae, Oligochaeta, and Bivalvia are among the least sensitive macroinvertebrates. These taxa are capable of surviving under anoxic conditions where dissolved oxygen levels are extremely low and water temperatures are relatively high.

9. Importance and Ecological Role of Macroinvertebrates

Macroinvertebrates are fundamental components for understanding the structure and functioning of aquatic ecosystems. They are recognized as indicators of the ecological health of aquatic environments and have been used for decades to assess the condition of aquatic ecosystems following environmental disturbances (**Bonacina *et al.,* 2023**).

Numerous studies have evaluated the extent of human-induced disturbances in lotic and lentic ecosystems using aquatic insects as biological indicators (**Wallace and Webster, 1996**).

Macroinvertebrates also constitute an essential link within aquatic food webs, connecting primary producers to higher-level consumers in the food chain (**Fig. 3**), such as amphibians, fish, and birds **(Merritt *et al.,* 2017; Batzer and Wissinger, 1996).**

In addition, they contribute significantly to nutrient cycling, organic matter decomposition, and energy transfer within aquatic ecosystems, thereby playing a crucial role in maintaining ecological balance and ecosystem functioning.

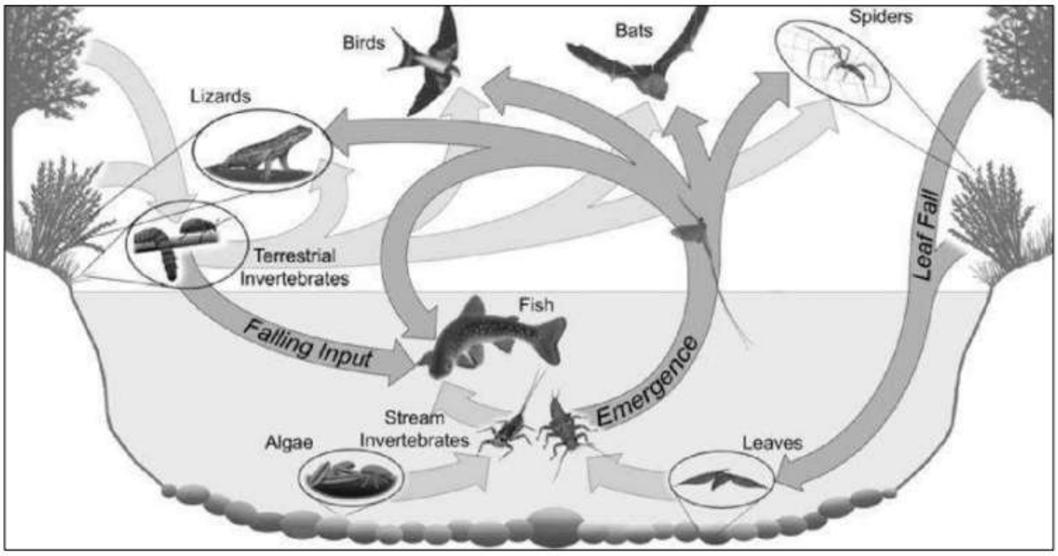


Figure 3: General diagram illustrating the role of macroinvertebrates in the food chain **(Baxter et *al.,* 2005).**

10. Use of Macroinvertebrates in Environmental Assessment

Macroinvertebrates have been widely used to assess the degree of anthropogenic disturbance in both lotic and lentic ecosystems, as well as to monitor the accumulation of heavy metals and insecticides in watercourses. Their use is often based on tolerance values assigned to specific taxa, ranging from 0 (highly sensitive) to 10 (highly tolerant) **(Wallace and Webster, 1996).**

In general, macroinvertebrates are considered excellent indicators of environmental quality because they are ubiquitous throughout hydrographic networks, are relatively easy to collect, and exhibit a wide range of responses depending on the type and intensity of environmental stress **(Lin *et al.,* 2016).**

10.1. Advantages of Macroinvertebrates

According to **Gagnon and Pedneau (2006),** macroinvertebrates offer several advantages as biological indicators and provide a direct signal of environmental conditions at a given site.

- Their sampling is relatively simple and can be carried out by any trained researcher.
- Their identification at the family level, transportation from the sampling site, and preservation are relatively easy **(Chessman, 1995).**
- They play a crucial role in aquatic food webs, serving as a primary food source for fish, amphibians, and aquatic insects. Therefore, their abundance and diversity are essential for maintaining river ecosystems in a balanced, active, and healthy state.
- As living organisms with relatively long-life cycles ranging from a few months to two or three years, they integrate environmental conditions over time and reflect the cumulative effects of habitat quality and pollution **(Camargo *et al.,* 2004; Pelletier *et al.,* 2002).**
- Unlike physicochemical analyses, benthic macroinvertebrates can reveal disturbances that occurred before sampling, even if the pollution event is no longer detectable at the time of collection **(Chessman, 1995).**
- They exhibit a high capacity to respond to variations in water quality.
- They are permanently present in most aquatic ecosystems.
- They are not subject to economic exploitation or recreational use, reducing the likelihood of human-induced bias in their populations.
- They integrate seasonal variations as well as differences in the chemical, physical, and biological characteristics of water.
- Their tolerance to pollution varies considerably among taxa, making them useful for detecting different levels of environmental degradation.

10.2. Limitations of Using Macroinvertebrates in Bioindication

Despite their numerous advantages, the use of macroinvertebrates as bioindicators also presents certain limitations:

- The quality and reliability of the data obtained may be influenced by the expertise, experience, and methodological rigor of the sampler.
- Their use does not allow the precise identification of the source or nature of the pollution affecting the ecosystem **(Pelletier, 2002).**
- Environmental factors unrelated to pollution, such as natural habitat variability, seasonal changes, and hydrological conditions, may also influence macroinvertebrate communities and complicate data interpretation.
- Accurate identification often requires taxonomic expertise, particularly when organisms must be identified beyond the family level.

CHAPTER II:

MATERIEL AND METHODES

MATERIEL AND METHODES

1. Presentation of the Study Area

The El Kala region is considered the wettest region in Algeria due to its high rainfall and exceptional ecological diversity. Owing to its remarkable biological richness and diversity, both in terms of flora and fauna, it has been the subject of numerous scientific studies since the beginning of the twentieth century. For this reason, it was officially declared a National Park on July 23, 1983 (Anonymous, 1996).

1.1. Presentation of El Kala National Park (PNEK)

The El Kala National Park (36°52′ N, 8°27′ E), commonly referred to as EKNP, is located in northeastern Algeria. It covers an area of approximately 80,000 hectares, entirely situated within the Wilaya of El Tarf. In addition, about 19,300 hectares are classified as peripheral zones surrounding the park.

The site received legal protection when it was designated a National Park by Decree No. 83-462 of July 23, 1983. In 1991, it was further recognized by UNESCO as a protected area **(De Belair, 1990) (Fig. 4).**

The geographical boundaries of El Kala National Park are as follows:

- **To the North:** the Mediterranean Sea;
- **To the South:** the Mejerda Mountains;
- **To the East:** the Algerian–Tunisian border;
- **To the West:** the Annaba Plains.

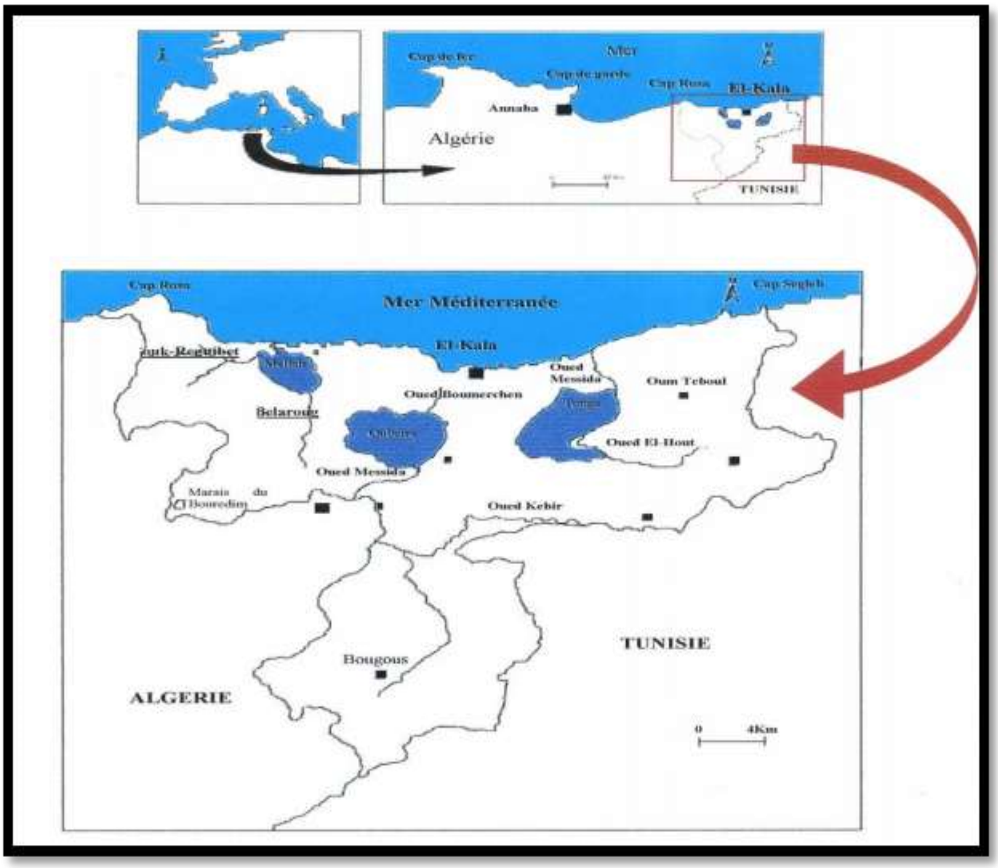


Figure 4: Map of El-Kala National Park **(De Belair, 1990)**

1.2. Presentation of the Study Sites

1.2.1. Lake Tonga

Lake Tonga is one of the three most important wetlands within El Kala National Park. These wetlands constitute the primary wintering area for waterbirds in Algeria in terms of population size **(Chalabi, 1990).** The lake covers an area ranging from approximately 2,400 to 2,600 hectares, depending on seasonal rainfall conditions.

This remarkable marsh ecosystem is characterized by its exorheic drainage system, which connects to the Mediterranean Sea through the Messida Canal.

Located in Eastern Numidia, at the extreme northeastern part of Algeria, Lake Tonga is distinguished by being the easternmost wetland within the territory of El Kala National Park. Situated approximately 5 km from Lake Oubeira **(Morgan, 1982**), it occupies a vast coastal depression between El Kala and Oum Teboul. The lake has an elliptical shape, with its major axis extending for approximately 7.5 km.

To the east, south, and west, the lake is bordered by the last foothills of the Kroumirie Mountains, which are covered by more or less degraded cork oak **(*Quercus suber*)** forests. To the north, the lake is separated from the Mediterranean Sea by a belt of coastal dunes, mainly covered by dense maquis vegetation dominated by Kermes oak **(*Quercus coccifera*)** **(Chalabi, 1990; Kadid, 1990).**

The lake basin and its surrounding deltas cover a total area of approximately 3,917 hectares, of which the lake basin itself occupies about 2,517 hectares **(Chalabi, 1990) (Fig. 5).**

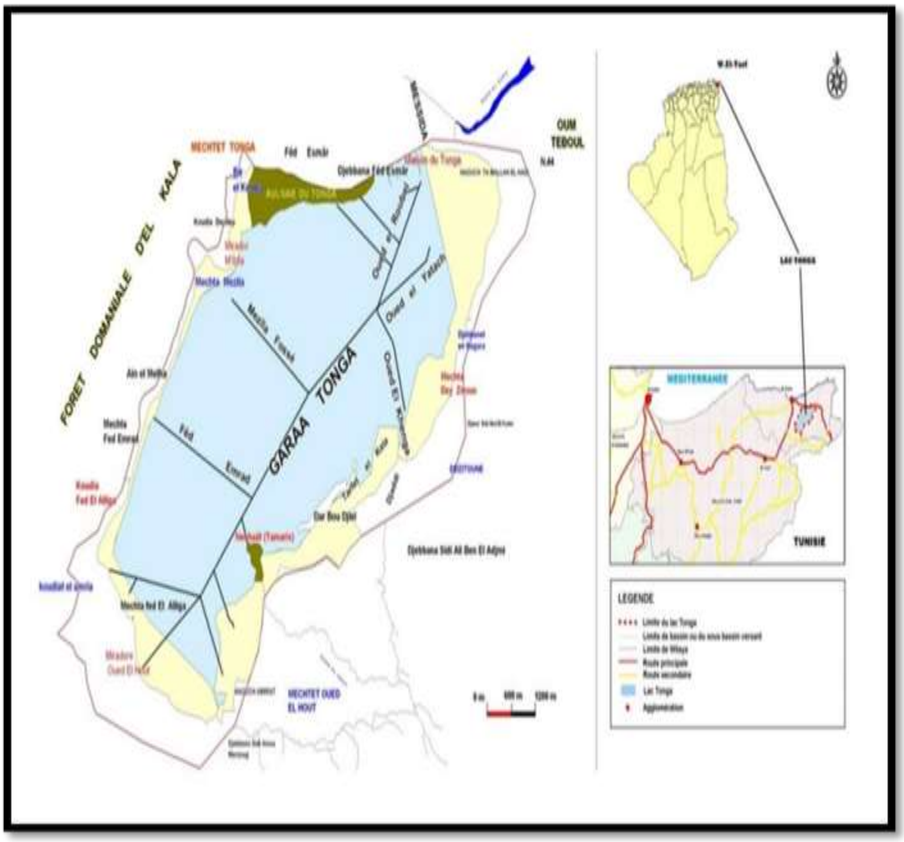


Figure 5: Localisation géographique du lac Tonga **(Saïfouni et *al.*, 2020)**

1.2.2. Messida Wadi

Messida Canal is an artificial watercourse constructed during the French colonial period with the aim of draining Lake Tonga. Located at sea level, it exhibits a particular hydrological characteristic: its flow direction varies according to the water level of the lake. During the winter season, water flows from the lake toward the Mediterranean Sea, whereas in summer, the flow reverses and moves from the sea toward the lake **(Zeraoula, 2011).**

This canal, which connects Lake Tonga to the Mediterranean Sea, is situated within El Kala National Park (EKNP) in the extreme northeastern part of Algeria. It is bordered to the south by Lake Tonga, to the north by the Mediterranean Sea, to the west by the plains of the municipality of Souarekh, and to the east by pine forests that stabilize most of the dunes along Messida Beach.

