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En Vue de l'Obtention du Diplôme de Doctorat en Troisième Cycle

Domaine : Sciences de la Nature et de la Vie   Filière : Ecologie et Environnement
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Présentée par

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Intitulée

Ecologie de l'hivernage des Anatidés au niveau des zones humides de la Numidie algérienne : phénologie, comportement diurne et descripteurs abiotiques des milieux.

Soutenue le: 04/06/2025   Devant le Jury composé de :

Nom et Prénom	**Grade**		
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Thesis

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Field: Natural and Life Sciences Stream: Ecology and Environment
Speciality: Agro-Ecology

Presented by:
BOUSSAHA Amina

Title

Wintering ecology of Anatidae in the wetlands of Algerian Numidia: phenology, diurnal behavior and abiotic environmental descriptors

Defended on: 04/06/2025 Before the jury composed of:

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ABSTRACT

To examine the ecology of wintering Anatidae in two Ramsar-listed wetlands in Algeria, Garaet Hadj Tahar (Western Numidia) and Lac des Oiseaux (Eastern Numidia), bimonthly exits were carried out during two consecutive wintering seasons (2021/22 and 2022/23). In addition, during an annual cycle extending from November 2021 to October 2022, we have studied the physicochemical and bacteriological quality of the water based on the evaluation of certain pollution indicators such as electrical conductivity (EC), dissolved oxygen (DO), nitrates (NO_3^-), nitrites (NO_2^-), ammonium (NH_4^+), phosphates (PO_4^{3-}), biological oxygen demand (BOD5) as well as the four categories of faecal contamination indicators (total heterotrophic bacteria, total coliforms, faecal coliforms, and faecal Streptococci).

A total of 14 species were recorded (12 at Garaet Hadj Tahar and 12 at Lac des Oiseaux). Most of the species (57%) were winter migrants; 21% were occasional visitors (passage visitors), and 22% were winter migrants with sedentary populations. Four of these species are listed as rare on the IUCN Red List: Endangered (White-headed duck *Oxyura leucocephala*), vulnerable (Common pochard *Aythya ferina*), and Near Threatened (*Marmaronetta angustirostris* and Ferruginous duck *Aythya nyroca*). Analysis of the ecological indices reveals that the two bodies of water harbor a similar number of species in terms of species richness, but show a significant difference in terms of abundance, with 311 individuals observed at Garaet Hadj Tahar and 2411 individuals at Lac des Oiseaux. The Shannon-Weaver diversity index (H') and Pielou equitability index (E) indicate that Garaet Hadj Tahar has the highest values, with a maximum of H' = 1.66 bits and E = 0.98. These results suggest that Garaet Hadj Tahar is ecologically more balanced than Lac des Oiseaux. These wetlands are a perfect haven for these birds, as evidenced by the diurnal balances being dominated by sleeping activity.

All the water samples studied showed results that exceeded the thresholds set by the WHO and Algerian standards, indicating significant pollution. Spearman's correlation shows that water parameters influence four (4) species of Anatidae in the GHT and seven (7) species in the LDO. Our research highlights the importance of the wetlands of the Algerian Numidia for the protection of Anatidae and provides valuable information for the development of effective strategies to safeguard these waterbirds and their habitats, a task that is essential for biosecurity and the prevention of waterbird epidemics.

Key words: Phenology Status, Wintering birds, Wetland, Water quality, Waterbirds Ecology.

Résumé

Afin d'examiner l'écologie des Anatidés hivernants dans deux zones humides classées Ramsar en Algérie, Garaet Hadj Tahar (Numidie occidentale) et Lac des Oiseaux (Numidie orientale), des sorties bimensuelles ont été effectuées durant deux saisons d'hivernage consécutives (2021/22 et 2022/23). Par ailleurs, au cours d'un cycle annuel s'étendant de novembre 2021 à octobre 2022, nous avons étudié la qualité physico-chimique et bactériologique de l'eau à partir de l'évaluation de certains indicateurs de pollution tels que la conductivité électrique (CE), l'oxygène dissous (OD), les nitrates (NO_3^-), les nitrites (NO_2^-), l'ammonium (NH_4^+), les phosphates (PO_4^{3-}), la demande biologique en oxygène (DBO5) ainsi que les quatre catégories d'indicateurs de contamination fécale (bactéries hétérotrophes totales, coliformes totaux, coliformes fécaux et streptocoques fécaux).

Au total, 14 espèces ont été enregistrées (12 à Garaet Hadj Tahr et 12 au lac des Oiseaux). La plupart des espèces (57 %) étaient des migrateurs hivernaux ; 21 % étaient des visiteurs occasionnels (visiteurs de passage) et 22 % étaient des migrateurs estivaux avec des populations sédentaires. Quatre de ces espèces sont considérées comme rares sur la liste rouge de l'UICN : En danger (Erismature à tête blanche *Oxyura leucocephala*), vulnérable (Fuligule milouin *Aythya ferina*) et quasi menacée (Sarcelle marbrée *Marmaronetta angustirostris* et Fuligule nyroca *Aythya nyroca*). L'analyse des indices écologiques révèle que les deux plans d'eau abritent un nombre similaire d'espèces en termes de richesse spécifique, mais présentent une différence significative en termes d'abondance, avec 311 individus observés au Garaet Hadj Tahar et 2411 individus au Lac des Oiseaux. L'indice de diversité de Shannon-Weaver (H') et l'indice d'équitabilité de Pielou (E) indiquent que Garaet Hadj Tahar a les valeurs les plus élevées, avec un maximum de H' = 1,66 bits et E = 0,98. Ces résultats suggèrent que le Garaet Hadj Tahar est écologiquement plus équilibré que le lac des Oiseaux. Ces zones humides constituent un refuge idéal pour ces oiseaux, comme en témoignent les bilans diurnes dominés par l'activité de sommeil.

Tous les échantillons d'eau étudiés ont montré des résultats dépassant les seuils fixés par l'OMS et les normes algériennes, indiquant une pollution importante. La corrélation de Spearman montre que les paramètres de l'eau influencent quatre (4) espèces d'anatidés dans le GHT et sept (7) espèces dans le LDO. Notre recherche met en évidence l'importance des zones humides de la Numidie algérienne pour la protection des Anatidés et fournit des informations précieuses pour le développement de stratégies efficaces de sauvegarde de ces oiseaux d'eau et de leurs habitats, une tâche essentielle pour la biosécurité et la prévention des épidémies d'oiseaux d'eau.

Mots clés : statut phénologique, oiseaux hivernants, zone humide, qualité de l'eau, oiseaux d'eau, écologie.

الملخص

من أجل دراسة بيئة الطيور الإوزية الشتوية في منطقتين رطبتين مصنفتين ضمن اتفاقية رامسار في الجزائر، وهما "ڨارعة الحاج طاهر" (نوميديا الغربية) و"بحيرة الطيور" (نوميديا الشرقية)، تم إجراء خرجات ميدانية نصف شهرية خلال موسمي شتاء متتاليين (22/2021 و23/2022). بالإضافة إلى ذلك، وخلال دورة سنوية امتدت من نوفمبر 2021 إلى أكتوبر 2022، قمنا بدراسة الجودة الفيزيائية-الكيميائية والبكتريولوجية للمياه من خلال تقييم بعض المؤشرات الملوثة، مثل التوصيلية الكهربائية (EC)، الأكسجين الذائب (DO)، النترات (NO_3^-)، النتريت (NO_2^-)، الأمونيوم (NH_4^+)، الفوسفات (PO_4^{3-})، الطلب البيولوجي على الأكسجين (BOD5)، بالإضافة إلى أربع فئات من مؤشرات التلوث البرازي (البكتيريا غير المتجانسة الكلية، الكوليفورم الكلي، الكوليفورم البرازي والمكورات العقدية البرازية).

تم تسجيل 14 نوعًا (12 نوعًا في "ڨرعة الحاج طاهر" و12 نوعًا في "بحيرة الطيور"، كانت غالبية الأنواع مهاجرة شتوية (57%)، بينما كانت 21% زوارًا عرضيين (عابرة)، و22% مهاجرة صيفية مع وجود تجمعات مستقرة. تم تصنيف أربعة أنواع على أنها نادرة وفقًا للقائمة الحمراء للاتحاد الدولي لحفظ الطبيعة(IUCN) : مهددة بالانقراض (البط أبيض الرأس *Oxyura leucocephala*) ومعرضة للخطر (البط الرخامي *Marmaronetta angustirostris* والبط ذو الرأس الأبيض *Aythya ferina*)، وشبه مهددة (البط الرخامي *Marmaronetta angustirostris* والبط الفيروجيني *Aythya nyroca*).

كشف تحليل المؤشرات البيئية أن الموقعين يستضيفان عددًا متشابهًا من الأنواع من حيث الغنى النوعي، ولكنهما يختلفان بشكل ملحوظ من حيث الوفرة، حيث تم تسجيل 311 فردًا في "ڨرعة الحاج طاهر" مقابل 2411 فردًا في "بحيرة الطيور". أظهرت قيم مؤشر تنوع شانون-ويفر (H') ومؤشر تجانس بييلو (E) أن "ڨرعة الحاج طاهر" سجل أعلى القيم، حيث بلغ الحد الأقصى H' = 1.66 بت وE = 0.98، مما يشير إلى أن هذا الموقع أكثر توازنًا من الناحية البيئية

ABSTRACT

مقارنة بـ"بحيرة الطيور". تشكل هذه المناطق الرطبة ملجأً مثالياً لهذه الطيور، كما يتضح من الأنشطة اليومية التي يغلب عليها سلوك الراحة والنوم.

كشفت جميع عينات المياه المدروسة عن تجاوز المستويات المسموح بها وفقًا لمنظمة الصحة العالمية والمعايير الجزائرية، مما يدل على تلوث كبير. أظهر تحليل ارتباط سبيرمان أن العوامل المائية تؤثر على أربع (4) أنواع من الطيور الإوزية في "قرعة الحاج طاهر" وعلى سبع (7) أنواع في "بحيرة الطيور". تؤكد دراستنا على أهمية المناطق الرطبة في نوميديا الجزائرية في الحفاظ على الطيور الإوزية، وتوفر معلومات قيمة لتطوير استراتيجيات فعالة لحماية هذه الطيور المائية وموائلها، وهي مهمة أساسية للأمن البيولوجي والوقاية من الأوبئة التي تصيب الطيور المائية.

<u>الكلمات المفتاحية</u>: الحالة الفينولوجية، الطيور الشتوية، المنطقة الرطبة، جودة المياه، الطيور المائية، البيئة.

°C: Degree Celsius

ANOVA: Analysis of Variance

BCPL: Purple Bromocresol Lactose Broth

BOD5: Five-day biochemical oxygen demand

CA: Cluster Analysis

CFU: Colony-Forming Unit

D/C: Double Concentration

DO: Dissolved Oxygen

EC: Electrical Conductivity

FC: Faecal Coliforms

FS: Faecal Streptococci

GHT: Garaet Hadj Tahar

GLM: Generalized Linear Model.

KMO: Kaiser Meyer Olkin

LDO : Lac des oiseaux

MPN: Most Probable Number

NED: N-(1-naphthyl) ethylenediamine dihydrochloride

NH_4^+: Ammonium

NO_2^- : Nitrite

NO_3^- : Nitrate

PCA: Principal Component Analysis

PO_4^{3-} : Phosphate

S/C: Simple Concentration

TC: Total Coliforms

THB: Total Heterotrophic Bacteria

WHO: World Health Organization

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Introduction

Wetlands are complex ecosystems due to the various interactions between their biotic and abiotic components (**Ramamurthy and Rajakumar, 2014**). A wetland is an area where water is the main factor controlling the functioning of the natural environment. By definition, wetlands are 'Any area of marsh, fen, peatland or open water, whether natural or artificial, permanent or temporary, whether the water is standing or flowing, fresh, brackish or salt, including areas of marine and coastal water the depth of which does not exceed six metres at low tide' (**Ramsar, 1987**). These areas are home to tens of thousands of animal and plant species and are therefore considered to be major reservoirs of biodiversity (**Seyrig, 2007**). Their productivity provides several facilities to waterbirds and influences their distribution in staging areas during wintering season and migratory stopover (**Saker et al., 2016**).

Wetland quality and features are deemed important factors for predicting site occupancy in the Maghreb region (**BirdLife International 2025; Sidi Imad et al. 2016**). Fluctuations in waterbird populations will eventually provide valuable insights into habitat deterioration, the impact of climate change, and the urgency for establishing immediate and effective mitigation measures.

In wetlands, Anatidae represent one of the most notable fauna elements among aquatic birds. Most species in this group provide an excellent example of the migratory phenomenon: each year, these aquatic birds undertake periodic migrations that can extend over several thousand kilometers, from their breeding grounds to their wintering grounds, searching for better climatic and feeding conditions (**El Agbani, 1997**). In addition, Anatidae are considered indicators of wetland health and are often used to monitor the habitat status of these areas (**Richard and Arco van 2010**). Studying their wintering strategies, spatial and temporal occupancy patterns and diurnal behaviour remains one of the most important ways of determining the ecological role of a site.

Algeria, one of the southern Mediterranean countries, is rich in wetlands, one of the most valuable resources in terms of biodiversity and natural productivity. They play an important role in life processes, maintaining hydrological cycles and providing a habitat for a wide range of flora, fish, and birds (**Charchar, 2018**). In Algeria, geographical and environmental attributes make local wetlands a quality refuge for waterbirds, as they are located between two major international flyways: the Mediterranean/Black Sea Flyway and the Eastern Atlantic Flyway, acting as an ecological bridge between the two barriers of both the Sahara Desert and the Mediterranean Sea (**Bezzalla et al., 2019**). This is why the majority of Anatidae regularly winter on the lakes and marshes of the northern coast (**Bouali et al.,2021**).

Numidia, located in north-east Algeria, is renowned for its wetlands and includes an array of Important Bird Areas and Ramsar Sites (**Fishpool and Evans 2001**) and is important for breeding, wintering and staging Palearctic waterbirds (**Samraoui and Samraoui 2008; Samraoui et al. 2011**). This region is divided into two large complexes separated by the Oued Seybouse: Western Numidia (the Guerbes-Sanhadja complex and Lake Fetzara) and Eastern Numidia, comprising the complex and El-Kala. The Guerbes-Sanhadja complex, a Ramsar site since 2001 (**Boumezbeur, 2001**), comprises 31 wetlands (Samraoui and De Belair, 1997), represented here by Garaet-Hadj Tahar (36°51'.50 N, 07°15'.57 E), located some twenty kilometres from the Mediterranean Sea and one of the largest bodies of water in the complex. Second, Lac des Oiseaux, a Ramsar site since 1999, is located in the wilaya of El-Tarf in the far northeast of Algeria and is part of the most important wetland complex in Algeria, a preferred wintering and breeding site for many waterbird species (**Houhamdi, 2002**) and home to a number of different species of wintering waterbirds, mainly Anatidae, Scolopacidae, Rallidae, Podicipididae & Ardeidae (**Boubekeur et al., 2020**).

Garaet Hadj Tahar and Lac des oiseaux are among the many lakes and marshes in the Numidie region that were the focus of our work. The two hydrosystems are made up of lush vegetation that provides a refuge for numerous bird species, including anatidae (diving ducks and dabbling ducks). A total of sixteen species, including two on the IUCN (International Union for Conservation of Nature) Red List, regularly visit these two bodies of water.

The initial research (**Houhamdi et Samraoui, 2008; Merzoug et al., 2014; Saidi et al., 2017; Charchar, 2018; Merzoug et al., 2021**) conducted so far for the region have demonstrated the ornithological and ecological significance of these wetlands; these ecoregions are home to species that are listed on the IUCN Red List of Threatened Species (**IUCN, 2025**) as being particularly endangered and vulnerable, including the marbled duck (*Marmaronetta angustirostris*), ferruginous duck (*Aythya nyroca*), white-headed duck (*Oxyura leucocephala*), and the common pochard (*Aythya ferina*).

However, despite their crucial role, they face serious threats worldwide, such as habitat loss (**Mokany et al. 2022; Zhang and Ouyang 2019**) and illegal hunting (**Pérez-García et al. 2023; Söderquist et al. 2021**). Despite international awareness-raising, materialized by the signing of the Ramsar Convention in 1971, to which 169 nations are currently parties (**Ramsar, 2014**), these regions continue to experience alarming regression. Unfortunately, these regions are exposed to a number of risks: drying out, water extraction generally for agriculture (excessive use of nitrogen and phosphate fertilizers causing eutrophication of the environments concerned), pollution: the discharge of wastewater (domestic and industrial), pesticide residues, and others; hunting and poaching, which exterminate wetland fauna. Intensification of aquaculture without concern for existing biodiversity (**Bezzalla, 2019**).

Numerous recent scientific studies have shed light on the impacts of climate change on wetlands. Changing precipitation patterns can have profound effects on hydrological systems, biodiversity composition (**Calhoun et al. 2017; Montemayor et al. 2017**) and species distribution (**Campos-Cerqueira et al. 2021; Zhong et al. 2022**). In addition, rising temperatures may significantly affect the structure and function of wetland ecosystems (**Amano et al. 2020**). For example, the biodiversity associated with Mediterranean wetlands has been significantly reduced (**Balbo et al. 2017; Geijzendorffer et al. 2018; Parrinello and Bécot 2019**) due to multiple threats that may operate at different stages of the annual cycle of species (**Khelifa et al. 2022**). This could exacerbate existing pressures, particularly on threatened and native species (**Amano et al. 2020; Zhong et al. 2022**), as they are more likely to bear the brunt of these pressures. Consequently, the process of identifying key issues and important research questions is crucial to gaining an understanding of the challenges and opportunities for conservation in this region (**Taylor et al. 2021**).

For many years, the most common human impact on water quality has been the introduction of pathogenic organisms through the disposal of waste into water bodies (**Boyd, 2020**). The latter act as sources and reservoirs of faecal indicator bacteria, thereby facilitating the emergence of major health problems, hence the importance of assessing the quality of water bodies. This facilitates a more accurate diagnosis of their ecological health and provides a scientific basis for the protection and restoration of these habitats (**Fang et al. 2019**).

Determining the structure and composition of an aquatic ecosystem is often a good indicator of the state of health of an environment and of the biotope (**Delarras, 2007**). This assessment of surface water quality is based as much on (monitoring of) the measurement of physico-chemical and microbiological parameters.

We are therefore concerned not only about the microbiological quality of water, but also its physico-chemical characteristics. Under natural conditions, water is generally free of pathogenic microbes (bacteria, parasites, fungi, or viruses) and the chemical elements (mineral salts, organic matter, etc.) that are normally present in it are at levels acceptable to humans.

However, agricultural, and urban activities can alter the natural composition of water, making it unsuitable for various uses. From a bacteriological point of view, the major problem remains the proliferation of polluting and even pathogenic bacterial species in aquatic ecosystems, leading to environmental disruption and major health risks (**Aboulkacem, 2007**).

As for the physico-chemical aspect, the problem lies in the high levels of major nutrients (NO2, NO3, NH4, PO4), toxic substances and the risks associated with their effects (eutrophication, etc.).

There are different types of pollution, with different origins and impacts. The most prevalent type of pollution and one to be concerned about is organic, resulting from discharges of wastewater or industrial food waste. This organic matter is decomposed by bacteria that consume a lot of oxygen, which can lead to the asphyxiation of aquatic fauna. Wastewater also contains microbes that can cause disease, contributing to microbial pollution (**Halassi, 2016**).

Overall, previous research has established that Numidian Algeria is an important distribution area for Anatidae. However, almost all studies have assessed a single species of Anatidae or a single site, but appropriate analyses for all Anatidae at the same time are very limited. Studies on their ecology, behavior, and demography need to be carried out regularly in order to build up a long-term database and support their management and conservation.

The objectives of this thesis were:

1. To study the ecology of Anatidae through a census and an analysis of the structure of the populations in two wetlands of the Algerian Numidie, Garaet Hadj-Tahar (Western Numidie) and Lac des Oiseaux (Eastern Numidie).
2. To study the phenology and spatio-temporal distribution of all Anatidae species in the two study sites.
3. To study the diurnal activity patterns of all Anatidae species in order to highlight the ecological importance of these two sites.
4. To study the physico-chemical and bacteriological quality of the water in these two hydrosystems.