Its geographical coordinates extend between 36°53′60″ North latitude and 8°31′00″ East longitude. The site is located approximately 22 km west of the Algerian–Tunisian border and about 11 km east of the city of El Kala **(Fig. 6).**

The wadi is mainly supplied by the waters of Lake Tonga, which constitutes its principal source. Two additional secondary sources also contribute to its water supply: the Maloul dune aquifer and the aquifer associated with the neighboring Tonga pine forest. These two aquifers play a particularly important role during the dry season by discharging water into the wadi and thereby maintaining its flow **(Zeraoula, 2011).**

Figure 6 : Location of Oued Messida **(Google Earth, 2026)**

1.2.2.1. Characteristics of Oued Messida

The characteristics of Oued Messida are summarized in the following table (Table 1)

Table 1: Main characteristics of the Messida Wadi **(Bazine et Bourenane, 2011).**

Watercourse	Messida Wadi
Type	Canal
Average Width (m)	> 3
Average Depth (m)	1 – 2.5
Current Velocity	Moderate
Substrate Type (Streambed)	• Predominantly sandy substrate• Minor presence of gravel, coarse particles, and mud
Bottom Conditions	• Branches• Leaves• Small amounts of waste• Decomposing organic matter
Bank Structure	Natural
Exposure	Open
Aquatic Vegetation	• Abundant along the banks• Moderate in the central channel
Surrounding Environment	• Lodge/Guesthouse• Agricultural land• Grazing areas• Scattered dwellings

1.3. General Conditions of the Study Area

1.3.1. Pedology

The valuable work of **Durand (1952)** contributed considerably to the understanding of the pedology of the El Kala region. Subsequently, several studies on the soils of the region, particularly those of the **Lake Tonga basin**, were carried out **(Fig. 7).**

In 1983, these investigations were resumed and refined by the Hydrological Studies Company of Constantine. **Durand (1952)** distinguished ten (10) soil types, which he classified into two major categories: zonal soils and azonal soils.

The soil types described are:

1. Dune soil
2. Marsh soil
3. Non-flooded peat soil
4. Oxhydric soil
5. Meadow soil
6. Podzol
7. Hydromorphic soil
8. Acid soil
9. Alluvial soil
10. Water-saturated soil (or Saturated soil)

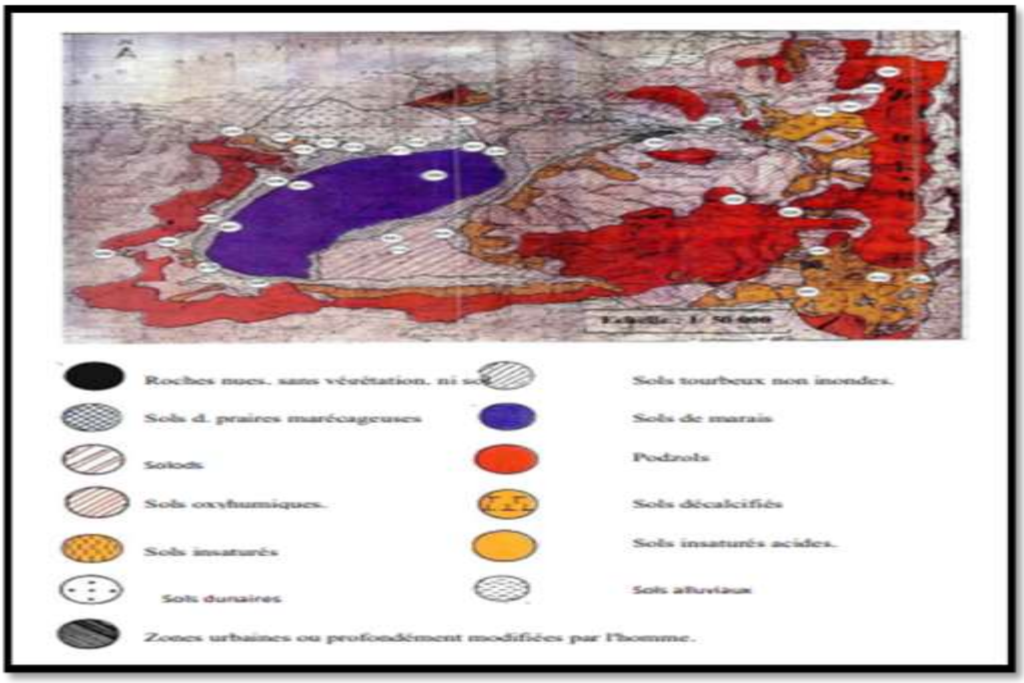


Figure 7: Soil Map of the Lake Tonga Watershed **(Landscap amenagement, 1998)**

1.3.2. Geology

The geology of the region, and more precisely the Lake Tonga watershed, of which Messida Wadi is part, is composed of various geological formations: marsh soils, formed from lowland silts; silty alluvial deposits, formed of recent sands and silts; Pontian formations, composed of conglomerates with clayey cement; Numidian sandstones, which are quartz-rich, whitish, forming steep reliefs; Numidian clays, composed of clayey-schistose marls; Middle Eocene clays, sandstones and black limestones, which constitute the foothills surrounding the lake **(Raachi, 2007) (Fig. 8).**

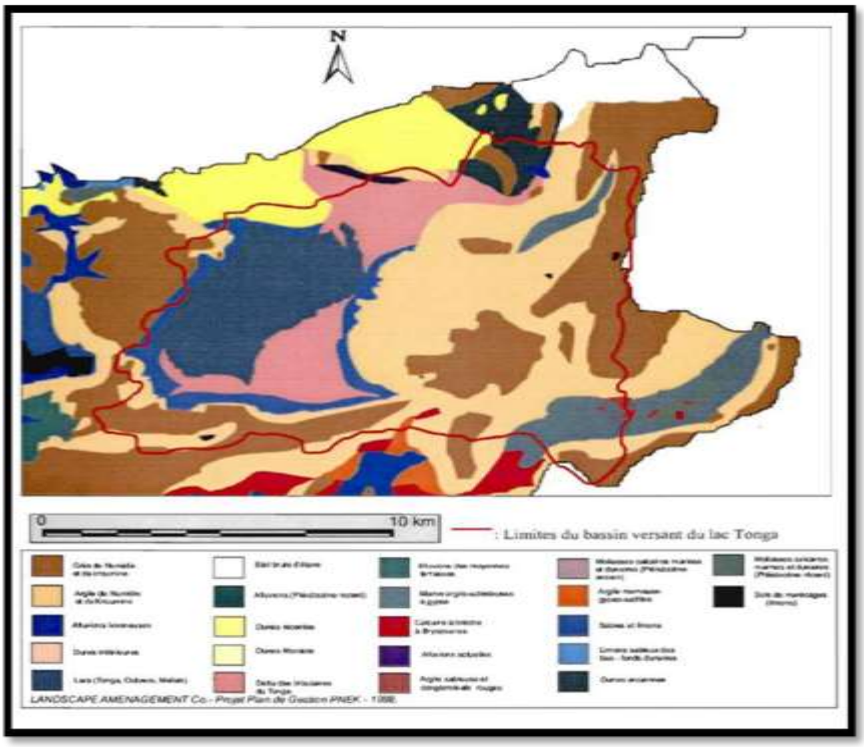


Figure 8: Geological map of the study area **(Landscapamenagement, 1998)**

1.3.3. Hydrologie

The hydrographic network of the watershed includes all the watercourses draining the territory of the watershed. It comprises all the channels and streams leading to the main watercourse. It presents two major watercourses that flow throughout the year toward Lake Tonga (Oued El Hout, 14 km long, and Oued El Eurg, 10 km long) **(Fig. 9).**

These two wadis have had the capacity to build deltas thanks to a torrential flow upstream resulting from the development of their sub-watersheds. Whereas the surroundings of Lake Tonga are eroded by a non-hierarchical network **(Raachi, 2007).**

In general, the hydrological network of the region is not sufficiently developed; the beds of these wadis have a very low capacity and are therefore not suitable for the drainage of rainwater or floodwaters. Such a hydrographic network only accentuates the phenomenon of hydromorphic conditions in this area **(Benslama, 1993).**

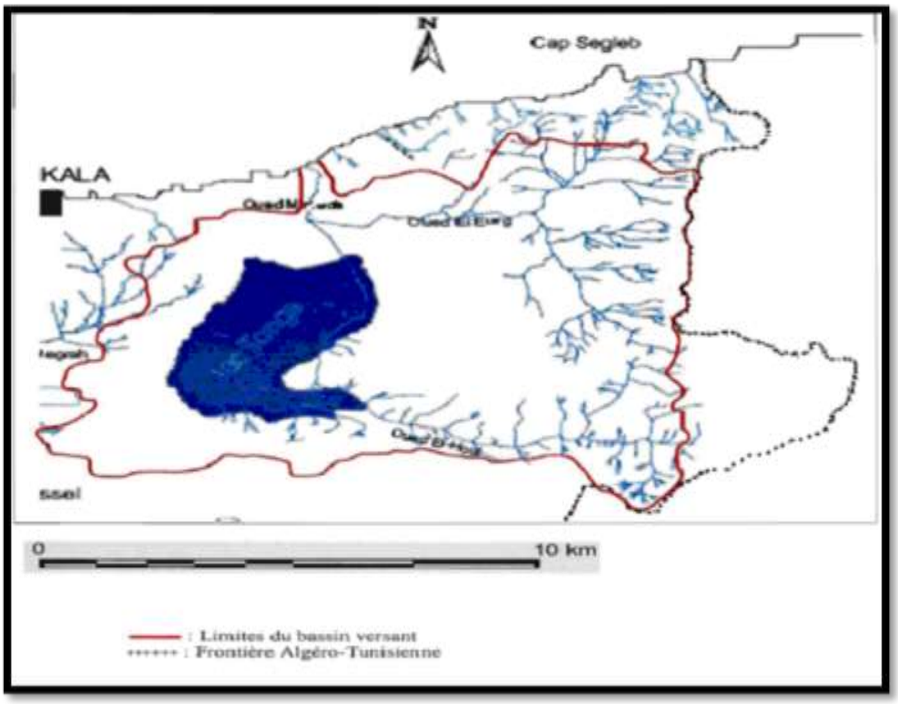


Figure 9: Map of the river system in the study area **(Landscap amenagement, 1998)**

1.3.4. Climatic Conditions

The El Kala region is characterized by a Mediterranean climate with abundant rainfall during the wet season and the cold months, and by drought during summer **(Ozenda, 1982; Samraoui and De Belair, 1998).**

1.3.4.1. Average Monthly Temperatures

Air temperature is a determining factor in regulating water losses due to evapotranspiration. The study of average monthly temperatures is therefore crucial for estimating flow deficits in watersheds **(Ramade, 2003).**

Temperature is a key climatic element because its variations directly influence evaporation and evapotranspiration, thus affecting the salinity level of water bodies. **Toubal (1986)** states that this parameter is modulated by altitude, proximity to the sea, and seasonal variations.

Temperature data **(Table 2)** reveal that the months of July and August are the hottest in the study region, with a maximum average temperature of 43.5°C. In contrast, January recorded a minimum average temperature of 23.8°C. The monthly average temperatures recorded in the study area range between 25.7°C in August and 11°C in February.

Table 2. Average monthly and extreme temperatures (°C) recorded in the study area (2010–2023). **(ONM, 2024)**

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Average
Extreme Temperatures (°C)	23.8	28.8	36.0	37.8	37.5	42.4	43.5	43.5	41.8	40.4	31.6	27.8	43.5
Maximum Temperatures (°C)	16.1	15.2	18.3	21.1	22.9	27.5	30.3	31.2	28.7	26.2	21.3	17.6	23.1
Minimum Temperatures (°C)	8.1	7.0	9.2	10.8	12.9	15.9	19.5	20.2	18.8	16.3	12.6	9.3	13.4
Average Temperatures (°C)	12.1	11.0	13.8	15.9	17.9	21.7	24.9	25.7	23.7	21.3	16.8	13.5	18.2

1.3.4.2. Monthly Precipitation

Precipitation plays an essential role in ecosystems, not only for the proper functioning and distribution of limnetic ecosystems **(Ramade, 2003),** but also for all biological activities, particularly photosynthesis **(Ozenda, 1975) (Table 3).**

Table 3: Average monthly precipitation (2010–2023) in the study area **(ONM, 2024)**

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average	6.5	9.1	7.7	5.4	4.5	3.4	3.0	9.7	7.8	9.4	7.8	7.1

1.3.4.2. Winds

Winds have a significant influence on the region, characterized by their frequency, direction, and speed **(Raachi, 2007).** The dominant winds, particularly in winter, come from the northeast **(Samraoui and De Bélair, 1998).** These winds are associated with equinox rains, bringing the most important precipitation of Atlantic origin. In contrast, during summer, the Sirocco, a southeast wind, dries the atmosphere and, combined with high temperatures, contributes to an increased risk of forest fires **(De Bélair, 1990) (Fig. 10).**