This work comprises three interdependent chapters:

- Chapter I: describes the two study sites (Garaet Hadj Tahar and Bird Lake): general presentation, hydrology, geological characteristics, biotic framework (fauna and flora), climatology, and threats to the ecological characteristics of the two study sites.
- Chapter II describes the equipment and methodology used to carry out this work, which is divided into two parts. The first concerns the study of Anatidae ecology, including counting techniques, methods for studying the status and diurnal behaviour of all Anatidae species and, finally, the calculation of changes in several ecological parameters (abundance, species richness, Shannon diversity index and Pielou

equitability index). The second part relates to the biotope characterization study (physico-chemical and bacteriological quality of the water at the two study sites).

- Chapter III describes the results and the discussion:

- The spatio-temporal occupation of all Anatidae species.
- The study of some of the bio-ecological statuses of Anatidae at the two sites
- The use of data using ecological indices applied to the Anatidae population.
- A study of the diurnal activity rhythms of all the Anatidae species at the sites studied in correlation with an analysis of their wintering strategies for two consecutive years (October 2021 to April 2023).
- The study of the physico-chemical and bacteriological quality of the water in the two bodies of water (Garaet Hadj Tahar and Lac des oiseaux), and their effect on the Anatidae population

- A conclusion drawn from the results obtained, highlighting the ecological role of the two bodies of water in order to better manage their restoration and conservation.
- Finally, old, and recent bibliographical references that have enabled the results to be used, followed by a series of appendices providing further information.

Chapter I: Description of the Algerian Numidia region

I.1. General information on Algerian Numidia

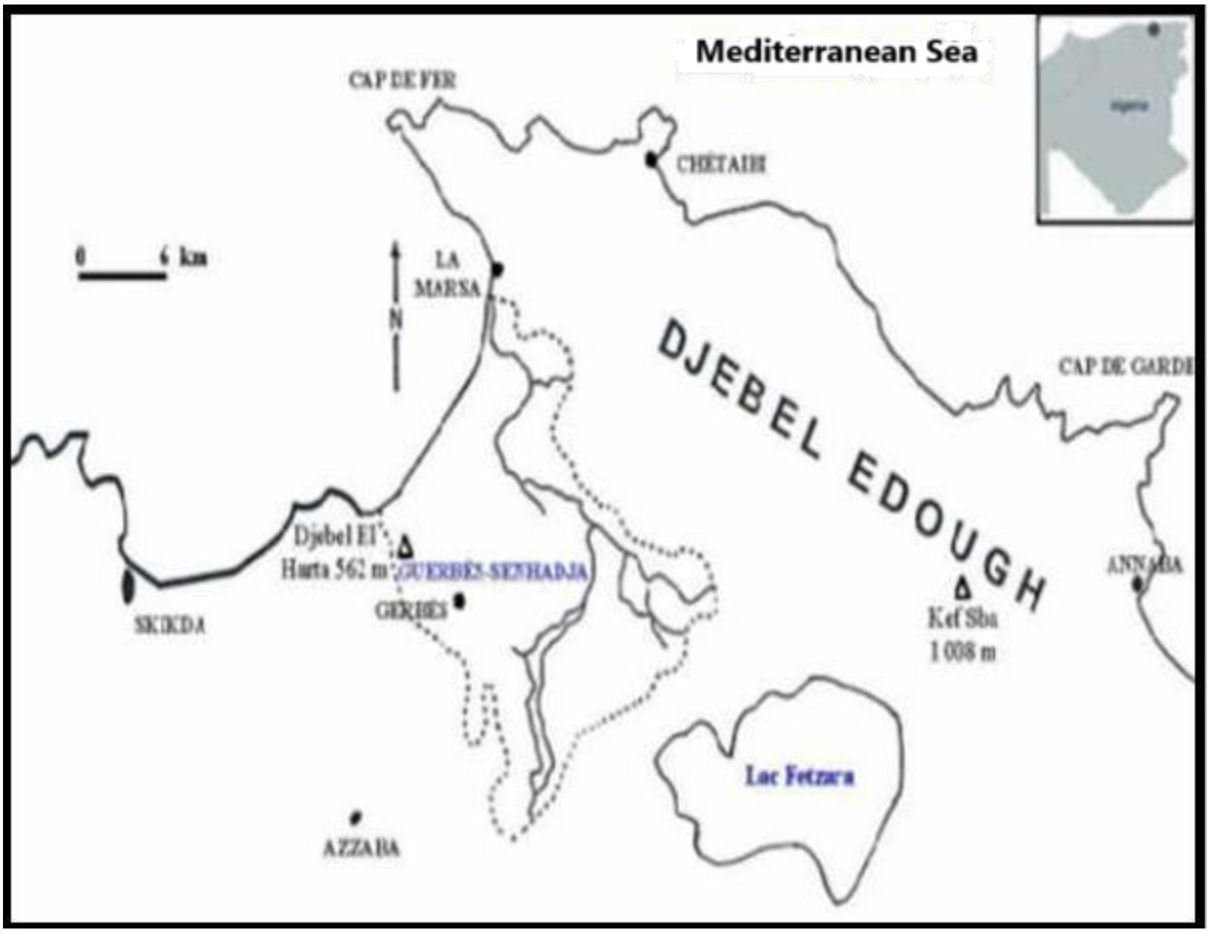
Algerian Numidia (north-east of Algeria) is renowned for its wetlands, which are divided into two large complexes separated by the Oued Seybouse: Western Numidia, represented by the flood plains Guerbes-Sanhadja of Skikda and Eastern Numidia, including the Annaba and El Taref complexes (**Samraoui et de Belair 1998**). Numidia is bordered by the Tunisian Kroumirie to the east, the Mediterranean to the north, Souk-Ahras and Constantine to the south and Skikda-Constantine to the west, or the Oued Seybouse (**Samraoui and de Belaire, 1997**).

I.1.1. Western Numidia

The wetlands of Western Numidia, represented by the Guerbes-Sanhadja complex (Ramsar site since February 2, 2001), are in the north-east of Algeria in the Wilaya of Skikda and to the west of Annaba and the El-Kala wetland complex. It is bounded to the north by the Mediterranean, to the east by the Wilaya of Annaba, to the south by the Bekkouche Lakhdar plain, and to the west by the Sanhadja forests.

The total surface area of the homogeneous zone is 42,100 ha. It is a large coastal plain bordered to the west by the coastal hills of Skikda and to the east by the Chitaibi coastal massif. Altitudes in the area range from 0 to 200 m. 48.5 of the land has a laying density of less than 3 (conservation des forets de la wilaya de Skikda, 2002) (**Metallaoui and Houhamdi, 2008**). The Guerbes-Sanhadja wetland complex is located between altitudes (36°45‘-37°1’ N) and longitudes (7°13‘ -7°30’ E) in eastern Algeria.

It contains 31 wetland sites (**Samraoui and De Belair, 1997**), the main bodies of water being as follows: Garaet Hadj Tahar, Garaet Ain-Magroune, Garaet Beni M’hamed, Garaet El-Haouas, Garaet Sidi Lakhdar, Nechaa Demnat Ataoua, Garaet Boumaïza, Nechaa Khallaba, Lac Sidi Fretis, Garaet Chichaya, Garaet Sidi Makhlouf (**Map 1**).



Map 1. Location of the Guerbes-Senhadja wetland eco-complex (Skikda -Algeria).

I.1.2. Eastern Numidia

Eastern Numidia, made up of the Annaba and El Tarf complexes, bordered to the east by the Algerian-Tunisian border and to the west by the Oued Seybouse, with the Mediterranean Sea as its northern boundary and the Tellian Atlas hills as its southern boundary (**Samraoui and De Belair, 1997**). This region of Algeria contains many exceptional wetland sites with a great diversity of marine, lacustrine and forest ecosystems characterized by a high level of animal and plant diversity. These remarkable sites offer a biodiversity that is unique of its kind compared with other wetlands in the country (**Merzougue A, 2015**). These wetlands cover an area of 156,000 ha (**Houhamdi, 1998**).

The main hydrosystems are Marais de la Mékhada, Marais de Bourdim, Lac Oubeira, Lac Mellah, Lac des Oiseaux, Lac Bleu and Lac Tonga **(Map 2).**

Map 2. Location of the Eastern Numidia wetland eco-complex (El Tarf -Algeria).

1 : La Fetzara - 2 : Mairais de la Mekhada - 3 : Lac des Oiseaux - 4 : Lac Mellah

5 : Lac Oubeïra - 6 : Lac Tonga - 7 : Lac Bleu - 8 : Marais de Bourdim

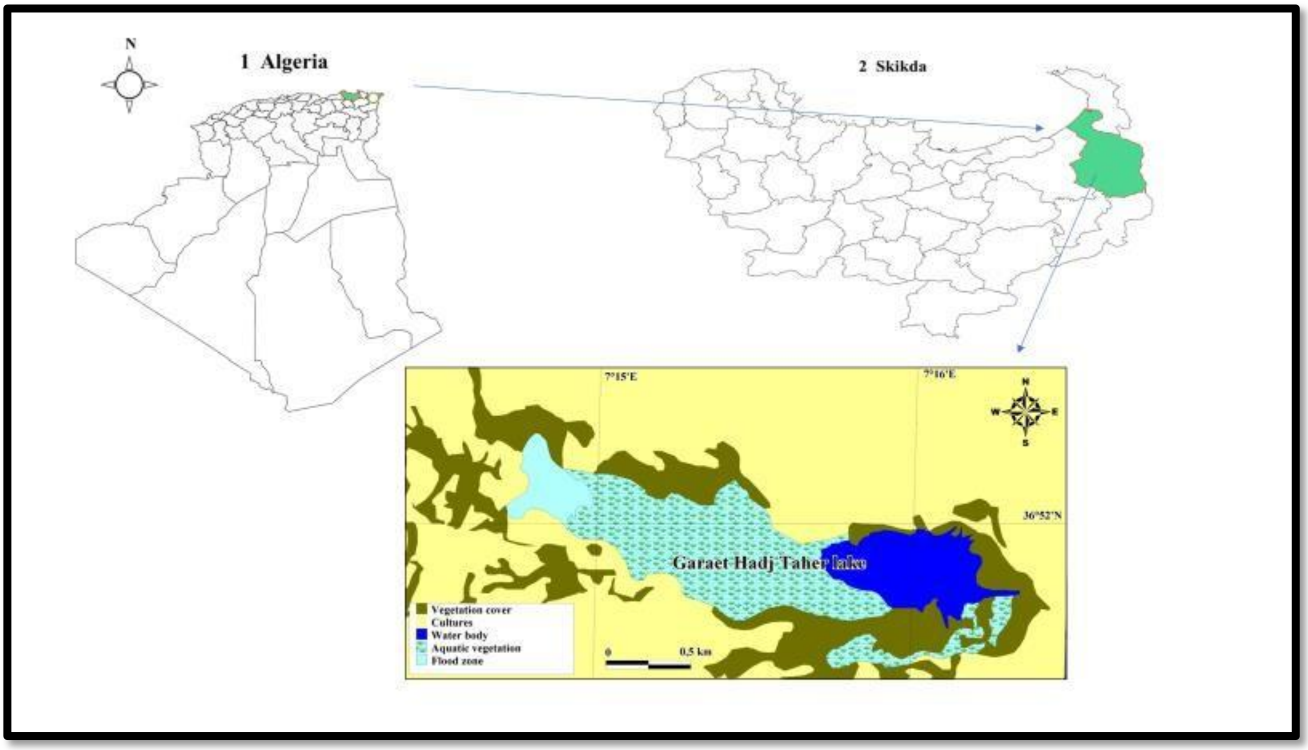
I.2. Presentation of the study areas (Garaet Hadj-Taher and Lac des oiseaux)

I.2.1. General presentation

❖ Garaet Hadj-Tahar

Garaet Hadj-Tahar is a freshwater pond that is often flooded, except in exceptional circumstances, between latitude 36◦51'50 ‘N and 07◦15'57 ’E, at an altitude of 16 m and covers an area of 112 ha. It has been a Ramsar site since 2 February 2001 and is part of the Guerbes-Sanhadja wetland complex. Administratively, it belongs to the wilaya of Skikda (Western Numidia, north-east Algeria), the Daïra of Ben Azzouz and the commune of Ben Azzouz.

It is located around twenty kilometres from the Mediterranean and has a very elongated oval shape, surrounded to the north-west by a clay and sandstone hill, to the east by dunes and to the south-east by the alluvial plain of the Oued El-Kebir **(Map 3)**.



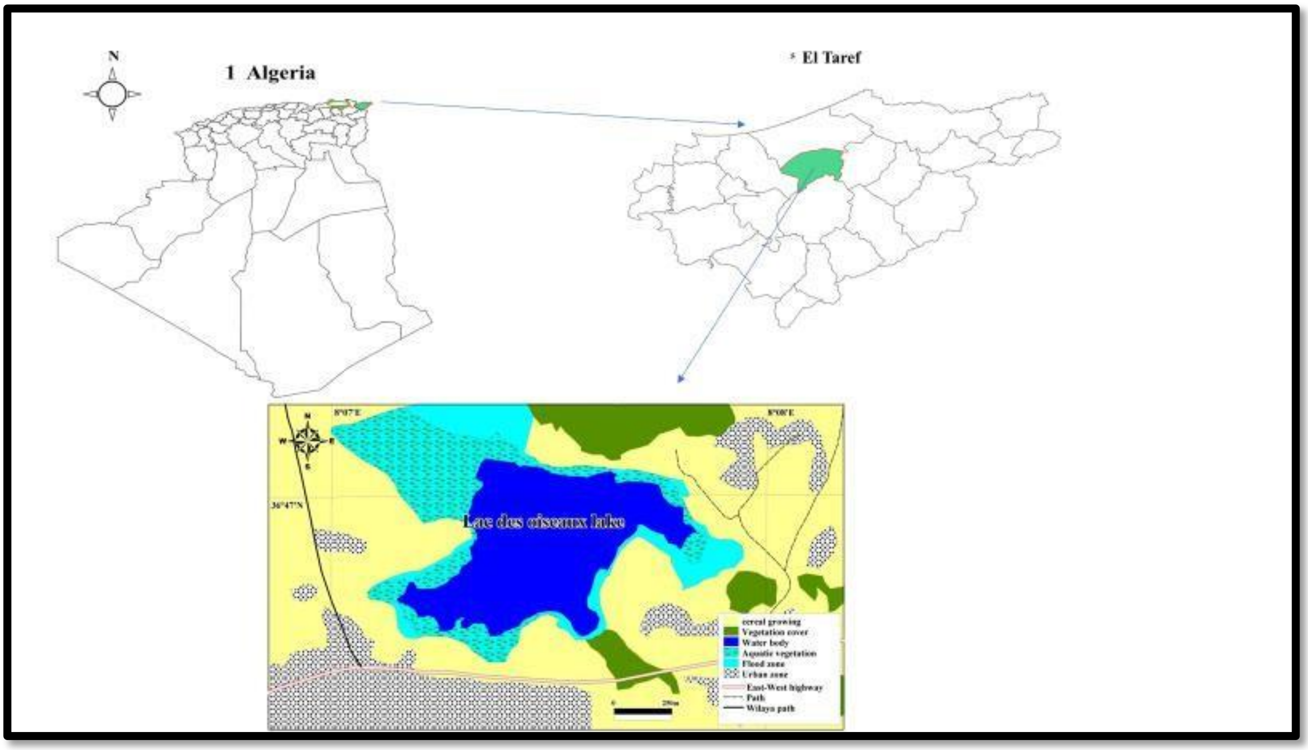
Map 3. Geographical location of the Garaet Hadj-Tahar

- ❖ **Lac des Oiseaux**,

Lac des Oiseaux or Garâat Ettouyour (36° 47‘N, 08° 7’ E), owes its name to the richness of its birdlife, especially in winter (**Maazi, 1992**). This body of water is an oval permanent freshwater lake, stretched to the north-east by a very characteristic pond tail (**Arrignon. 1962, Houhamdi. 1998, 2002**) **(Map 4)**.

It was included on the list of Ramsar sites in 1999. It currently covers an area of 70 ha with a 20 cm organic matter deposit in the rainy season and up to 40 ha in the dry season (**Boubekeur et al., 2020**). The maximum depth previously recorded was 2.5 m. It slopes towards Koudiat Nemlia to the north and north-east and towards Djebel Bouabed to the south and south-east. To the west, it opens onto the alluvial plain of the Mekhada.

The ‘Lac des Oiseaux’ municipality is administratively attached to the wilaya of El Tarf, 25 km from its capital. It is located on the banks of Route Nationale 44 (RN 44), 45 m east of the town of Annaba and 45 km west of the town of El Kala.



Map 4. Geographical location of the Lac des oiseaux

I.2.2. Hydrology

In **Gareat Hadj Tahar**, the hydrographic system is part of the large Constantino is coastal basin. The flow regime is exoreic. The hydrographic network is made up of a main drain, called Oued El-Kebir, which crosses the Ben-Azzouz alluvial plain over a length of more than 20 km. It forms small depressions all along its course. Its main tributaries are: El-Maboun, Magroun, Aneb, Siada, Bougsaiba, Fedj-El-Fhoul, Derouaka, and Moulay Djorf are all examples of Oued. These permanently feed the various Garaets (Joleaud, 1936).

The hydrological regime of **Lac des Oiseaux** depends on weather conditions (**Maazi 1992**). The relatively gentle slopes of the springs that feed it make it difficult for the water to drain into the lake. Similarly, several tributaries from the crests of the catchment area, which have high flows in winter, drain their water into the basin, giving Lac des Oiseaux a positive water balance. This lake, which dried up only occasionally in the past (**Morgan. 1982**), has experienced five major dry ups: 1957, 1965, 1992 (**Samraoui et al. 1992**), October 1994 and August 1997 (**Houhamdi. 1998, Houhamdi and Samraoui. 2002**).

I.2.3. The geographical features

- **Gareat Hadj Tahar**

The Guerbes plain is made up of two parts, one sandy and the other clayey (**Benderradji, 2000**). The sandy plain is developed in the northern and northeastern parts and forms a barrier separating the dunes from the valley of Wadi El-Kebir West. The surface remains simple, with superimposed deposits everywhere, from bottom to top. Red sands with little clay, with frequent hydro-morphological characteristics, are linked to the presence of a layer of clay that prevents the infiltration of water and thus encourages upward hydromorphic.

The clay plain extending from the southwest to the southeast, the Ben Azzouz clay plain, is distinguished by its flat topography, a characteristic shared by most coastal plains within the Mediterranean basin. It is traversed by Oued El-Kebir West, which flows sluggishly through the valley. The plain's formations predominantly consist of recent alluvial deposits, except in the Ain Nechma region, where lower Rharbian terraces are observed.

- **Lac des Oiseaux**

The "Lac des Oiseaux" commune, located in the El-Kala region, exhibits a unique juxtaposition of two distinct natural entities, combining mountainous terrain and low-lying marshy plains (**Cherouana, 1996**). The area's relief can be broadly categorized as follows:

The Mountainous Zone "clay-sandstone" includes Djebel Hammoun (352 m), which extends southward into a series of ridges progressively increasing in elevation, culminating at Djebel Mekefel (484 m). The series of ridges oriented from southwest to northeast defines the territorial boundary of the commune and marks the beginning of the watershed that feeds the surrounding plains (**Cherouana, 1996**).

The Hills are primarily represented by Mont Nemlia (98 m), located in the northeastern part of the commune. This feature resembles an isolated island within the plain.

The Plain consists of the lowest-lying terrain adjacent to the marshlands. It is predominantly clay-sandstone in composition in the southern area near Djebel Hammoun, while its northern part, known as Sebâa, transitions into dynamic marshland.

The Marshland, the stagnant waters cover a total area of 1,068 hectares, forming part of the larger Mekhada wetland that stretches for several kilometers. These flood-prone areas can extend into lands designated for agricultural use (**Cherouana, 1996**).

This unique combination of varied geomorphological features highlights the commune's significant ecological and hydrological diversity.

I.2.4. Biotic framework

The biological diversity of the Algerian Numidia complex, summarized in the following table (**Tab 1**), reflects the quality of the habitats within the two study sites, which have led them to be classified as very important sites for many species.