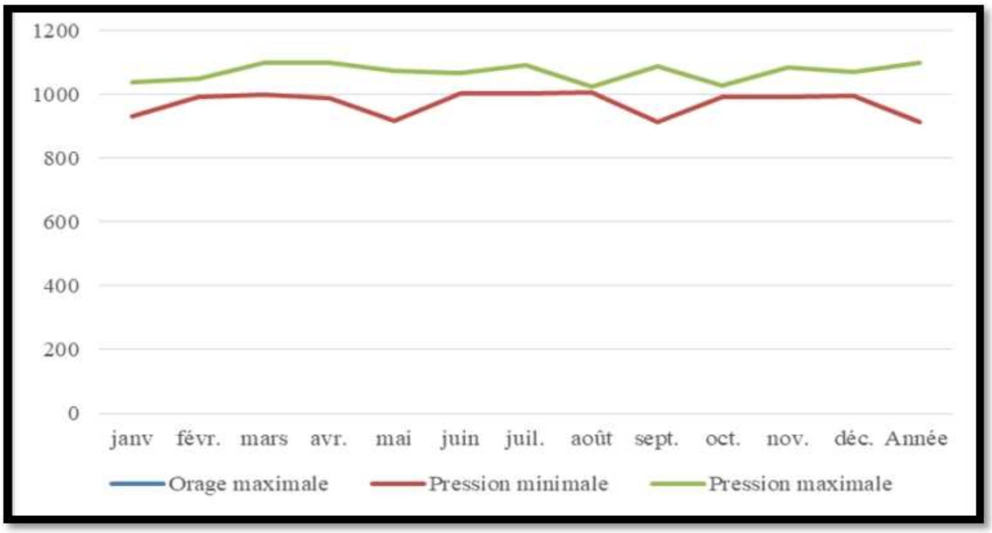


Figure 10 : Changement des pressions mensuelles de la région d'El Tarf (2010–2023) **(ONM, 2024)**

2. Methodology

2.1. Selection of Study Stations

The selection of study stations was carried out to ensure the representativeness of different aquatic environments. Thus, six stations were selected and distributed across two main sites: three within Lake Tonga and three others along Oued Missida. This sampling strategy aims to analyze the structure and distribution of macroinvertebrates, as well as to compare the ecological quality of these two ecosystems **(Fig. 11 and 12).**

Figure 11: Oued Missida Sampling Station **(©Bounasri Lamis,2026)**

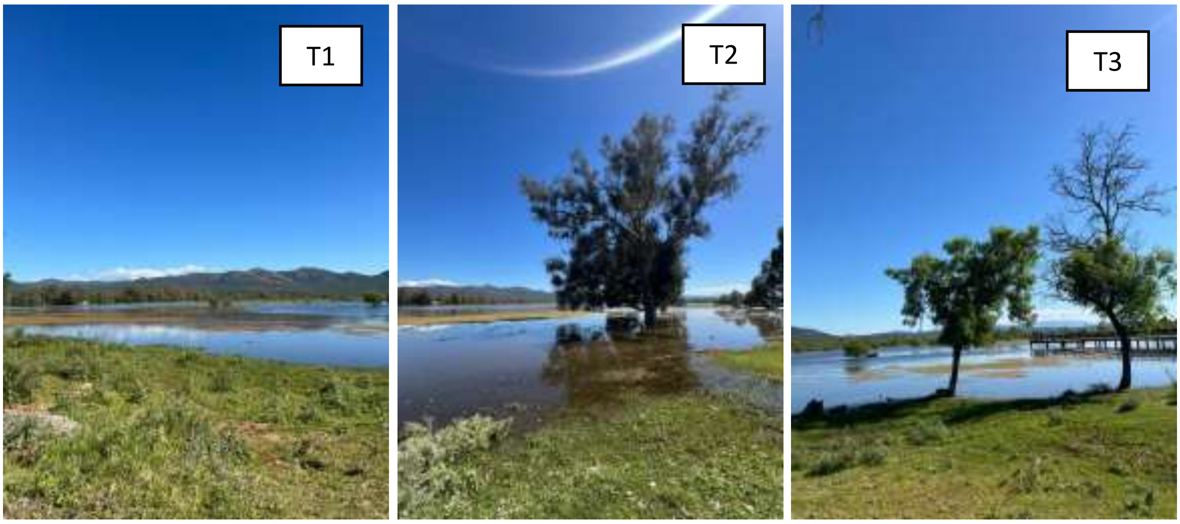


Figure 12: Lake Tonga Sampling Station **(©Bounasri Lamis, 2026)**

2.2. Materials Used

For the implementation of sampling and analyses, various tools were used both in the field and in the laboratory.

2.2.1. In the field

- Net
- Sieve
- Labels
- Field notebook
- Camera
- Entomological forceps
- Plastic vials
- Ethanol

2.2.2. In the laboratory

- Binocular magnifying glasses
- Petri dishes
- Notebook
- Tubes
- Labels
- Identification guides (Tachet et al., 2010)
- Ethanol
- Wash bottle
- Entomological forceps
- Gloves and masks

2.3. Study Methods

2.3.1. Sampling period

Macroinvertebrate sampling was carried out during the spring season from Mars-May 2026 .

2.3.2. Benthic fauna sampling methods

2.3.2.1. Sampling techniques

Macroinvertebrate sampling was conducted following a standardized protocol based on a fixed number of net sweeps, applied uniformly across all stations to ensure data comparability. Sampling was performed using a hand net with a mesh size of 0.3 mm. Particular attention was given to the diversity of available microhabitats, especially mud and aquatic vegetation, which were surveyed in a balanced way to ensure optimal representativeness of benthic communities.

The net contents, consisting of plant debris, sediments, and organisms, were transferred into a container and carefully rinsed with water to remove excess fine material. The sample was then sieved to facilitate organism recovery. Macroinvertebrates were manually sorted using soft entomological forceps to preserve their integrity.

Collected specimens were preserved in vials containing 90% ethanol to ensure proper conservation for subsequent analyses. Careful labeling was performed directly in the field, indicating essential information such as sampling date, site, and station. Finally, all samples were transported to the laboratory, where they underwent detailed sorting, taxonomic identification, and ecological analysis **(Fig. 13).**

Figure 13 : Technique for sampling benthic fauna **(©Bounasri Lamis, 2026)**

2.3.2.2. Sorting and Identification Techniques

The identification of macroinvertebrates was carried out using a binocular stereomicroscope for large individuals and a microscope for the observation of small organisms or body parts. This step aims to determine the taxa present in the samples, thereby allowing the assessment of biological diversity and the identification of groups that are most sensitive to pollution **(De Pauw and Vanhooren, 1983).**

Macroinvertebrates were identified at the most precise possible taxonomic level, generally to genus or species, using specialized reference books, reference collections, and identification keys **(Tachet *et al.*, 2010) (Fig. 14).**

Figure 14 : Techniques for sorting and identifying benthic fauna **(©Bounasri Lamis, 2026)**

3. Methods for the Analysis of Benthic Communities

In order to synthesize data related to the status of aquatic ecosystems, several biological indices based on benthic invertebrates are commonly used. These indices allow the assessment of the biological quality of aquatic environments through a synthetic and representative value **(Boissonneault, 2006).**

These are mathematical tools providing information on the structure of communities, particularly by facilitating the rapid estimation of their diversity. Thus, the evaluation of parameters such as taxonomic richness, species diversity, and evenness is essential for characterizing a community, comparing different communities, or monitoring the evolution of the same community over time **(Barbault, 1981).**

Moreover, these indices have the advantage of taking into account the relative abundance of species, thus allowing comparisons between communities and the analysis of their spatio-temporal dynamics **(Dajoz, 1985).**

3.1. Diversity indices

A number of indices are used to characterize a community, to globally compare different communities, or to assess the state of the same community studied at different times **(Barbault, 1995).**

3.2. Ecological composition indices

The ecological composition indices used are species richness (S), relative frequency (F%) or relative abundance (AR), and frequency of occurrence (Fi%).

3.2.1. Species richness (total)

According to **Blondel (1979),** richness is the total number of species in a community within a given ecosystem. It represents one of the fundamental parameters characterizing a community **(Muller, 1985).** It is the most commonly used measure in biodiversity **(Ramade, 2003).**

3.2.2. Species abundance

Abundance of an organism is the total number of that organism or the number of organisms per unit area or volume. In the face of pollution, species will show three types of responses depending on their sensitivity:

- Disappear, for the most sensitive species.
- Persist, for indifferent species.
- Benefit from the new conditions and develop, for tolerant and opportunistic species.

These different responses are reflected in species abundance. Temporal abundance patterns are therefore widely used as indicators of the effects of pollutants.

3.2.3. Relative abundance or relative frequency

Relative abundance (AR) is a concept that allows the evaluation of a species, category, class, or order (ni) relative to the entire animal community (N) in an inventory **(Faurie et *al.*, 2003).** It is calculated as follows:

F (%) = (ni / N) × 100

ni = number of individuals of species i.

N = total number of individuals.

3.2.4. Frequency of occurrence or constancy

Constancy is expressed as the number of sampling units containing the studied species relative to the total number of sampling units (Dajoz, 1982). It is calculated using the following formula:

Fi (%) = (Pi / P) × 100

Pi = number of sampling units containing the studied species.
P = total number of sampling units.

According to the value of Fi, the following categories are distinguished:

- If Fi = 100% → the species is omnipresent
- If 75% ≤ Fi < 100% → the species is constant
- If 50% ≤ Fi < 75% → the species is regular
- If 25% ≤ Fi < 50% → the species is accessory
- If 5% ≤ Fi < 25% → the species is accidental
- If Fi < 5% → the species is rare

3.3. Ecological structure indices

3.3.1. Shannon–Weaver diversity index (H')

Community diversity expresses the degree of complexity of a community. It is expressed by an index that integrates both species richness and species abundances. Among the available indices used to express community structure and characterize ecosystem balance is the Shannon index:

$H' = - \Sigma Pi \, Log2 \, Pi$ where $Pi = ni / N$

This index, expressed in bits, measures the degree of complexity of a community. A high value of this index corresponds to a species-rich community with a balanced distribution of abundance. Conversely, a low value corresponds either to a community characterized by a small number of species with a large number of individuals, or to a community dominated by a single species. Its value ranges from 0 (one species) to log S (when all species have the same abundance).

3.3.2. Evenness index (E)

Communities with very different appearances may have the same diversity. It is therefore necessary to calculate evenness alongside diversity. This index expresses the distribution of individuals among species in a given environment. The evenness index ranges from 0 to 1. If E approaches 1, the community is balanced, and the distribution of individuals among species is even. Conversely, an evenness approaching zero characterizes an unbalanced community **(Barbault, 1981).**

$E = H' / H' \max$ or $H' \max = Log2 \, S$

H' = Shannon–Weaver index.

S = species richness.

3.3.3. Margalef index (Margalef, 1951)

This index is particularly used to compare diversity between different sites or periods **(Margalef, 1951).** It is defined by the following relationship:

$\alpha = (ni - 1) / \log N$

With:

- ni = number of individuals of the species ranked i
- N = total number of individuals

Diversity is minimal when α tends toward zero (0) and maximal when α tends toward infinity (∞).

3.3.4. Bray–Curtis dissimilarity index

The Bray–Curtis index is a dissimilarity index used to assess differences in composition between two biological communities by taking into account taxon abundances. Its value ranges between 0 and 1, where a value close to 1 indicates strong dissimilarity between communities.

3.3.5. Jaccard similarity index

The Jaccard index is a similarity index used to compare the faunal composition of two stations or biological communities based on the presence or absence of taxa. Its value ranges between 0 and 1, where a high value indicates strong similarity between communities.

3.3.6. Assessment of the biological quality of watercourses

The assessment of the biological quality of watercourses is based on the analysis of biological communities, particularly benthic macroinvertebrates, which are excellent bioindicators of environmental conditions. Unlike physicochemical parameters, which reflect a punctual situation, living organisms integrate the effects of disturbances over a longer period, thus allowing a more reliable assessment of the ecological status of aquatic environments **(Rosenberg & Resh, 1993; Bonada et *al.,* 2006).**

Among the most widely used tools, biological indices based on organism tolerance to pollution play an important role. These indices are calculated by taking into account the sensitivity of macroinvertebrate taxa and their relative abundance in samples.

3.3.6.1. Pollution tolerance indices

Tolerance indices are based on the principle that some species are sensitive to pollution while others are tolerant. Thus, the composition of benthic communities can be used to estimate the level of environmental disturbance **(Hilsenhoff, 1988).**

3.3.6.2. Hilsenhoff index or Family Biotic Index (FBI)

The Family Biotic Index (FBI) is widely used to assess organic pollution in watercourses. It is based on a tolerance value assigned to each macroinvertebrate family, generally ranging from 0 (very sensitive) to 10 (very tolerant) **(Table 4).**

FBI = Σ xi × ti / n

xi = number of individuals of a given taxon.

ti = tolerance value of that taxon

n = total number of individuals in the sample

Table 4: Water quality associated with the Hilsenhoff index (FBI) **(Hilsenhoff, 1988).**

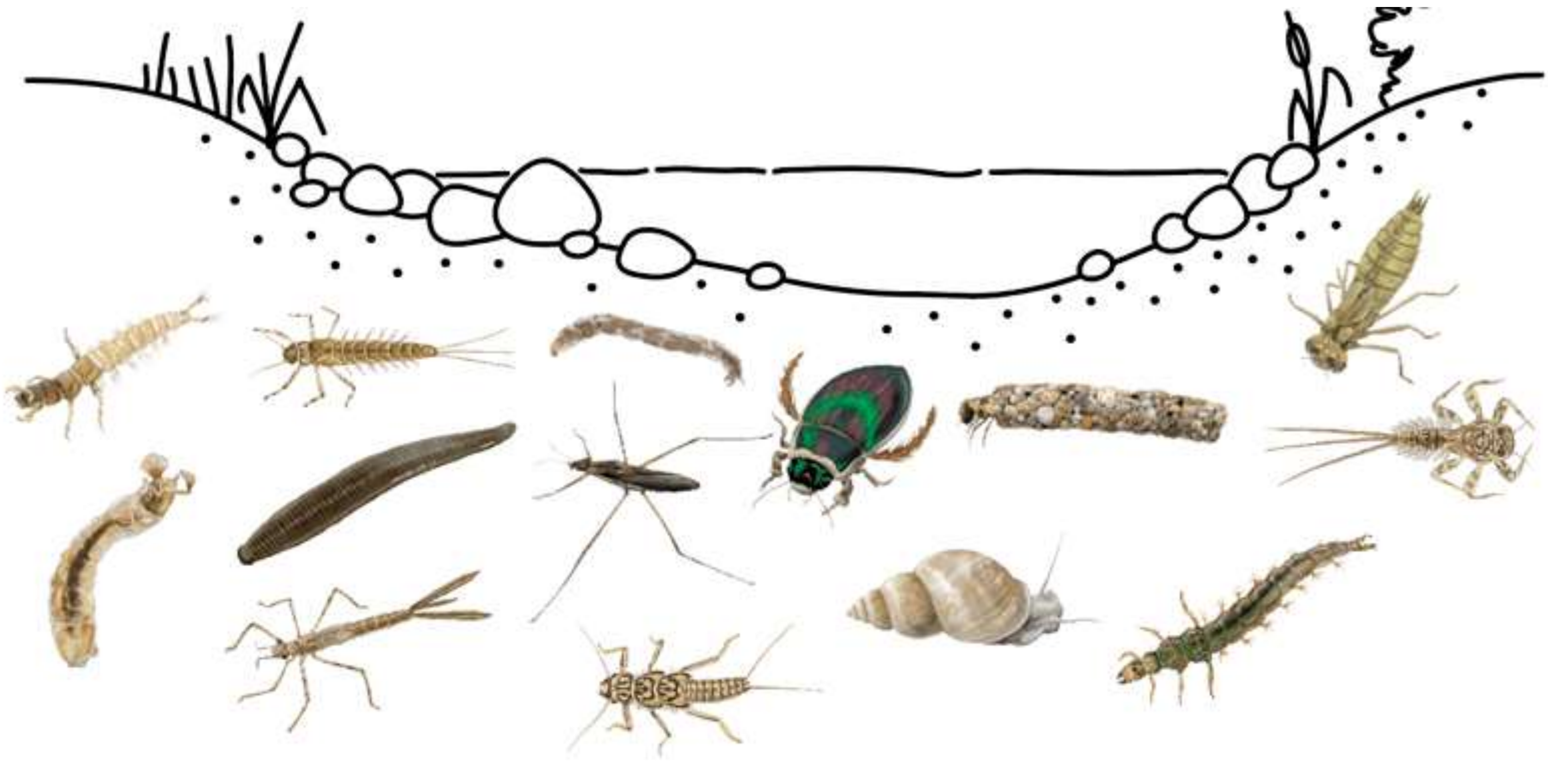
FBI	Water quality	Interpretation
0–3.75	Excellent	No organic pollution
3.76–4.25	Very good	Possible slight organic pollution
4.26–5.00	Good	Probable organic pollution
5.01–5.75	Fair	Considerable organic pollution
5.76–6.50	Fairly poor	Substantial organic pollution
6.51–7.25	Poor	Very substantial organic pollution
7.26–10.00	Very poor	Severe organic pollution

3.4. Statistical analysis

Statistical analyses of the data were performed using XLSTAT and PAST software, which allowed the execution of statistical and multivariate analyses as well as the generation of corresponding graphical representations.

Graphical representation of the results was carried out using Microsoft Excel software, mainly in the form of histograms and curves, in order to facilitate interpretation and comparison of the obtained data.

CHAPTER III: RESULTS AND INTERPRETATIONS



RESULTS AND INTERPRETATIONS

1. Analysis of benthic communities

Following the taxonomic analysis of benthic macroinvertebrates carried out in the laboratory, the different taxa identified at the two studied sites were inventoried and compiled into a faunal list. These results were subsequently grouped into a summary table **(Table 5).**

Table 4 : Abundance of macroinvertebrates recorded at Oued Messida and Lake Tonga.

Phylum	Subphylum	Class	Order	Family	Genus	Oued Messida	Lake Tonga
Arthropode		Insectes	Coleoptera	Hydrophilidae	*Hydrophilus*	12	22
				Dytixidae	*Dytixus (larve)*	41	48
					Ilybius ou Agabus	38	55
					Laccophilus	68	52
					cybister	36	46
					Hyphydrus	57	30
					Hygrotus	14	1
					Rhantus	29	26
					Hydroporus	20	16
				Hydrophilidae	*Laccobius*	158	60
				Hydrochidae	*hydrochus*	330	141
				Noteridae	*Noterus*	108	34
				Grinidae	*Gyrinus*	3	13
				Hydrenidae	*Limnebius*	7	3
				Hydroxaphidae		18	3
				Dryopidae		25	15
			Deptera	Culicidae	*Culex*	66	51
				Chironomidae	*Chironomus*	181	105
				Simulidae	*Similium*	39	42
				Tabanidae		59	13
			Odonata	Coenagrionidae	*Coenagrion*	2	8

				Zygopterae		2	26
				Libellulidae	*Libellula*	26	13
				Aeshnidae	*Aeshna*	49	59
			Hemiptera	Naucoridae	*Ilyocoris*	12	24
				Notonectidae	*Notonecta*	57	13
				Corixidae	*Sigara*	560	558
				Pleidae	*Plea*	104	96
				Naucoridae	*Naucoris*	69	45
				Fleidae		75	145
			Ephemeroptera	Baetidae	*Baetidae*	34	51
				Leptophlebiidae	*Leptophebida*	0	57
				Ephemeridae	*Ephemera*	48	2
			Trichoptera	Hydropsychidae	*Hydropyche*	13	16
				Limnephilidae	*Limnephilus*	27	0
			Megaloptera	Sialidae	*Sialis*	12	3
		Arachnida	Araneae	Lycosidae	*Pardosa*	1	3
			Trombidiformes	Hydrachnidae	*Hydeacha*	2	3
			Ixodida	Ixodidae	*Ixodes*	2	1
Mollusca		Gastropoda	Basomatophore	Physidae	*Physa*	94	295
	Crustacea	Branchiopoda	Anostraca	Artemiidae	*Artemia*	0	48
		Malacostraca	Amphipoda	Gammaridae	*Gammarus*	25	19
Annelida		Clitellata	Haplotaxida / Tubificida	Naididae	*Tubifex*	63	48
			Arhynchobdellida	Erpobdellidae	*Erpobdella*	1	2
				Hirudinidae	*Hirudo*	5	2
Nematoda		Enoplea	Dorylaimida			18	16

2. Ecological Composition Indices

2.1. Families Richness (Total)

2.1.1. Oued Messida

The macroinvertebrate community of Oued Messida is largely dominated by Coleoptera with 964 individuals, followed by Hemiptera (877 individuals) and Diptera (345 individuals). These three orders constitute the majority of the community and reflect their strong adaptation to the ecological conditions of the habitat. Basommatophora also show a notable abundance (94 individuals), while Ephemeroptera (82 individuals) and Odonata (79 individuals) are represented by intermediate abundances. Tubificida (63 individuals) and Trichoptera (40 individuals) are less abundant, whereas other groups, including Amphipoda (25 individuals), Dorylaimida (18 individuals), Megaloptera (12 individuals), and Arhynchobdellida (6 **individuals**), remain poorly represented. Araneae, Trombidiformes, and Ixodida were observed only in very low numbers (1 to 2 individuals), while Anostraca were completely absent. This structure reflects a community strongly dominated by a few taxa, with a low contribution from most of the other groups (**Fig. 15**).

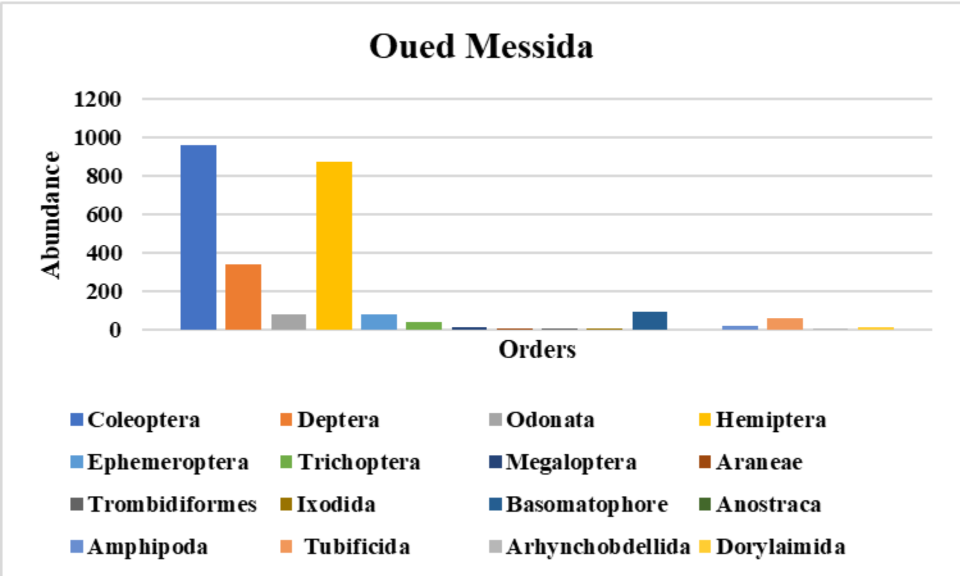


Figure 15: Taxonomic richness of benthic macroinvertebrates in Oued Messida**.**

2.1.2. Lake Tonga

At Lake Tonga, Hemiptera constitute the most abundant group with 881 individuals, followed by Coleoptera (656 individuals). Basommatophora rank third with 295 individuals, highlighting the particular importance of mollusks in this lacustrine ecosystem. Diptera (211 individuals), Ephemeroptera (110 individuals), and Odonata (106 individuals) also exhibit relatively high abundances. Anostraca, absent from Oued Messida, are represented here by 48 individuals, as are

Tubificida (48 individuals). Amphipoda (19 individuals), Trichoptera, and Dorylaimida (16 individuals) show lower abundances. Finally, Arhynchobdellida are represented by 4 individuals, whereas Megaloptera, Araneae, and Trombidiformes are each represented by 3 individuals. Ixodida remain very poorly represented, with only one individual recorded. The Lake Tonga community therefore appears more balanced, with a relatively important contribution of mollusks and several secondary groups, reflecting a greater diversification of the community compared with Oued Messida (**Fig. 16**).

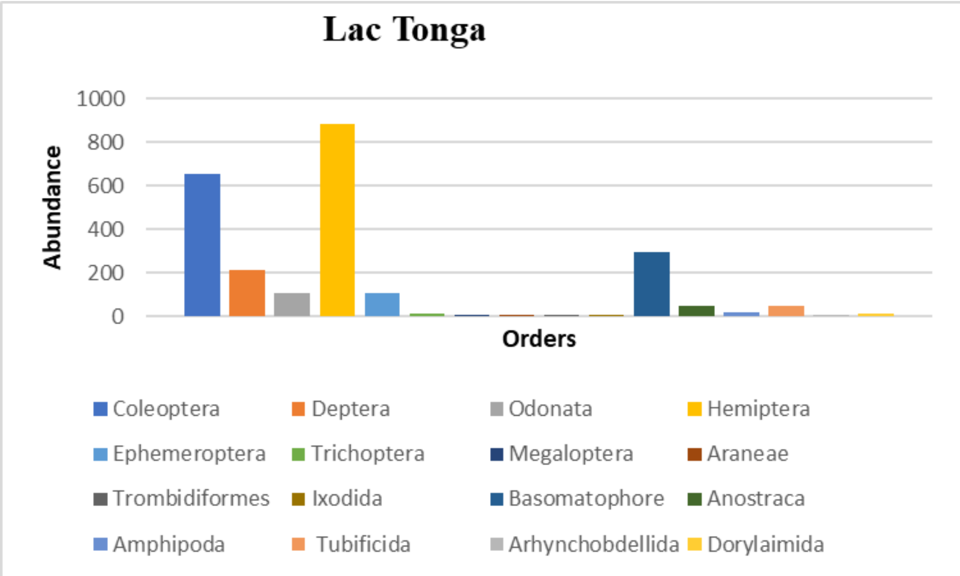


Figure 16: Taxonomic richness of benthic macroinvertebrates in Lake Tonga

2.1.3. Comparison between Oued Messida and Lake Tonga

The comparison between the two sites reveals a dominance of Coleoptera and Hemiptera. Coleoptera are more abundant at Oued Messida (964 individuals) than at Lake Tonga (656 individuals), whereas Hemiptera show similar abundances at both sites (877 and 881 individuals, respectively). Diptera are also more numerous at Oued Messida (345 individuals) than at Lake Tonga (211 individuals).

In contrast, Lake Tonga is characterized by higher abundances of Basommatophora (295 versus 94 individuals), Odonata (106 versus 79 individuals), and Ephemeroptera (110 versus 82 individuals). Anostraca are absent from Oued Messida but present at Lake Tonga (48 individuals).

Overall, Oued Messida is characterized by the strong dominance of a few taxa, whereas Lake Tonga supports a more diversified and better-balanced community **(Fig. 17).**

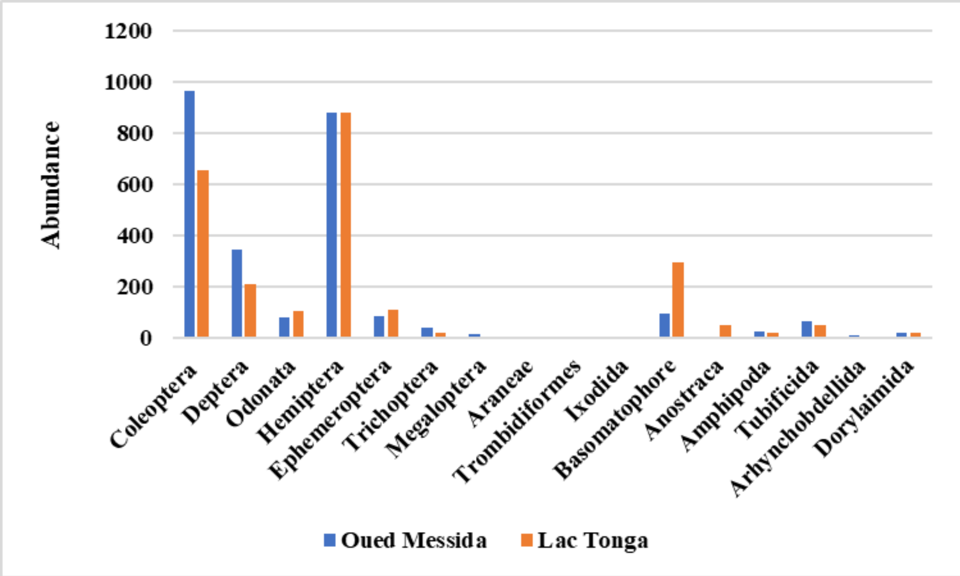


Figure 17: Difference between Oued Messida and Lake Tonga in terms of family richness.