Table 1. The biological diversity of the Algerian Numidia complex

		GHT	LDO
Flora	**Floristic richness**	194 plant species belonging to 62 families (Metllaoui et al,.2010)	187 species belonging to 47 families (Houhamdi, 1998)
	Aquatic vegetation	*Nymphaea alba*, *Typha angustifolia*, *Phragmites australis*, *Scirpus maritimus*, *Scirpus lacustris*, *Iris pseudoacorus* which colonise around 60 to 70% of the total surface area of the wetland, as well as the pteridophyte *Salvinia natans.*	*Typha angustifolia*, *Ranunculus baudotii*, *Nymphaea alba*, *Scirpus lacustris*, *S. maritimus and Myriophyllum spicatum*, *Cyperus aristatus*, *C. fuscus*, *Callitriche sp.*, *Rumex algeriensis*, *and R. pulcher*, *and a belt of Juncus acutus.*
	Vegetation surrounded by water	*Juncus acutus*, *J. maritimus*, *Olea europea*, *Asphodelus aestivus*, *Rubus ulmifolius* and *grasses*, the most abundant of which are dactylon and *Paspalum distichum (*Metallaoui et al, 2009*).*	*Cotula coronopifolia (Compositae)* and *Asparagus officinalis (Lilliaceae)* and *Cyperus aristatus (Cyperaceae) (Houhamdi, 1998)*
Fauna	**Avifauna richness**	62 species grouped into 17 families (Samraoui et De Bélair,1997)	69 species (Anatidae and Rallidae in winter and Laro-limicoles and Waders in summer) (Houhamdi, 1998)
	Species of international interest	The sultana hen *Porphyrio porphyrio*, the Ferruginous Duck *Aythya nyroca* and the White-headed Duck *Oxyura leucocephala*	White-headed Duck *Oxyura leucocephala* and Ferruginous Duck *Aythya nyroca*
	Entomofauna	19 species of Odonata, including 5 species of Zygoptera belonging to 2 families and 11 species of Anisoptera belonging to 2 families (Metallaoui, 2010)	23 species of odonata, five of which are rare: Orthetrum Chrysostigma, Diplacodes lefebvrii, Brachythemis Leucotica and Trithemis annulata (Bouchrit,2014)
	Vertebrates	Wild boar Sus scrofa, genet, amphibians, terrestrial turtles, fish, eel and freshwater turtles (Metallaoui and Houhamdi, 2010).	Mammalian fauna (jackal, fox, mongoose, herisson and wild boar) and turtles (Houhamdi, 2002) Eels, barbel, mullet and carp (Houhamdi,1998)
	Macro and micro invertebrates	Ostracods (Cladocerans), Planorbidae and aquatic beetles (Pleidae, Naucoridae and Diptera)	

I.2.5. Climatology of Algerian Numidia:

The impact on the physical environment in North Africa, and therefore in Algeria, is amplified by variations in rainfall and temperature, the amplitudes of which have always been strongly accentuated (in terms of space and time) (**Quezel & Barbero, 1990**).

Climate is an important abiotic factor in the study of the typology and functioning of a natural environment (**Ladlani, 2007**), and has a direct influence on the fauna and flora (**Samraoui and De Belair, 1997**).

I.2.5.1. Analysis of the climate in the study area:

Both study areas are characterized by a Mediterranean climate, with abundant rainfall during the wet season and cold, dry months in summer (**Samraoui and De Belair, 1997; Houhamdi, 1998**).

In the absence of a weather station on the sites of our zones, our data were collected from the weather stations of Azzaba (wilaya of Skikda) and Ain assel (wilaya of el Tarf), spread over a 30-year period (1989-2019). They include rainfall P (mm), temperature T (°C) (**Tab 2**).

Table 2. Monthly average temperatures and precipitation of the Skikda region during the period 1989-2019.

Month	*Temperature (°C)*			*precipetation*
	Maximum	**Minimum**	**Mean**	**(mm)**
Jan	14,35	5,53	8,94	113,95
Feb	14,94	4,99	8,89	86,15
Mar	18,04	6,18	11,08	76,22
Apr	20,84	7,76	13,63	66,57
Mai	25,67	10,87	18,09	38,21
Jun	31,05	14,78	23,03	14,11
July	34,82	17,77	26,40	2,10
August	35,08	18,85	26,30	8,86
Sep	30,53	17,23	22,56	42,99
Oct	26,39	14,62	18,98	67,08
Nov	19,74	10,23	13,82	114,10
Dec	15,67	7,17	10,43	133,81

Table 3. Monthly average temperatures and precipitation of the El Tarf region during the period 1989-2019.

Month	*Temperature (°C)*			*precipetation*
	Maximum	**Minimum**	**Mean**	**(mm)**
Jan	13,96	5,66	8,93	124,27
Feb	14,47	5,17	8,87	84,99
Mar	17,49	6,36	11,01	74,19
Apr	20,40	7,97	13,58	63,46
Mai	25,30	10,88	17,92	40,40
Jun	30,82	14,33	22,73	14,32
July	34,65	17,17	26,04	1,77
August	35,01	18,21	26,01	6,16
Sep	30,45	16,85	22,42	49,27
Oct	26,02	14,34	18,84	69,55
Nov	19,35	10,14	13,73	120,94
Dec	15,28	7,33	10,44	125,00

A. Rainfall

The origin of rainfall in Algeria is more orographic (**Seltzer, 1946**). Rainfall is determined by the direction of the mountains in relation to the sea and the wet winds. Rainfall tends to decrease towards the south as the wet winds become exhausted. This is typical of the Mediterranean climate, with a minimum in summer and a maximum in winter.

Both study areas often experience a concentration of precipitation during the winter months. Rainfall peaks in December with 142 mm at GHT and in January with 135.9 mm at LDO. Summer is the least rainy season, with a marked drop in July, when only 1 mm is recorded at GHT and 1.69 mm at LDO. (**Fig 1**) shows the distribution of average monthly rainfall over a 30-year period.

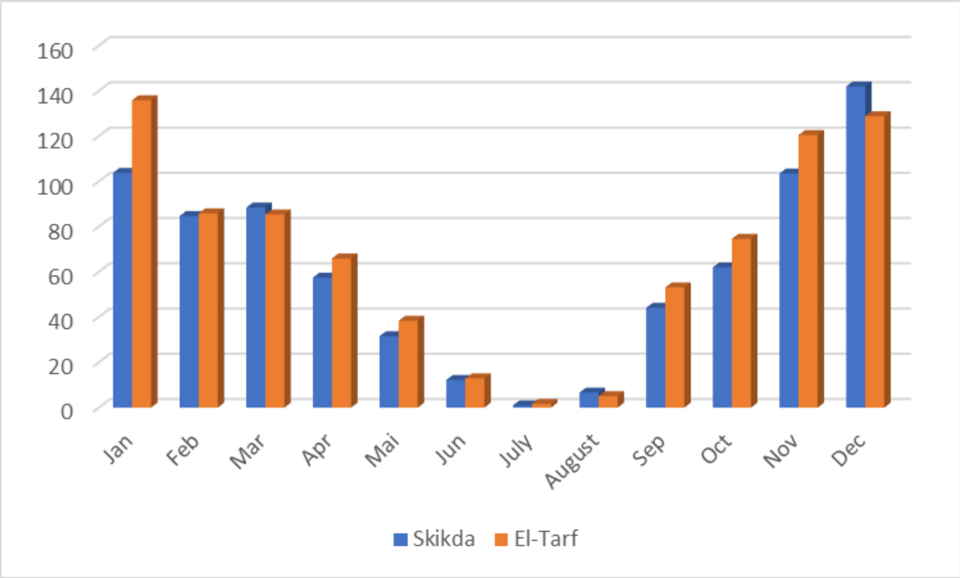


Figure 1. Average monthly precipitation (mm) of Garaet Hadj Tahar (Skikda) and Lac des Oiseaux (El-Tarf) during the period (1989-2019).

B. Temperature

Air temperature is a very important parameter directly linked to the development of most living beings and influences their activities, the climate, and the water balance, as it conditions evaporation and actual evapotranspiration. It is a function of altitude, distance from the sea, seasons, and topography (**Kannat, 2019**).

The coldest month is January, with a temperature of 8.45 °C at GHT, while at LDO, the minimum temperature is recorded in February with a temperature of 8.9 °C. Summer is the hottest period, with temperatures ranging from 25.62 °C at GHT in July to 26.05 °C at LDO in August (**Fig 2**).

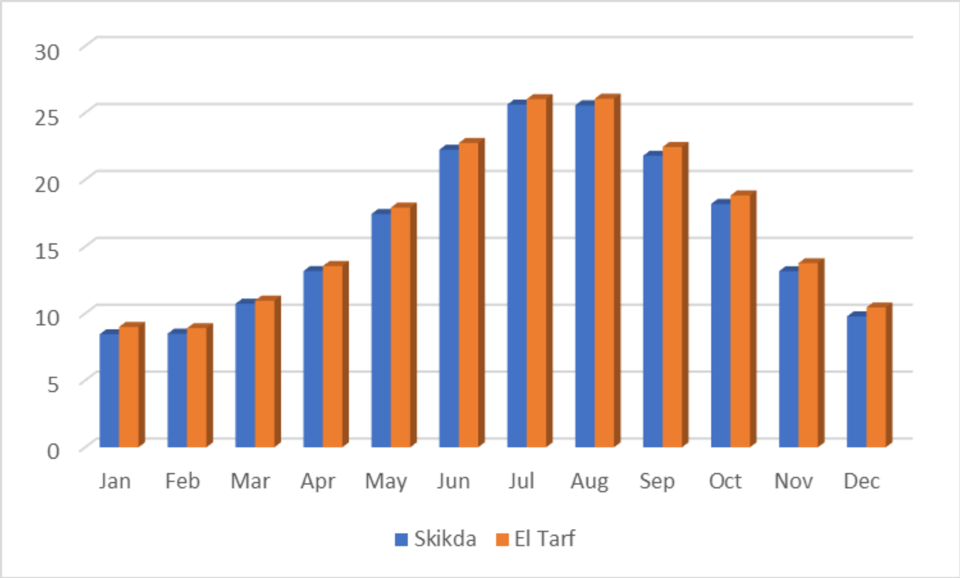


Figure 2. Mean monthly temperatures (°C) of Garaet Hadj Tahar and Lac des Oiseaux over the period (1989-2019).

I.2.5.2. Climatic synthesis

I.2.5.2.1. Ombrothermic diagram by Gaussen and Bagnouls

The ombrothermic diagram by Bagnouls and Gaussen shows the dry period in our study area. A month is considered dry if rainfall, expressed in millimeters, does not exceed twice the mean temperature in degrees Celsius (**Bagnouls & Gaussen, 1953**). The dry season corresponds to the period when the rainfall curve is lower than the temperature curve (**Bagnouls and Gaussen, 1957**) (**fig 3**).

In this study, given that Skikda is very close to El Tarf, which has approximately the same annual precipitation and temperature, the GHT and LDO climates are somewhat convergent. For the 2 study sites and over a 30-year period (1989-2019), ombrothermic diagrams have enabled us to separate the year into a dry period extending over 6 months, from mid-April to mid-October, and 6 rainy months.