2.2. Families Abundance

2.2.1. Oued Messida

The Oued Messida station exhibits a high abundance of benthic macroinvertebrates, mainly dominated by Corixidae (560 individuals), Hydrochidae (330 individuals), Dytiscidae (303 individuals), and Chironomidae (181 individuals). This strong representation of aquatic Coleoptera and Diptera reflects favorable ecological conditions, particularly the availability of food resources and the diversity of microhabitats.

Noteridae (108 individuals), Pleidae (104 individuals), and Physidae (94 individuals) are also well represented, indicating the presence of suitable habitats for the development of both benthic and nektonic organisms. The occurrence of sensitive families such as Hydropsychidae, Baetidae, and Limnephilidae also suggests a relatively satisfactory ecological quality of the environment.

In contrast, some families are poorly represented, including Lycosidae, Erpobdellidae, Hydrachnidae, and Ixodidae, with only one to two individuals recorded. This low abundance may be related to their specific ecological requirements or to the limited availability of suitable habitats. Overall, the dominance of aquatic Coleoptera and the diversity of the observed taxa indicate a relatively rich and functional ecosystem (**Fig. 18)**

Figure 18: Abundance of benthic fauna by family at Oued Messida

2.2.2. Lake Tonga

Lake Tonga is characterized by a high abundance of Corixidae (558 individuals), which also constitute the dominant group. This station is distinguished by the importance of Physidae (295 individuals), Dytiscidae (274 individuals), Hydrochidae (141 individuals), and Fleidae (145 individuals). The high abundance of Physidae reflects the presence of well-developed aquatic vegetation and a significant amount of organic matter favorable to mollusks. Chironomidae (105 individuals), Pleidae (96 individuals), and Aeshnidae (59 individuals) also show good adaptation to the lake conditions. The presence of Leptophlebiidae (57 individuals), absent from Oued Messida, may be considered an indicator of favorable ecological conditions for certain groups of Ephemeroptera.

The diversity observed in Lake Tonga is enhanced by the presence of several groups associated with vegetation-rich lentic environments, particularly Zygoptera, Coenagrionidae, and Physidae. The exclusive occurrence of Artemiidae in this station also reflects specific ecological characteristics of the lake. Overall, the faunal composition of Lake Tonga suggests a stable aquatic environment, rich in vegetation and providing a wide diversity of habitats favorable to the development of aquatic macroinvertebrates **(Fig. 19).**

Figure 19: Abundance by family of benthic fauna at Lake Tonga.

2. 3. Frequency of Occurrence

The comparative analysis of frequency of occurrence shows that several families are common to both stations, but with different levels of representation, reflecting variations in the ecological conditions of the studied environments.

In both stations, Corixidae constitute the most dominant family, accounting for 21% at Oued Messida and 24% at Lake Tonga, indicating their strong ability to adapt to the ecological conditions of both habitats. Dytiscidae also exhibit a high and comparable frequency in the two sites (12%), demonstrating their wide distribution.

However, some families show marked differences between the two stations. Hydrochidae are considerably more abundant at Oued Messida (13%) than at Lake Tonga (6%), suggesting that the conditions of this station are more favorable for this family. In contrast, Physidae display a much higher frequency at Lake Tonga (13%) than at Oued Messida (4%), indicating a better adaptation of these gastropods to the lake environment. Similarly, Fleidae are more represented at Lake Tonga (6%) than at Oued Messida (3%).

Chironomidae and Hydrophilidae also show higher frequencies at Oued Messida (7% and 6%, respectively) than at Lake Tonga (5% and 3%, respectively). Conversely, certain families such as

Leptophlebiidae and Artemiidae are absent or very rare at Oued Messida, whereas they are present at Lake Tonga, each representing 2% of the total individuals.

Overall, Oued Messida is characterized by a greater representation of aquatic beetles, particularly Hydrochidae and Hydrophilidae, whereas Lake Tonga is more strongly marked by the abundance of Physidae and certain specific families. These differences reflect the influence of the ecological conditions specific to each station on the composition and distribution of aquatic macroinvertebrates **(Fig. 20).**

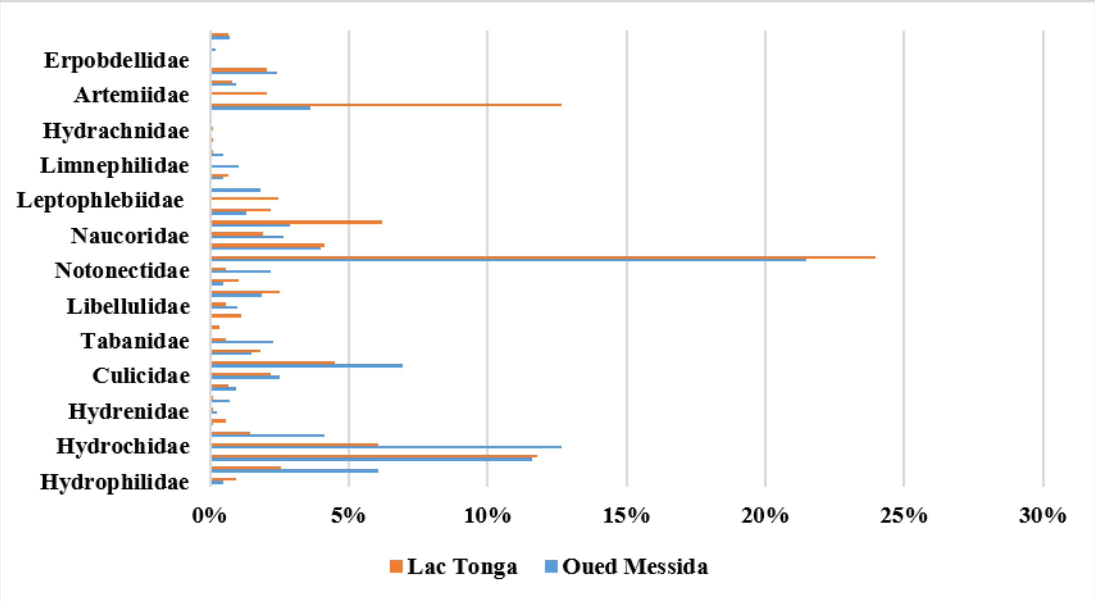


Figure 20 : Relative frequency of benthic fauna families at the study sites.

2.4. Structural Ecological Indices

2.4.1. Shannon Diversity Index (H')

The Shannon Diversity Index (generally denoted as H′) is a mathematical parameter used in ecology to assess the biodiversity of an ecosystem. Unlike simple species richness (the total number of taxa), this index takes into account both the number of species (or taxa) present and the evenness of their abundances (the distribution of individuals among the different taxa). The higher the value of the index, the more diverse, stable, and structurally balanced the environment is (**Fig. 21**).

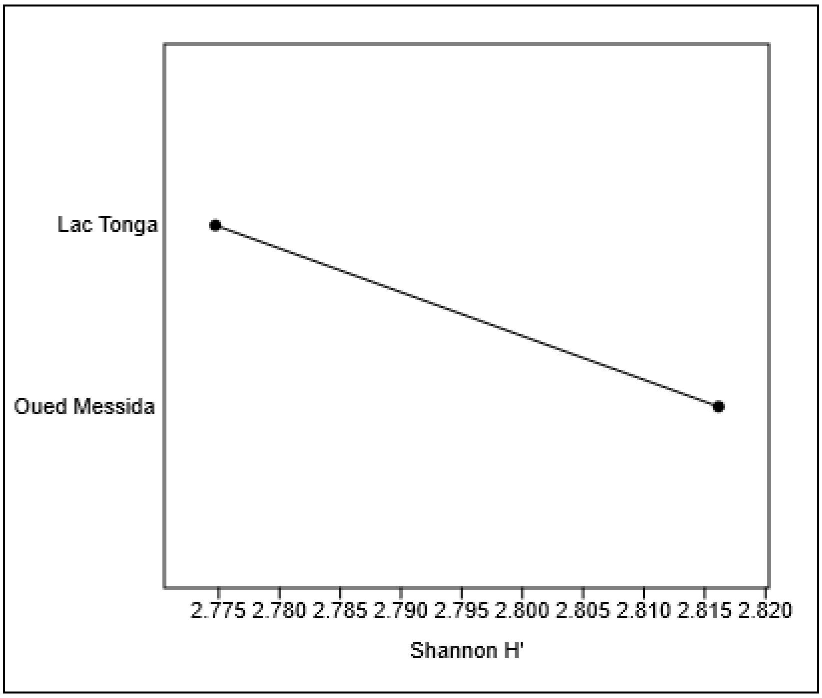


Figure 21: Shannon diversity index (H') of benthic macroinvertebrates from the study sites.

2.4.1.1. Oued Messida

The Shannon diversity index recorded at **Oued Messida** is **2.816**, indicating a relatively high species diversity. This value reflects the presence of a large number of taxa (**37 recorded taxa**) as well as a fairly balanced distribution of their abundances, without a marked dominance of one or a few species. Thus, the macrobenthic community at this site exhibits a diversified and generally well-balanced structure, reflecting favorable ecological conditions for the maintenance of biodiversity.

2.4.1.2. Lake Tonga

The Shannon diversity index value recorded at Lake Tonga is 2.775. This result, which is very close to that of Oued Messida, also indicates substantial biological richness and good ecological complexity within the lacustrine environment. However, the slight decrease observed suggests a somewhat less homogeneous distribution of individuals among taxa. This difference can be explained by the high abundance of a few dominant genera, such as Sigara (558 individuals) and Physa (295 individuals), which slightly reduces evenness compared to the Oued Messida watercourse.

The comparison of Shannon index values between the two sites highlights very similar levels of diversity. Oued Messida exhibits a slightly higher diversity than Lake Tonga, but the observed difference remains small (0.041), indicating a generally similar community structure in both environments. The recorded values, both exceeding 2.5, reflect a relatively high diversity, characteristic of ecosystems capable of supporting varied and balanced macrobenthic communities. This similarity in index values reflects comparable species richness between the two sites, with a slight tendency toward a more even distribution of individuals at Oued Messida, whereas Lake Tonga is distinguished by a slightly higher number of taxa.

2.4.2. Evenness Index (E)

The Pielou's Evenness Index (J) measures the uniformity of the distribution of individuals among the species present. It ranges from 0 (extreme dominance of a single species) to 1 (all species have exactly the same abundance). This index complements the Shannon diversity index by indicating whether the observed diversity results from high species richness or from a balanced distribution of individuals among species (**Fig. 22**).

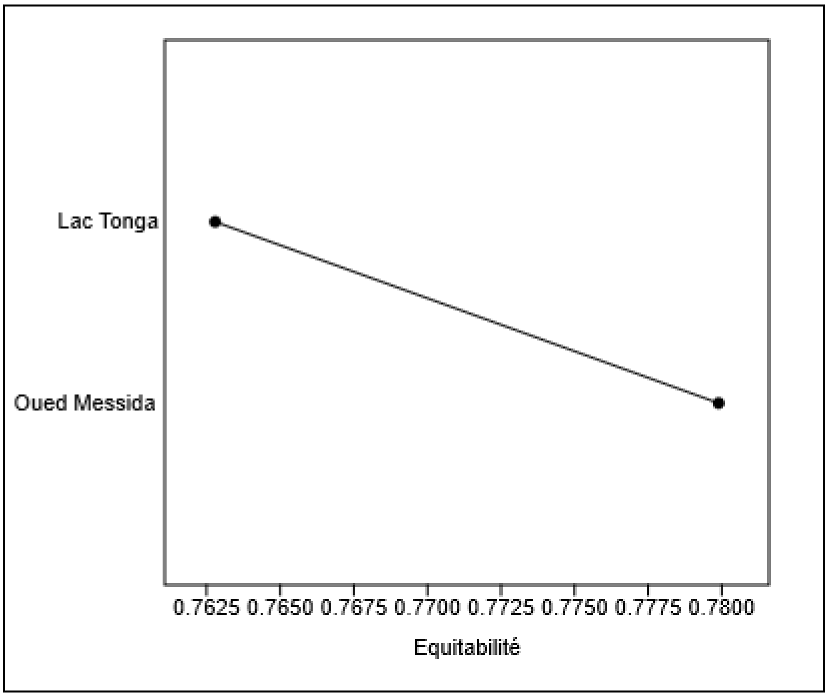


Figure 22 : Evenness diversity index (E) of benthic macroinvertebrates of study sites.

2.4.2.1. Oued Messida

The Pielou's Evenness Index (J = 0.778) indicates a relatively homogeneous distribution of individuals among the 37 recorded taxa. This value, which is fairly close to 1, reflects a generally balanced macrobenthic community characterized by good uniformity of abundances and low species dominance. Although some taxa, particularly Sigara, exhibit higher abundances, no species dominates sufficiently to cause a marked imbalance in the community structure. This situation reflects a well-organized and ecologically stable community.

2.4.2.2. Lake Tonga

The Pielou's Evenness Index (J = 0.761) reveals a generally regular distribution of individuals among the 38 recorded taxa. This relatively high value indicates a fairly balanced macrobenthic community, although it is slightly less homogeneous than that observed at Oued Messida. Indeed, certain taxa, such as Sigara and Physa, show higher abundances, which slightly increases their dominance and reduces the uniformity of individual distribution among species. Nevertheless, the community maintains an overall balanced and diversified structure.

The values of Pielou's Evenness Index are very similar at the two study sites (0.778 for Oued Messida and 0.761 for Lake Tonga). This small difference indicates that the communities have a comparable organization, with a slightly more homogeneous distribution of individuals at Oued Messida than at Lake Tonga.

2.5.2. Margalef Index (Margalef, 1951)

The Margalef Index measures the species richness (number of taxa) of an environment while correcting for the effect of sample size (the total number of individuals). Unlike raw species richness (**S**), this index allows a more reliable comparison of biodiversity between two stations with different abundances. The higher its value, the greater the taxonomic richness of the environment (**Fig. 23**).

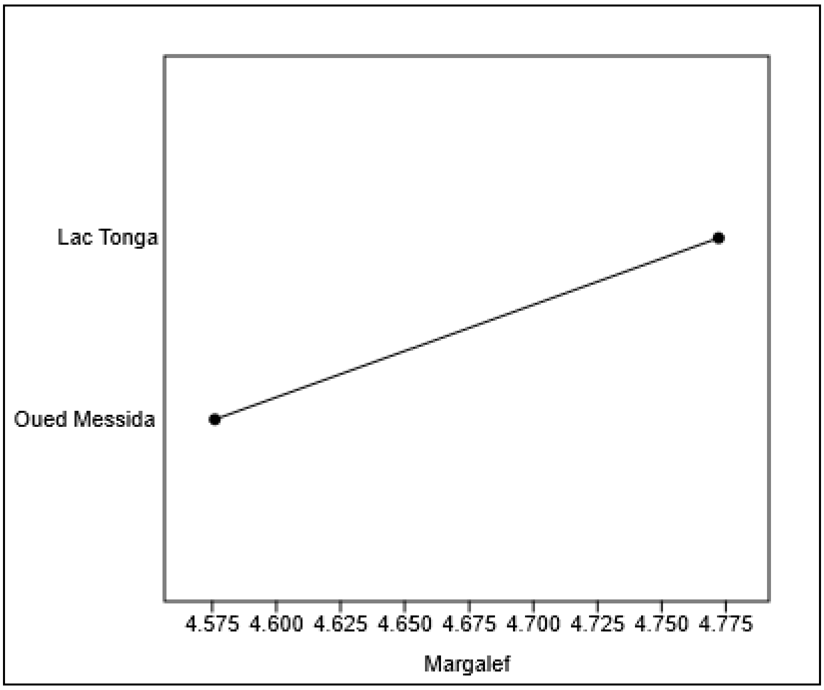


Figure 23 : Margalef diversity index of benthic macroinvertebrates of the study sites.

2.5.2.1. Oued Messida

The Margalef species richness index (Dmg = 4.576), calculated from 37 taxa and 2,610 individuals, highlights a relatively high taxonomic richness within this site. This value reflects the presence of a substantial number of taxa relative to the total sampled abundance, indicating appreciable species diversity. It therefore characterizes an environment favorable to the development of a varied macrobenthic community.

2.5.2.2. Lake Tonga

The Margalef index (Dmg = 4.772), calculated from 38 taxa and 2,329 individuals, indicates a high level of taxonomic richness within this lacustrine environment. This value, slightly higher than that observed at Oued Messida, reflects a relatively greater species richness when related to the total sampled abundance. Thus, despite the small difference in the number of taxa between the two sites, Lake Tonga exhibits slightly higher species diversity, indicating the presence of a greater number of taxa per unit of abundance. This situation reflects the capacity of the environment to support a rich and diversified macrobenthic community.

The comparative analysis shows that Lake Tonga (4.772) has a higher Margalef index than Oued Messida (4.576). Although the raw richness is nearly identical (38 taxa versus 37 taxa), the index is higher at Lake Tonga because this richness is associated with a smaller total sample size (2,329 individuals versus 2,610 individuals).

3. Community Comparison Indices

3.1. Bray–Curtis Dissimilarity Index

The Bray–Curtis dissimilarity index measures the ecological distance between two sites based on species abundances. It ranges from 0 (the two sites contain exactly the same species with the same abundances) to 1 (no species are shared or abundances are completely different). It is often expressed as the complement of similarity (1 − dissimilarity).

The hierarchical classification analysis based on the Bray–Curtis dissimilarity index highlights the similarity relationships among benthic macroinvertebrate families recorded at the two study sites (Oued Messida and Lake Tonga), taking into account their relative abundances. The resulting dendrogram reveals a structure composed of several groups of families exhibiting similar abundance patterns, reflecting both overall similarities and finer differences in community composition.

At a very low similarity level (approximately 18%), the community is divided into two major groups. The first group includes a small assemblage of families with low abundances or particular ecological characteristics, notably Hydrachnidae, Lycosidae, as well as certain leeches (Erpobdellidae and Hirudinidae) and taxa such as Gyrinidae and Coenagrionidae. These groups are generally characterized by low abundances and/or specific lifestyles (predators, surface-dwelling species, or inhabitants of marginal habitats), which explains their separation from the rest of the fauna.

The second group includes the majority of the recorded taxa and exhibits a more complex internal structure. An intermediate subgroup appears at around 45% similarity, composed of relatively abundant and dominant families such as Corixidae, Physidae, Dytiscidae, and Hydrochidae. Furthermore, several clusters occurring at high similarity levels (greater than 80–95%) indicate very similar abundance patterns between the two environments, as observed for Culicidae and Naididae.

Overall, this analysis indicates that the macrobenthic communities of Oued Messida and Lake Tonga are relatively comparable, while also highlighting structural differences related to the distribution and abundance of certain families, probably associated with the specific ecological conditions of each ecosystem (**Fig. 24**).

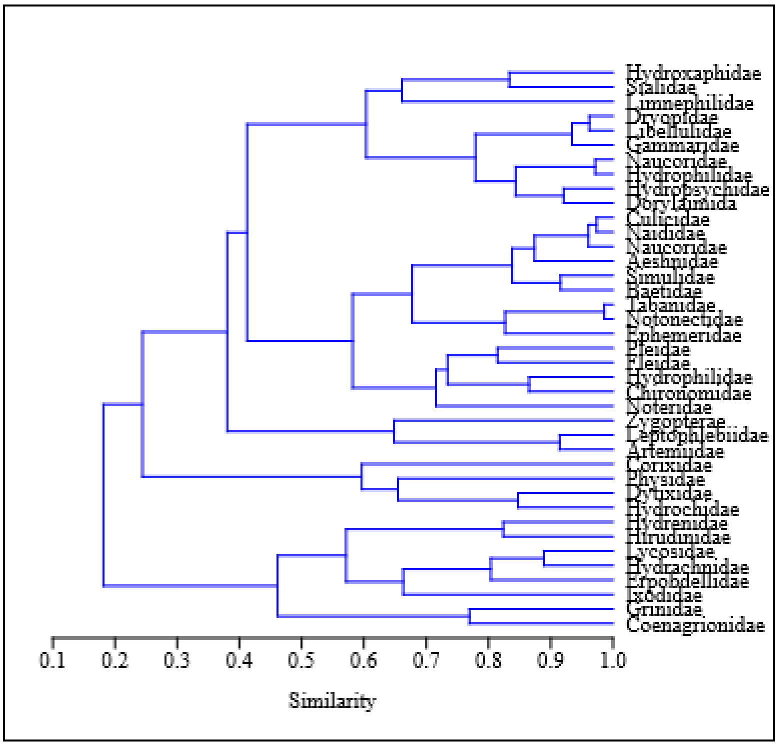


Figure 24: Bray Curtis diagram by family between Oued Messida and Lake Tonga.

3.2. Jaccard Similarity Index

The dendrogram based on the Jaccard similarity index groups the invertebrate families according to the similarity of their distribution (presence or absence) between Oued Messida and Lake Tonga. Unlike the previous analysis, the results here reveal an extremely homogeneous structure, where almost all families are clustered at a maximum similarity level of 1.00 (100% similarity).

This complete clustering on the right side of the dendrogram indicates that the vast majority of the collected taxa are ubiquitous within the study area, meaning that they occur simultaneously in both stations (Oued Messida and Lake Tonga). From a qualitative composition perspective, the two environments therefore share essentially the same invertebrate faunal assemblage.

However, the dendrogram highlights a clear separation at a similarity level of approximately 0.50 (50% similarity). At this threshold, several horizontal branches separate individually from the main cluster. These isolated branches represent taxa that occur in only one of the two stations (exclusive species). This is the case for families such as Leptophlebiidae, Ephemeridae, Limnephilidae, and Artemiidae. Since these families are found in only one site, their qualitative similarity with the rest of the community is logically reduced to 50%, explaining their early separation in the dendrogram (**Fig. 25**).

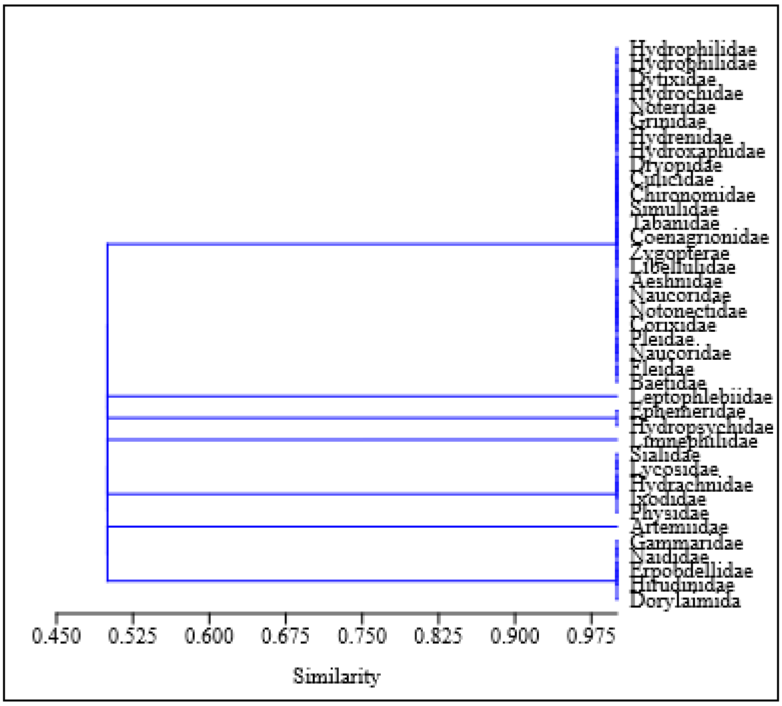


Figure 25 : Jaccard Similarity Index

4. Assessment of the Biological Quality of Watercourses

The assessment of the biological quality of watercourses is based on the use of synthetic indices derived from aquatic communities, particularly benthic macroinvertebrates. These indices make it possible to estimate the level of environmental disturbance (organic pollution, eutrophication, and physical habitat alterations) by considering the presence of sensitive or pollution-tolerant indicator species. The present study was conducted within this framework and aims to characterize the ecological status of the two study sites. The results presented below concern the different descriptors as well as the biological indices calculated for Oued Messida and Lake Tonga.

4.1. Hilsenhoff Index or Family Biotic Index (FBI)

The Family Biotic Index (FBI) is based on assigning each family a tolerance value ranging from 0 (species highly sensitive to organic pollution) to 10 (species highly tolerant to organic pollution). The FBI corresponds to the weighted average of tolerance values according to the relative abundance of the taxa. The calculation was performed using all recorded taxa after assigning tolerance values according to the reference system established by Hilsenhoff (1987) **(Table 6).**

Table 5 : Calculation of the FBI index for study sites.

Family	Oued Messida (n)	Lake Tonga (n)	Tolerance Value (t)	Oued Messida (n × t)	Lake Tonga (n × t)
Culicidae	66	51	8	528	408
Chironomidae	181	105	6	1086	630
Tabanidae	0	59	6	0	354
Simuliidae	39	42	6	234	252
Naucoridae (*Naucoris*)	69	45	7	483	315
Naucoridae (*Ilyocoris*)	12	24	7	84	168
Notonectidae	57	13	5	285	65
Corixidae	560	558	5	2800	2790
Pleidae	104	96	5	520	480
Dytiscidae (all genera)	303	274	5	1515	1370
Hydrophilidae (*Hydrophilus*)	12	22	5	60	110
Hydrophilidae (*Laccobius* and others)	158	60	5	790	300
Hydrochidae	330	141	5	1650	705
Noteridae	108	34	5	540	170
Gyrinidae	3	13	5	15	65
Baetidae	34	51	4	136	204
Leptophlebiidae	0	57	2	0	114
Ephemeridae	48	2	1	48	2
Hydropsychidae	13	16	4	52	64
Limnephilidae	27	0	3	81	0
Aeshnidae	49	59	3	147	177
Zygoptera	2	26	5	10	130
Erpobdellidae	1	2	8	8	16
Hirudinidae (*Hirudo*)	5	2	10	50	20
Other taxa (not	—	—	—	35	63

assigned)					
TOTAL	2610	2329	—	11117	10622

- **Oued Messida**

FBI – Oued Messida = 11117 / 2610 ≈ 4.26

- **Lake Tonga**

FBI – Lake Tonga = 10622 / 2329 ≈ 4.56

The assessment of water quality using Hilsenhoff's Family Biotic Index (FBI) highlights an overall good ecological condition for both studied stations. At Oued Messida, the index shows a value of 4.26. According to Hilsenhoff's standard classification scale, this result places the watercourse in the "Good" quality category, indicating slight organic pollution. This value is explained by the dominance of families with intermediate to low tolerance scores, reflecting a system where water renewal and oxygenation remain functional.

For Lake Tonga, the FBI value reaches 4.56. This result also classifies the lacustrine ecosystem as "Good" quality, with low organic pollution. The slight increase in the index (+0.30) compared to the stream reflects the transition to a lentic (stagnant) environment. Such conditions naturally promote a higher accumulation of organic matter and a temporary decrease in dissolved oxygen, leading to the development of slightly more tolerant organisms, without significantly affecting the overall biological balance of the lake.

4.2. BMWP Index (Biological Monitoring Working Party)

The BMWP index is a biological scoring system based on the presence of benthic macroinvertebrate families, designed to assess overall water quality, particularly in relation to organic pollution. The final score is obtained by summing the sensitivity scores assigned to each recorded family (**Tables 7 and 8**).

Table 6 : BMWP scores specific to each family.