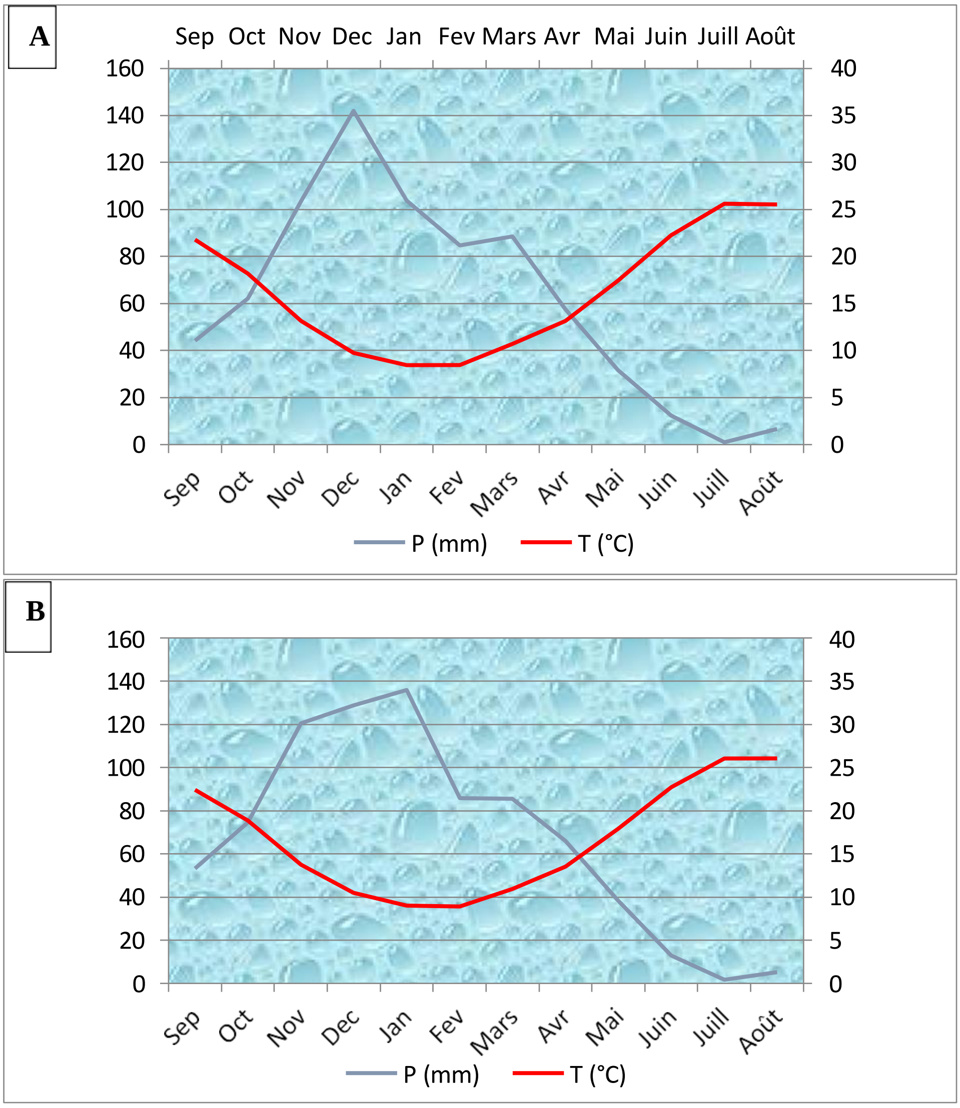


Figure 3. Ombrothermic diagram for (A) Garaet Hadj Tahar and (B) Lac des Oiseaux over the period (1989-2019).

I.2.5.2.2. Quotient pluviométrique d'Emberger

This index helps us define the 5 types of Mediterranean climate, from the most arid to that of the high mountains (**Emberger, 1955**). This assessment is based on the average maximum temperature (M) in the hottest month, the average minimum (m) in the coldest month and the average annual rainfall (P). Where the region is wetter, this quotient is higher (**Stewart, 1969**). It is calculated using the following formula:

$$Q_2 = \frac{1000.\,P}{\left(\frac{M+m}{2}\right)(M-m)}$$

Where:

- Q_2: Embergr rainfall quotient.
- P: Average annual precipitation (mm).
- M: Maximum temperatures of the warmest month (°K).
- m: Minimum temperatures of the coldest month (°K).

Temperatures are expressed in absolute degrees [T°K = T°C + 273.2].

This index is only defined for the Mediterranean region and, depending on the value of this coefficient, the following zones are identified:

- Wet for: Q> 100.
- Damp for: 100> Q> 50
- Semi-arid for: 50> Q> 25
- Arid for: 25> Q> 10
- Deserts for: Q <10.

Both study sites belong to the bioclimatic stage of subhumid vegetation with warm winters.

Table 4. Emberger rainfall quotient and bioclimatic stage for the Skikda and El- Tarf region over the period (1989-2019)

Station	P (mm)	M(c°)	m(c°)	Q2	Bioclimatic floors
Skikda	737.75	27.95	6.56	118.74	Sub-humid
El-Tarf	808.52	29.32	5.69	117.70	Sub-humid

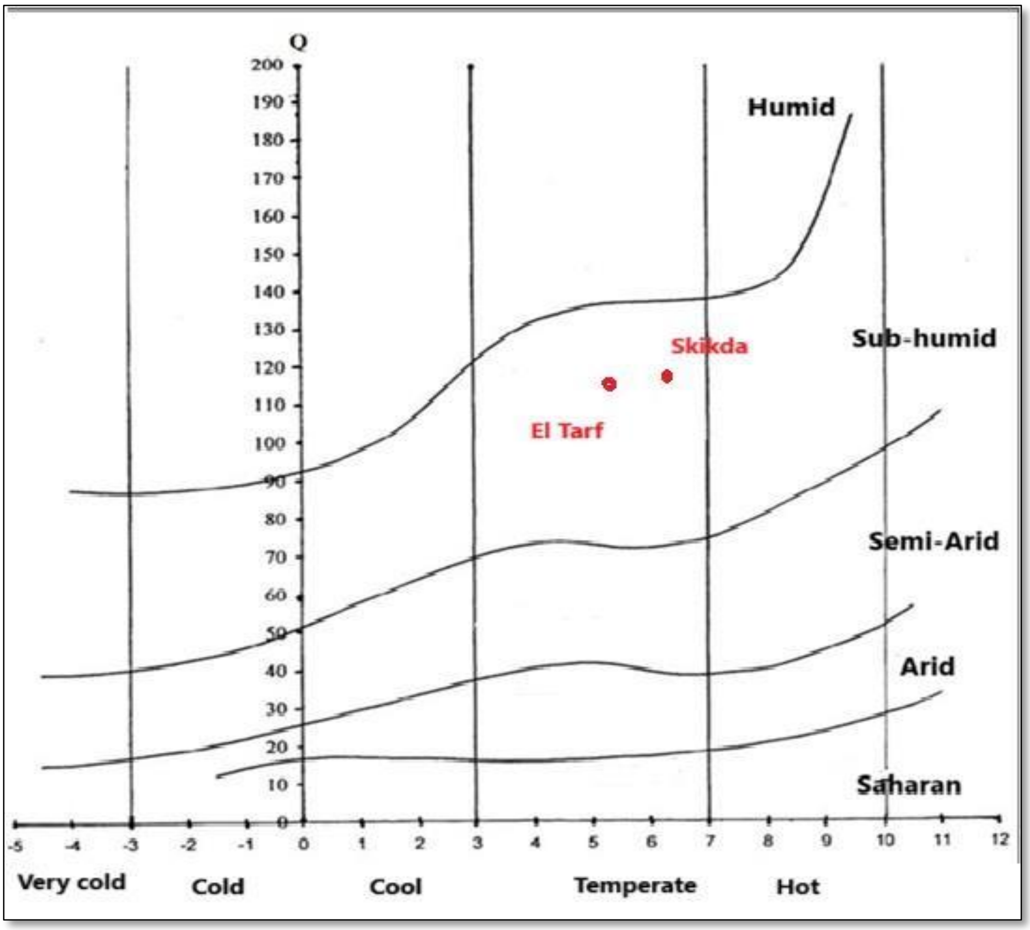


Figure 4. Emberger rainfall quotient for the Skikda and El- Tarf region over the period (1989-2019)

I.2.6. Threats to the ecological characteristics of the study sites

The wetland complex of Algerian Numidia in general is subject to certain threats that must be taken into consideration:

- **Gareat Hadj Tahar**

The study area, which is rich in livestock (mainly sheep, goats, and cattle), is threatened by the impact of these animals on the edges of the water. The herds graze on the vegetation along the banks and the cattle enter the water to drink and graze, disturbing the birds. In addition, shepherds allow their flocks to graze near the wetlands, while local people cut the vegetation, especially *Typha angustifolia* and *Juncus acutus*, to build shelters and reinforce the roofs of their houses.

Water from the wetland is used to irrigate the region's vegetable crops, with around ten pumps operating almost all day to irrigate surrounding and sometimes more distant land. In addition, the use of chemical products for agricultural purposes disrupts the mineral balance of the water.

Hunting, practised by both local people and poachers, targets all species, including protected ones. Outside the hunting season (June) we saw dozens of hunters, accompanied by dogs and guns, hunting the Ferruginous Duck (*Aythya nyroca*).

- **Lac des oiseaux**

The study site faces multiple threats that threaten its biodiversity and ecological balance. These pressures are mainly caused by human activities of the local population and uncontrolled urban development. The main threats identified are:

Intensive grazing: Livestock graze on the vegetation along the banks, destroying important plant species and disrupting natural habitats.

Urban development: The expansion of the village, the construction of infrastructure and human activities (sports, recreation) generate noise and disturbance that affect wildlife, especially birds.