Order	Family	BMWP Score
Coleoptera	Hydrophilidae, Dytiscidae, Hydrochidae, Noteridae, Gyrinidae, Hydraenidae, Dryopidae, Hydroxaphidae	5
Diptera	Simuliidae, Tabanidae	5
Diptera	Chironomidae, Culicidae	2
Odonata	Libellulidae, Aeshnidae	8
Odonata	Coenagrionidae	6
Hemiptera	Naucoridae, Notonectidae, Corixidae, Pleidae	5
Ephemeroptera	Ephemeridae, Leptophlebiidae	10
Ephemeroptera	Baetidae	4
Trichoptera	Limnephilidae	7
Trichoptera	Hydropsychidae	5
Megaloptera	Sialidae	4
Araneae	Lycosidae	5
Trombidiformes	Hydrachnidae	4
Gastropoda	Physidae	3
Amphipoda	Gammaridae	6
Haplotaxida	Naididae / Tubificidae	1
Arhynchobdellida	Erpobdellidae, Hirudinidae	3
Dorylaimida	Nematoda (Dorylaimida)	1

Table 7 : Summary of BMWP scores and organic quality classes

Station	BMWP Score Obtained	Quality Class	Ecological Meaning
Oued Messida	153	Class I	**Excellent quality** (clean, unpolluted water)
Lake Tonga	161	Class I	**Excellent quality** (clean, unpolluted water)

The overall biological quality assessment using the BMWP (Biological Monitoring Working Party) index highlights an excellent ecological status for both studied ecosystems. For Oued Messida, the index shows a cumulative score of 153. According to the standard interpretation scales of this index, any score above 100 classifies the site in the "Excellent" quality category (Class I: clean, unpolluted waters). This result is explained by the high taxonomic diversity of the station and the presence of pollution-intolerant aquatic insect families (such as Ephemeridae or Aeshnidae).

For Lake Tonga, the BMWP score is 161. This value also places the lacustrine ecosystem in the "Excellent" quality class (Class I). The slight increase in the lake score (+8 points) compared to the stream does not reflect a difference in pollution, but is directly due to the presence of a few additional taxa from stagnant environments with intermediate or high sensitivity (such as Leptophlebiidae and Artemiidae), which mechanically increases the sum of qualitative presence scores. In conclusion, both stations show remarkable biological integrity, characterized by a high proportion of sensitive taxa.

5.ASPT (Average Score Per Taxon) associated with BMWP

The ASPT index corresponds to the average of the sensitivity scores of the taxa present in the sample. It is calculated by dividing the total BMWP score by the total number of indicator families counted for this score. While BMWP can increase artificially with the number of taxa, ASPT standardizes the result and isolates the average sensitivity level of the community. A high ASPT value (generally above 6) indicates a community dominated by sensitive organisms, characteristic of a clean and well-oxygenated environment.

Oued Messida:

Sum of BMWP scores = 153 (previously calculated)

Number of families = 32

ASPT – Oued Messida = 153 / 32 = 4.78

Lake Tonga:

Sum of BMWP scores = 161

Number of families = 33

ASPT – Lake Tonga = 161 / 33 = 4.88

The analysis of the ASPT index (Average Score Per Taxon) provides an important nuance to the biological assessment of the study area. At Oued Messida, the index shows an average value of 4.78. According to ASPT interpretation scales, a value between 4.5 and 5.5 indicates moderate or fair water quality, revealing a system subject to slight to moderate organic enrichment. This result shows that although the BMWP score is overall high due to high family richness, the intrinsic community structure remains dominated by taxa with intermediate sensitivity (BMWP score of 5), which lowers the average per taxon.

For Lake Tonga, the ASPT value is 4.88. This result also places the lacustrine ecosystem in the moderate quality class, showing a very similar biological situation to that of the stream (difference of only +0.08). The relative stability of this index between the two stations confirms that, although Lake Tonga presents a higher raw BMWP score due to the presence of additional taxa (such as Leptophlebiidae), the average sensitivity of its biocenosis remains aligned with the same ecological profile as Oued Messida, characterized by a strong dominance of moderately tolerant macroinvertebrates.

DISCUSSION

DISCUSSION

The results obtained revealed that both stations exhibited high and globally comparable taxonomic richness, with 37 taxa recorded in Oued Messida and 38 taxa in Lake Tonga. This richness exceeds that reported in several studies conducted in similar aquatic environments in Algeria. For instance, **Meradi et *al.*, (2024)** recorded 26 insect families in Oued Bouilef (Belezma Biosphere Reserve) during a one-year monitoring period, while a study conducted in the Abiod Basin (Aurès region) identified 25 macroinvertebrate families belonging to four major zoological groups. Likewise, 38 taxa were inventoried in the Mediterranean urban pond of Boussedra (Northeastern Algeria). The high richness observed in the present study therefore highlights the biodiversity potential of both ecosystems and reflects the favorable ecological context of the El Kala region, which is well known for its remarkable biological diversity. The relatively similar richness recorded in both environments may be attributed to their geographical proximity and the existence of ecological conditions favorable to the maintenance of diverse benthic communities, despite differences between the lotic environment of Oued Messida and the lentic environment of Lake Tonga.

In terms of abundance, Oued Messida contained 2,610 individuals compared with 2,329 individuals in Lake Tonga, indicating a slightly higher benthic population density in the lotic environment. This difference may be related to greater substrate heterogeneity and increased trophic inputs promoted by the continuous renewal of water (**Ward, 1992; Townsend *et al.*, 2008)**. **Meradi et *al.*, (2024)** also demonstrated that pebble and boulder substrates provide particularly favorable habitats for the colonization of benthic insects in Algerian streams, with higher abundances observed during wet periods.

The analysis of relative abundances further revealed a strong community structure dominated by a few major groups, particularly Hemiptera and Coleoptera. Corixidae represented the most abundant family in both stations, with 560 individuals in Oued Messida and 558 individuals in Lake Tonga. This dominance, frequently reported in North African wetlands, can be explained by the remarkable adaptability of these organisms, which are capable of colonizing both lentic and lotic environments owing to their high mobility and diversified feeding habits. Hydrochidae also occupied an important position within the studied communities, with 330 individuals in Oued Messida compared with 141 individuals in Lake Tonga, confirming their affinity for aquatic habitats rich in organic matter.

Conversely, some families displayed a more contrasted distribution between the two environments. This was particularly the case for Physidae, which reached 295 individuals in Lake Tonga compared with only 94 individuals in Oued Messida. Their higher abundance in the lake is probably related to the characteristics of the lentic environment and the presence of macrophytes that provide suitable substrates for periphyton development, the primary food source of gastropods, while also offering protection from predators (**Allan & Castillo, 2007; Dudgeon, 2008**). These differences in distribution illustrate the influence of ecosystem-specific ecological conditions on the structure and organization of benthic communities.

The Shannon–Wiener diversity index (H′) is one of the most widely used diversity measures in community ecology because it incorporates both species richness and the distribution of abundances among taxa. It therefore provides a comprehensive characterization of community structure. The values obtained in this study were very similar for the two stations, reaching 2.816 in Oued Messida and 2.775 in Lake Tonga, indicating high diversity in both ecosystems. In general, values exceeding 2.5 are considered characteristic of relatively diverse and well-structured communities (**Krebs, 1999; Magurran, 2004**). The slightly higher value observed in Oued Messida suggests a somewhat more balanced distribution of individuals among taxa, although the difference remains limited.

This trend was confirmed by Pielou’s evenness index (J), which reached 0.778 in Oued Messida and 0.761 in Lake Tonga. These relatively high values indicate a fairly homogeneous distribution of abundances within the communities and reflect low dominance by the most abundant taxa. Theoretically, maximum diversity is achieved when all species have similar abundances (**Pielou, 1966**). Although the values observed in both stations were close, the moderate dominance of certain families, particularly Corixidae and Chironomidae, slightly reduced evenness, especially in Lake Tonga. These findings indicate the presence of relatively balanced benthic communities and suggest ecological conditions favorable to biodiversity conservation.

The slightly higher Shannon and Pielou indices observed in Oued Messida may be related to the greater habitat heterogeneity of this lotic ecosystem, characterized by the coexistence of different microhabitats (variable current zones, diverse substrates, and riparian vegetation), which provide a larger variety of ecological niches than the lacustrine environment.

Margalef’s richness index (Dmg), which evaluates species richness while accounting for the total number of sampled individuals, showed a slightly higher value in Lake Tonga (4.772) than in Oued Messida (4.576), despite the lower total abundance recorded in the lake (2,329 versus 2,610 individuals). This result indicates that taxonomic richness relative to the number of individuals was slightly greater in Lake Tonga. The values obtained remain high and confirm the considerable biological richness of both environments. Comparatively, **Haji Aghaei Ghazi Mahalleh et al. (2024)** reported a mean Margalef index of 1.38 in the Ghale Rudkhan River (Iran) for 5,134 individuals distributed among 30 families. The richness observed in the present study, with 37–38 recorded taxa, thus highlights the high biodiversity potential of the two hydrosystems investigated.

The similarity analysis between Oued Messida and Lake Tonga revealed a strong resemblance between the benthic macroinvertebrate communities of the two sites. The Jaccard index reached 92.3%, indicating that both environments shared almost all recorded taxa. Indeed, of the 37 taxa identified in Oued Messida and the 38 observed in Lake Tonga, 36 were common to both stations. Only a few taxa, such as Leptophlebiidae and Tabanidae in Lake Tonga and Limnephilidae in Oued Messida, differentiated the two communities. This strong similarity may be explained by the geographical proximity of the sites and their hydrological connection, which facilitates faunal exchanges (**Ward, 1989; Amoros & Petts, 1993**). The Jaccard dendrogram confirmed this observation, showing that most families clustered at very high similarity levels, whereas exclusive taxa appeared isolated due to their specific ecological requirements or low occurrence frequencies.

The Bray–Curtis index, which incorporates taxon abundances, also confirmed the strong similarity between the two stations. Most families exhibited similarity levels ranging from 80% to 95%, reflecting relatively comparable abundances in both environments. Nevertheless, quantitative differences were observed for certain dominant families, particularly Hydrochidae and Physidae, whose abundances varied according to habitat-specific characteristics.

Overall, the Jaccard and Bray–Curtis indices demonstrated that Oued Messida and Lake Tonga host very similar benthic communities, both in terms of composition and abundance. The observed differences remain limited and appear to be more closely associated with the ecological particularities of each environment (lotic versus lentic) than with major variations in environmental quality.

The Family Biotic Index (FBI), developed by **Hilsenhoff (1988),** assesses water quality based on the tolerance of benthic macroinvertebrate families to organic pollution. Each family is assigned a tolerance value ranging from 0 (very sensitive) to 10 (highly tolerant). The values obtained in this study were 4.26 for Oued Messida and 4.56 for Lake Tonga. According to Hilsenhoff's classification, these results indicate generally good biological water quality, with low to moderate organic pollution. The slightly higher value recorded in Lake Tonga suggests a somewhat greater proportion of tolerant taxa. This situation may be linked to the lentic nature of the lake, where the accumulation of organic matter in sediments naturally favors the development of moderately tolerant organisms. Nevertheless, both values remain below the threshold of 5, indicating relatively favorable ecological conditions and a good self-purification capacity of the environments (**Wetzel, 2001**).

These findings are consistent with studies conducted in comparable hydrosystems and confirm the usefulness of the FBI as a biological assessment tool in northern Algerian aquatic ecosystems.

The Biological Monitoring Working Party (BMWP) index is based on the presence or absence of macroinvertebrate families and assigns each family a sensitivity score ranging from 1 to 10. Scores obtained were 153 for Oued Messida and 161 for Lake Tonga. According to BMWP classification standards, these values correspond to excellent biological quality.

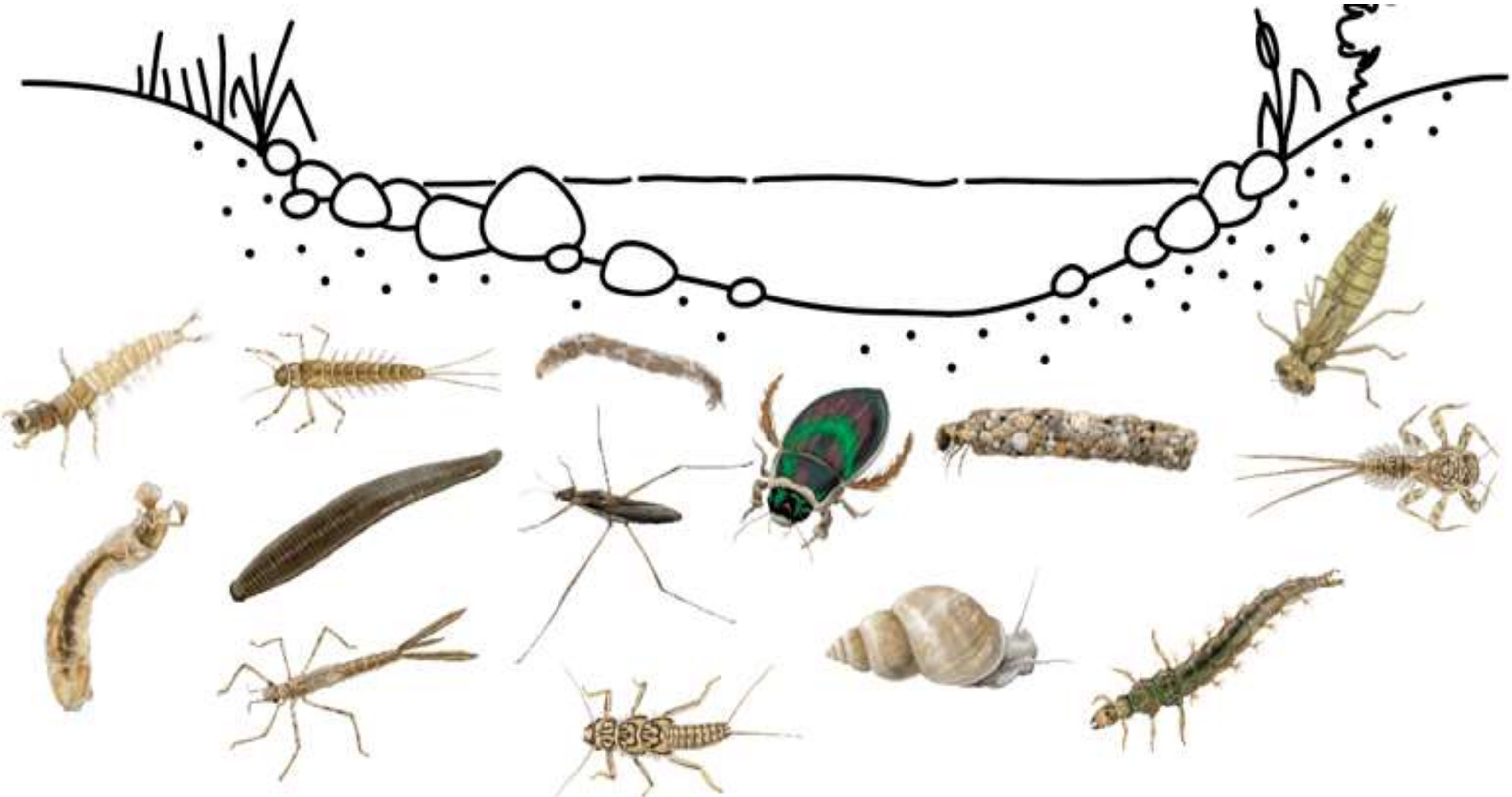
However, the BMWP index is strongly influenced by taxonomic richness. Since both stations hosted more than thirty indicator families, the cumulative scores naturally reached high values. To reduce this effect, the Average Score Per Taxon (ASPT) index was used as a complementary measure. ASPT represents the average tolerance score of the taxa present and provides an assessment that is less dependent on species richness.