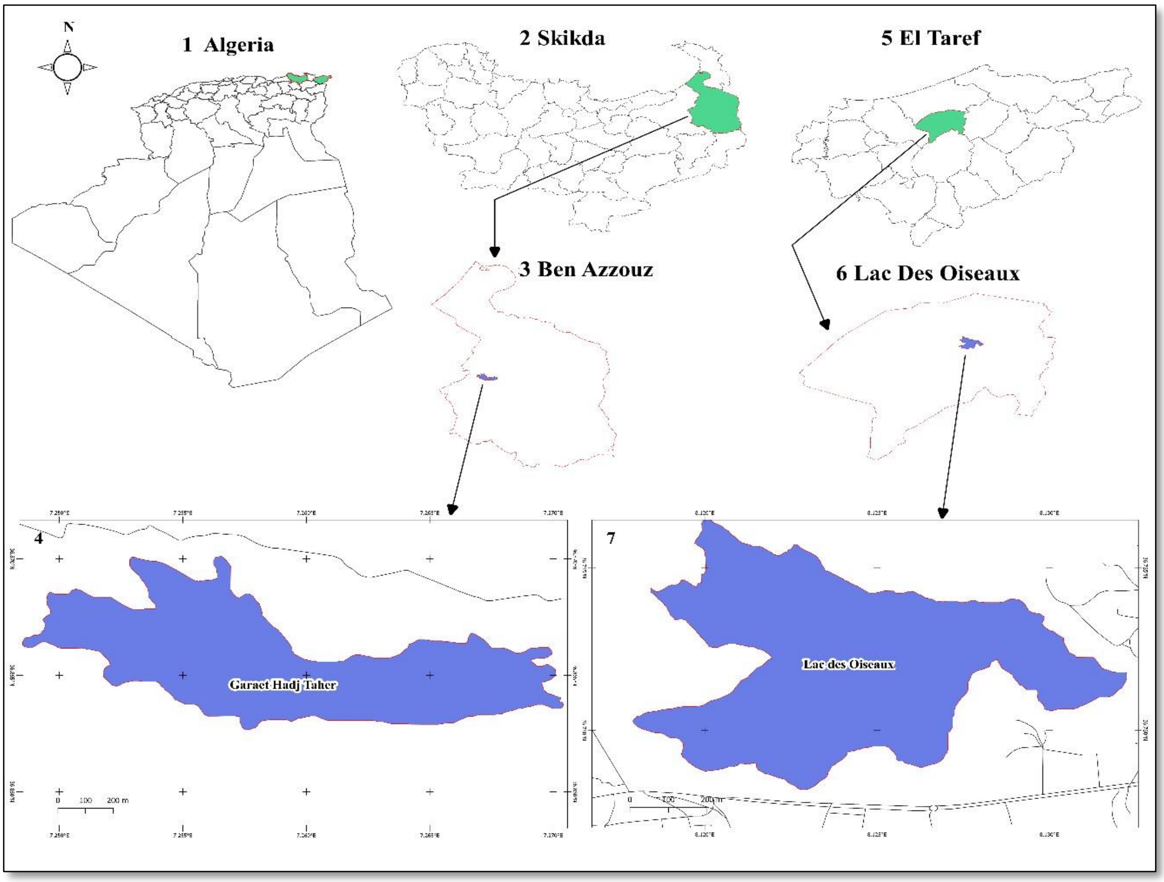
Agriculture: The use of fertilizers and pesticides pollutes the water of the lake and disrupts its chemical balance.

Bird disturbance: Human activities around the lake, such as fishing, hunting, and grazing, disturb birds, especially nesting species.

Pollution: The lake is used as a dumping ground, leading to significant water pollution from industrial, domestic, and waste discharges.

Chapter II : Materials & Methods

Our study was divided into two parts: the study of the ecology of Anatidae and the study and characterization of the biotope in these two bodies of water. In this study, we chose Garaet Hadj-Tahar (Western Numidia) and Lac des Oiseaux (Eastern Numidia) (**Map 5**)



Map 5. Elevation map and location of the GHT and LDO in Algerian Numidia, north-east Algeria

II.1. Ecological study of Anatidae species

The study is being carried out in two wetlands of international importance, classified as Ramsar sites, in northeastern Algeria: GHT (112 ha) and Lac des Oiseaux (70 ha). It concerns all the species belonging to the Anatidae family that frequented these two environments throughout two wintering season (2021-2022 and 2022-2023) from October to April. There are fourteen species: nine species of dabbling ducks and five species of diving ducks: Mallard *Anas platyrhnchos*, Northern shoveler *Anas clypeata*, Eurasian wigeon *Anas Penelope*, Gadwall *Anas stepera*, Eurasian teal *Anas crecca*, Northern pintail *Anas acuta*, Marbled duck *Marmaronetta angustirostris*, Garganey *Spatula querquedula*, Common shelduck *Tadorna tadorna*, Common pochard *Aythya ferina*, Ferruginous duck *Aythya nyroca*, Tufted Duck *Aythya fuligula*, Red-crested Pochard *Netta rufina*, White-headed Duck *Oxyura leucocephala.*

II.1.1. Anatidae counting techniques

The phenology and structure of the Anatidae population was monitored bi–monthly using a long ornithological view (Konus Spot 20 × 60). Birds were surveyed from vantage points that were chosen because of their relative accessibility and unhindered view (**Appendix 01**).

When there were fewer than 200 birds in the group and they were within 200 meters, an individual count was conducted. We estimated whether the group had more than 200 birds or was more than 200 meters away, per **Baaziz et al. (2011)**. We accomplish this by splitting the visual field into multiple bands of birds, calculating the average number of birds in each band, and reporting the number of bands. The margin of error for this method can reach 10%. It is strongly tied to the observer's background and the caliber of the tools being used. (**Houhamdi and Samraoui, 2002, Amorabda et al., 2015, Merzoug et al., 2015; Boubakeur et al., 2020**).

II.1.2. Calculation of Diversity Indices

- **Abundance**

This is the sum of the abundances of the populations that make it up. In other words, the sum of individuals belonging to each species.

$$\boldsymbol{N = \sum ni}$$

- **Specific richness (S)**

Species richness was described by **Blondel (1975)** as the total number of species (S) recorded at least once in N surveys.

This parameter is extremely useful in characterizing populations, as it is closely dependent on the surface area sampled and provides information on the quality of an environment inhabited by a group of species, i.e. the greater the richness, the more complex and stable the environment.

Wealth is a raw value that cannot be interpreted statistically. However, it is impossible to compare two species richness's belonging to two different environments, but it is possible to compare two cumulative species curves under identical conditions.

- **Shannon-Weaver index (H')**

The Shannon-Weaver index is a diversity index that expresses the degree of complexity of a stand. This index only has ecological significance if it is calculated for a community of species performing the same function within the biocenosis (**Blondel, 1975**).

$$\boldsymbol{H' = -\sum_{i=1}^{s} Pi \log_2 Pi} \quad \text{Where} \quad \mathbf{Pi} = \boldsymbol{\frac{ni}{N}}$$

Pi: Frequency of species i

n_i: Number of species i

N: Total population

H': diversity index expressed in Bit (Binary digit)

Its value varies from 0 (a single species) to log S (when all species have the same abundance). If the value of H' is high, this means that the population is rich in species, balanced, and characterized by a complex, mature, and stable environment.

A low value of H', on the other hand, may correspond either to a population with a small number of species or to many individuals. Or an unbalanced population in which there is a dominant species living in a simple environment with non-diversified resources and likely to be frequently disturbed (unstable environment).

- **Pielou equitability index (E)**

The equitability index is used to assess the imbalances that the diversity index cannot detect. The closer its value tends to be to one, the more balanced the stand (**Legendre et al., 1979**).

$$\mathbf{E = \frac{H'}{H'max}} \quad \text{Or} \quad \mathbf{H'max = \log_2 S}$$

H': The diversity index

H' max: maximum theoretical diversity

The index varies from [0 to 1]; it tends towards 0 when almost all the numbers are concentrated in one species. It tends towards 1 when all the species have the same abundance.

II.1.3. Study of Anatidae activity rhythms

Concerning the study of the diurnal activity rhythms of Anatidae, we opted for the SCAN method that was done every hour, from 8 a.m. to 4 p.m (**Altmann 1974**). A total of 376 h was devoted to the time budget analysis (216 h at LDO and 160 h at GHT). The measured activities are sleeping, feeding, swimming, grooming, flying, parade and antagonism.

II. 2. Water physicochemical and bacteriological analyses

II. 2. 1. Water sampling

To explore the causes of the pollution and to study the spatio-temporal evolution of the surface water at the study sites, a 12-month analytical and sampling approach was carried out between November 2021 and October 2022 during the morning hours (8:00 to 10:00) for GHT and the evening hours (12:00 to 14:00) for LDO.

The survey approach and sampling plan were designed to cover all waters at both sites in an optimal and representative manner. Three sampling stations were chosen for each study site (**Tab 5**), based on the vegetation gradient for GHT and the urbanization gradient for LDO (**Appendix 02**). As a result, the three sampling stations are as follows:

Table 5. Characteristics of water sampling points

Sites	**Stations**	**Geological coordinates**		**Properties**
		X	Y	
GHT	1	36° 52' 02.40" N	07° 14' 42.80" E	Located at the extreme north-west of the Garaet and aquatic vegetation present at 90%.
	2	36° 51' 45.58" N	07° 15' 27.23" E	Located to the west of the Garaet and presence of aquatic vegetation at 50%.
	3	36° 51' 42.41" N	07° 16' 01.56" E	Located to the south-east of Garaet, lack of vegetation and very close to the local cemetery of Ben Azzouz.
LDO	1	36◦ 46′ 45.92″ N	08◦ 07′ 18.59″ E	Near the central sewer of the municipality
	2	36◦ 46′ 53.14″ N	08◦ 07′ 52.20″ E	There are some industrial activities close to some residents.
	3	36◦ 47′ 0.97″ N	08◦ 07′ 34.26″ E	Away from urbanization influences

Sampling is crucial because it establishes the analysis's significance. It must be of high quality and reflect what will be analyzed (**Réfea, 2000**).

According to **Rodier et al. (2009)**, it is necessary to take samples in a way that reflects the water to be analyzed and to place them away from the bank. To prevent deposit resuspension, sampling is done between 30 and 40 cm below the surface, or mid-depth if the water level is low (**Rodier and Teule, 2005**).

II. 2.1.1. Sampling for physico-chemical analysis

The physicochemical analyses were kept in plastic bottles that had been washed with distilled water and rinsed with the water to be tested before being transported to the laboratory on the same day for analysis.

During sampling, the bottle was immersed to a depth of 30 cm, with the neck pointing against the current, as recommended by **Rodier (1984)**.

The samples, hermetically sealed and carefully labelled, are placed in a cooler and transported to the laboratory (**Derwich et al., 2008**). It is possible to keep the sample for a few days, but it is advisable to carry out the chemical element analysis as soon as possible. Elements such as nitrates, etc. may undergo changes during storage (**Coulibaly, 2005**).