The ASPT values obtained were 4.78 for Oued Messida and 4.88 for Lake Tonga. According to commonly used interpretation scales, these values indicate moderate to good biological quality. These results therefore moderate the interpretation provided by the BMWP index: although both environments exhibit high taxonomic richness, the communities are mainly composed of taxa with intermediate sensitivity, such as Corixidae, Dytiscidae, and Hydrochidae, together with some more tolerant taxa such as Chironomidae and Physidae. Highly sensitive families are present but relatively scarce.

Thus, the combined use of the FBI, BMWP, and ASPT indices highlights a generally satisfactory biological quality for both ecosystems. The high BMWP scores reflect substantial faunal richness, while the FBI and ASPT values indicate relatively favorable ecological conditions without suggesting completely undisturbed environments. Overall, the results demonstrate a good biological status for both Oued Messida and Lake Tonga, with slight influences from natural factors related to the specific functioning of each hydrosystem.

In conclusion, all ecological descriptors and biological indices employed in this study converge toward the same interpretation. Oued Messida and Lake Tonga support rich and diverse benthic macroinvertebrate communities characterized by relatively balanced abundance distributions and high taxonomic richness. Similarity analyses revealed that the two sites share a large proportion of their fauna while maintaining certain specificities related to their respective hydrological characteristics. The biotic indices (FBI, BMWP, and ASPT) indicate generally satisfactory biological quality, reflecting ecological conditions favorable to the maintenance of significant benthic biodiversity. The differences observed between the two environments appear to be more closely linked to their intrinsic ecological functioning (lotic conditions in Oued Messida and lentic conditions in Lake Tonga) than to any pronounced degradation of water quality. These findings confirm the value of benthic macroinvertebrates as reliable bioindicators for assessing the ecological status of aquatic ecosystems in the El Kala region.

CONCLUSION



CONCLUSION

Wetlands are ecosystems of major ecological importance due to their biological richness, their role in hydrological regulation, and their contribution to maintaining natural balance. Among these environments, the lacustrine complex of El Kala National Park represents an exceptional natural heritage at both national and Mediterranean scales. However, climate change, recurrent drought periods, and various anthropogenic pressures are now increasingly affecting the functioning of these aquatic ecosystems. In this context, the study of benthic macroinvertebrates appears to be a particularly relevant tool for assessing the ecological status of aquatic environments.

The present work focused on the study of the diversity and structure of benthic macroinvertebrate communities in two aquatic ecosystems of El Kala National Park: Lake Tonga and Oued Messida. The main objective was to contribute to a better understanding of the benthic biodiversity of these environments and to assess their ecological quality through the use of different biological and ecological indices.

The results highlighted a significant faunal richness in both studied sites. In total, several families belonging to different taxonomic groups were recorded, including aquatic insects, molluscs, annelids, and various other invertebrates. This diversity reflects the ability of these environments to provide suitable habitats for a relatively diverse aquatic fauna despite the environmental constraints observed during the study period.

The analysis of community composition showed the dominance of certain families such as Corixidae, Dytiscidae, Hydrochidae, and Physidae, which represent a large proportion of the recorded individuals. This dominance reflects the adaptation of these organisms to the ecological characteristics of the studied environments. At the same time, the presence of sensitive groups such as Ephemeroptera and some Trichoptera constitutes a positive indicator of the overall ecological status of the sites, although their abundance remains relatively limited.

The study of ecological indices provided additional information on the structure of benthic communities. The relatively high values of the Shannon index, Pielou’s evenness index, and Margalef index indicate appreciable species diversity as well as a relatively balanced distribution of individuals among taxa. The results also reveal a strong similarity between Lake Tonga and Oued Messida, explained by their hydrological connection and comparable ecological conditions.

The application of similarity and dissimilarity indices, particularly Bray-Curtis and Jaccard indices, confirmed a high resemblance between the communities of the two sites. Most of the recorded families are common to both environments, indicating a homogeneous faunal composition. However, some exclusive taxa were observed in certain stations, highlighting local ecological particularities linked to specific environmental conditions in each habitat.

The assessment of biological quality using the Family Biotic Index (FBI) classified both sites as having good water quality. The values obtained indicate low organic pollution and a generally satisfactory ecological status. These results confirm the role of Lake Tonga and Oued Messida as suitable habitats for maintaining diverse and relatively balanced aquatic biodiversity.

This work contributes to the knowledge of benthic biodiversity in the wetlands of El Kala National Park. It highlights the importance of benthic macroinvertebrates as reliable bioindicators for assessing the ecological quality of aquatic ecosystems. Their use not only allows the detection of environmental disturbances but also enables long-term monitoring of ecosystem health.

In future perspectives, it would be desirable to continue investigations over several years and across all seasons to better understand temporal variations in benthic communities. The integration of physicochemical water parameters and the study of other biological indicator groups would also provide a more comprehensive assessment of ecosystem functioning. Likewise, the establishment of a permanent biological monitoring program would strengthen conservation strategies and sustainable management of the wetlands of El Kala National Park.

In conclusion, the results of this study confirm the ecological richness of Lake Tonga and Oued Messida, as well as their importance for the conservation of aquatic biodiversity. The preservation of these environments remains essential in the face of climate change and increasing anthropogenic pressures. Sustainable management and regular ecological monitoring are therefore necessary to ensure the long-term conservation of these remarkable ecosystems and the ecological services they provide.

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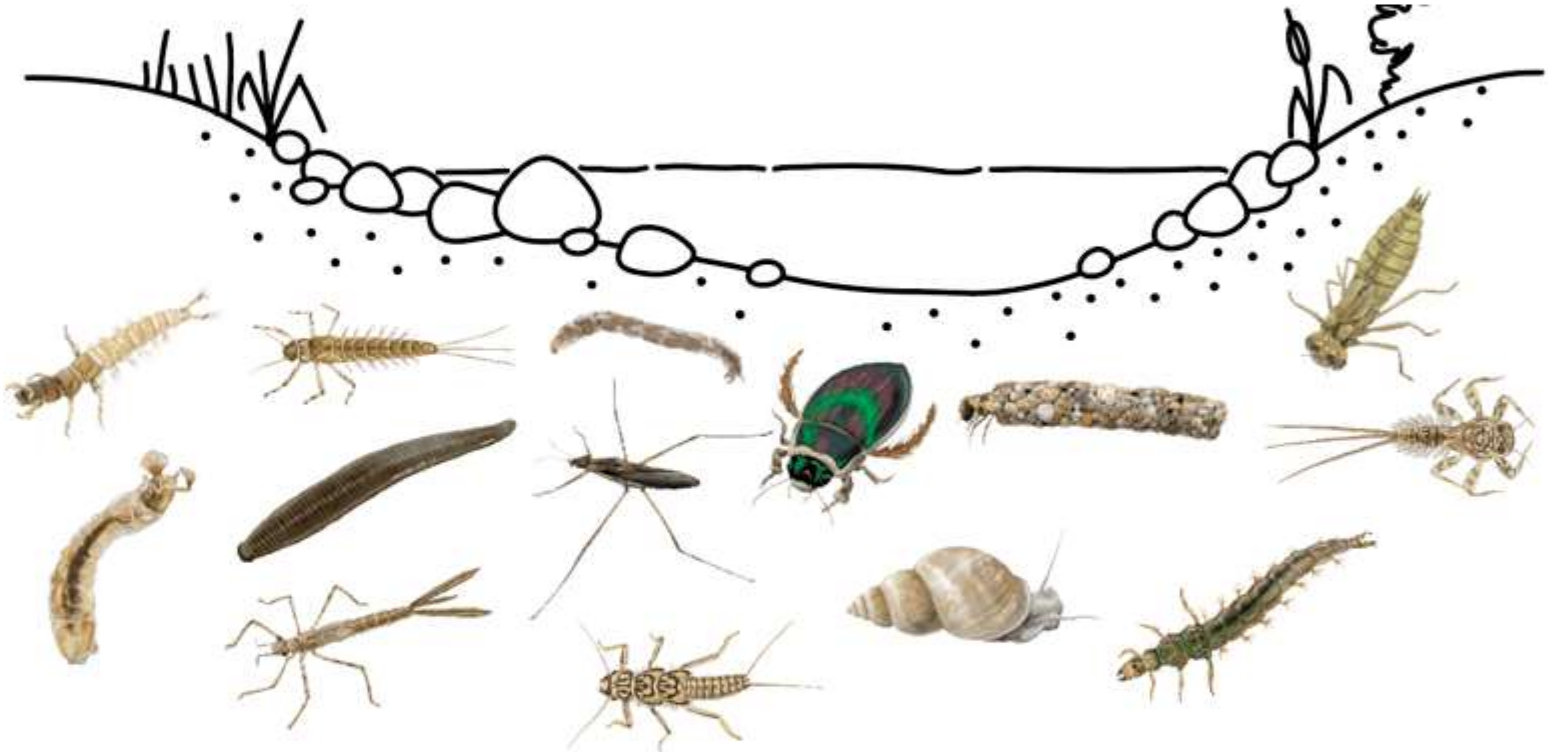

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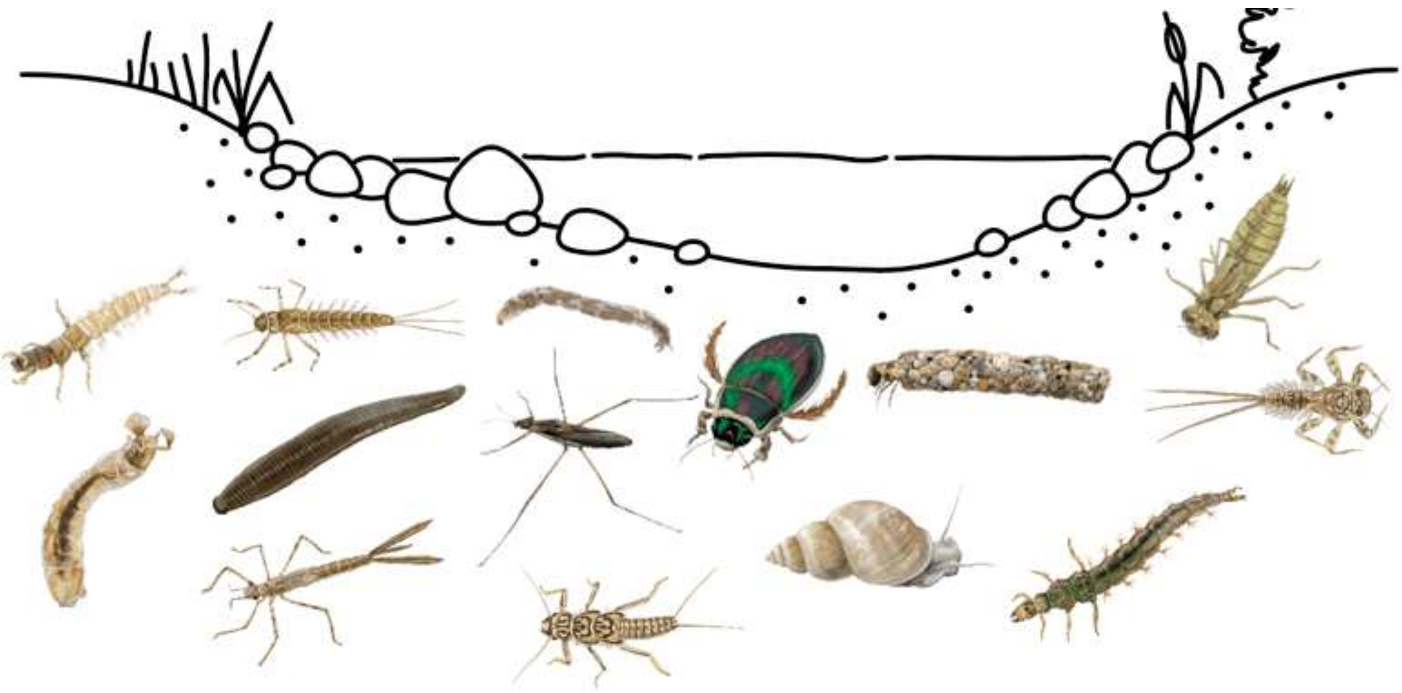

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(SNHBSEEDD'2025)

le 21 Octobre 2025-Mila

ATTESTATION DE PARTICIPATION

La Présidente du Séminaire National atteste que : Lamis Bounasri

A présenté une Communication e-Poster intitulée:

INVENTORY OF AQUATIC INSECTS IN RAMSAR LAKE (NORTH EAST ALGERIA)

Co-auteurs : Rizi Hadia, Chettibi Ahlam, Gacem Habiba, Kacha Samira & Louiza DOUAFER

Présidente du Séminaire	**Directeur de l'institut**
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