II.2.1.2. Sampling for bacteriological analysis

The water samples for the bacteriological analyses were taken aseptically in 250 ml Pyrex glass bottles fitted with screw caps, in accordance with the guidelines of **Rodier et al. (2009)**.

The bottle was uncapped and immersed completely in water in an inverted vertical position, holding it by the bottom; it was then turned upside down until the opening was slightly higher than the bottom and oriented against the current (**Derwich et al., 2008**).

After sampling, the vials should be carefully recapped, labeled, and transferred to the laboratory in a cooler to maintain the temperature at 4 ◦C. Between the time of sampling and the time of examination, the number of coliforms in the samples varies. It is therefore important to carry out the analysis as quickly as possible, preferably within one hour and under no circumstances later than 24 hours (**Coulibaly, 2005**).

II.2.2. Water analyses

II.2.2.1. Water physicochemical analyses

The water in the two wetlands was characterized by seven physico-chemical parameters: Electrical conductivity (EC), Dissolved oxygen (DO), Biological oxygen demand (BOD5), Phosphate (PO_4^{3-}), Ammonium (NH_4^+), Nitrate (NO_3^-) and Nitrite (NO_2^-). The measurements were carried out in the biology department laboratory, while some parameters were measured in a private laboratory due to a lack of reagents.

The levels of nutrients NO_3^-, NO_2^-, NH_4^+, and PO_4^{-3} were assessed using the spectrophotometric technique recommended by **Rodier et al. (2009)**. The water samples were analyzed using standard water analysis methods (**APHA, 1999; Rodier et al., 2009**).

A multiparameter analyzer (HANNA HI133) was used to measure the water's physicochemical properties in situ, including electrical conductivity (EC) and dissolved oxygen (DO).

A. Electrical conductivity (EC)

Electrical conductivity is measured in the field using an appropriate portable multiparameter (HANNA HI133), with the electrode immersed in the water to be analyzed.

B. Dissolved oxygen (DO)

Dissolved oxygen is assessed in the field using a portable multiparameter (HANNA HI133). The quantity of dissolved oxygen in the water can be expressed in milligrams per liter (mg/L) or as a percentage of saturation (**Laurentides, 2009**).

C. Biological oxygen demand (BOD5)

BOD5 is the standard 5-day determination of BOD (**Boyd, 2020**). The BOD of a sample represents the amount of dissolved oxygen that will be used by aerobic biological organisms to break down readily oxidizable organic matter.

The primary effect of releasing biodegradable organic matter into the environment is the subsequent consumption of oxygen, whereas the BOD5 concentration in lake water serves as a general indicator of water pollution (**Ustaoglu et al., 2021; Moussaoui et al., 2024**).

Biological oxygen demand (BOD5) was measured using the respirometry method. The decrease in oxygen consumed during biodegradation of a sample causes a decrease in pressure, which is measured using a manometer.

BOD5 was expressed in mg O2/L. The BOD5 of natural water is generally between 1 and 10 mg/L. The domestic wastewater has a much higher BOD5, generally between 100 and 300 mg/L (**Boyd, 2020**).

D. Phosphate (PO_4^{3-})

Phosphate is measured spectrophotometrically at 430 nm (**Rejsek 2002; Rodier et al., 2009**) by the colorimetric method with ascorbic acid and ammonium molybdate. The maximum threshold for phosphate is 5 mg/L (**Rodier et al., 2009; WHO, 2017**).

E. Ammonium (NH_4^+)

Ammonium ions are determined by spectrometry at a wavelength of 630 nm, using the Nessler reagent method. In an alkaline environment and in the presence of nitroprusside, which acts as a catalyst, the treated with a solution of chlorine to transform them into monochloramine (NH2Cl) and phenol give indophenol blue, which can be measured by spectrometry. The maximum limit for ammonium content set by the WHO is 0.5 mg/L (**WHO, 2017**).

F. Nitrate (NO_3^-)

Nitrates were identified using spectrophotometric analysis at 415 nm as recommended by **Rodier et al. (2009)**. When sodium salicylate is present, nitrates produce sodium paranitrosalicylate, which is yellow in color and can be identified spectrophotometrically (**Battas et al., 2019**). The maximum nitrate level established by the WHO is 50 mg/L (**WHO, 2017**).

G. Nitrite (NO_2^-)

Nitrite ions were determined spectrophotometrically. According to Ruiz Capillas et al (2007), nitrite determination is based on the colorimetric reaction between the nitrite in the sample and the reagents sulphanilamide and N-(1-naphthyl) ethylenediamine dihydrochloride (NED).

This reaction produces an azodyaminethat which is detected spectrophotometrically at 520-540 nm. The WHO has set the nitrite threshold at 0.1 mg/L **(WHO, 2017)**.

II.2.2.2. Water bacteriological examination

The methods used to determine faecal pollution indicators are numerous, and the criteria for choosing a technique depend on the origin and nature of the water to be examined (borehole or well water, turbid water, wastewater, etc.), factors relating to the quality of the results, and factors relating to the cost of the analyses (**Tandia, 2007**).

Measuring the microbiological quality of water is therefore based on the principle of 'indicator' bacteria. According to **Tamara (2006)**, these indicators (or bacteria that indicate contamination) are not necessarily pathogenic in themselves, but their presence indicates the presence of contamination by faecal matter, and their abundance indicates the level of risk of the presence of pathogenic microorganisms. It is accepted that if these indicator germs are present in sufficient quantities in an environment, this means that the environment has been contaminated at one time or another by animal and/or human faeces and excrement. In various countries and under different jurisdictions, several groups of bacteria are used as indicators of faecal contamination **(Rajonson et al., 1992)**.

In this study, we based our research solely on four groups of germs (Total heterotrophic bacteria, Total coliforms, Faecal coliforms, and Faecal Streptococci). All these germs are known as faecal contamination test germs (FCTG), along with intestinal enterococci, sulfute-reducing anaerobic bacteria (Clostridium sulfuto-reductor) and staphylococci (**Rajonson et al., 1992**).

Four bacteriological groups were identified in our study using the standard methods (APHA, 1999; Rodier et al., 2009) for microbiological analyses: total heterotrophic bacteria (THB), total coliforms (TC), fecal coliforms (FC), and fecal streptococci group (FS) (**APHA, 1999; Rodier et al., 2009**).

II.2.2.2.1. Enumeration of total heterotrophic bacteria

The methods for counting heterotrophic bacteria are straightforward, based on culture, and intended to recover a variety of organisms. Although there is no single culture medium, temperature, or incubation time that can guarantee the recovery of all organisms present in water, the 20th edition of Standard Methods for the Examination of Water and Wastewater (**APHA et al., 1998**) indicates the conditions that must be met to establish a meaningful estimate of certain culturable species. Three methods are currently used: poured media in Petri dishes, plates prepared by spreading, and membrane filtration for the enumeration of heterotrophic bacteria (**APHA et al., 1998**).

In this study, the Petri dish method was used, which involves adding a small volume of sample (0.1–2.0 ml) to molten agar (44–46 °C) and pouring the mixture into Petri dishes, which are then incubated for the required time.

Two incubation methods are generally used: Petri dishes can be kept at 35°C for 48 hours or at 20-28°C for 5 to 7 days. The poured media method generally produces small, compact colonies that are easier to count.

II.2.2.2.2. Enumeration of coliforms and faecal streptococci

For TC, FC, and FS, we used the most probable number (MPN) or liquid medium inoculation method.

A. Principle

The MPN technique uses the multiple tube fermentation method (**Roux, 2003**). The principle consists of inoculating numerous samples of the same sample and/or dilutions thereof into tubes of liquid culture medium.

The samples or dilutions are then incorporated into a series of tubes (3 series), 3 to 5 tubes per series, of non-genuinely selective medium; this is the presumptive test (growth or not). A second series of tubes on a more selective medium is inoculated by subculturing the tubes that gave a positive result in the first series; this is the confirmation test (**Tandia, 2007**).

The inoculated tubes are read, and the number of germs determined by determining the Most Probable Number (MPN), which is simply a statistical estimate of the number of bacteria that, more likely than not, would give the results observed; it is not the actual number of bacteria present (**Rajonson et al., 1992**). The findings are presented using the Mac-Grady statistical table and are expressed as CFU per 100 mL of water (**Appendix 03**).

B. Inoculation

B.1. Presumptive test

In accordance with the MPN technique, we use five tubes for each of the three logarithmic series, the terms of which are in geometric progression for every water sample that needs to be examined. We therefore have decimal dilution series: 10^{-1}, 10^{-2}, 10^{-3}, 10^{-4}, 10^{-5}. Dilutions are always carried out under aseptic conditions (**Bourgeois and Leveau, 1980**).

- **For Total coliforms**

We used five tubes of purple bromocresol lactose broth (BCPL), in single concentration, fitted with a Durham bell. After careful homogenization, remove 1 ml of the water to be analyzed using a Pasteur pipette and transfer it to the first tube of the dilution series (10^{-1}). The pipette must not be exposed to either the walls of the tubes or the diluting liquid. Using a new Pasteur pipette, homogenize the contents of this tube (10^{-1}) by aspiration and blowing, take 1 ml and inoculate the tube (10^{-2}), and so on up to tube (10^{-5}). Change pipettes each time (**Bourgeois et Leveau, 1980**) (**fig 5**).

Total coliforms are counted after incubation for 24 to 48 hours at 37°C. First, observe whether the tubes have changed color. Then, observe the cloudiness in the medium due to the growth of the bacteria present. Finally, observe the production of gas as indicated by the lifting of the Durham bell introduced into the medium (at least 1/10 of the bell should be empty) (**Tandia, 2007**) (**fig 6**). After inoculating the tubes, check that there are no air bubbles under the bell to avoid falsifying the results.

- **For streptococci**

Streptococci are detected on Rothe medium (**Bricha et al., 2007**), following the same procedure described for TC. Incubation at 37°C for 24 h (**Fig 6**).

B.2. Confirmative test

- **For Faecal coliforms**

BCPL tubes found to be positive during coliform enumeration will be subcultured using a looped loop into a tube containing Schubert medium fitted with a Durham bell (**Fig 5**).

Remove any air from the Durham bell and mix the medium and inoculum thoroughly. Incubation this time took place in a water bath at 44°C for 24 hours (**Labres et al., 2008**). Tubes showing both a release of gas and a red ring on the surface, indicating indole production by Escherichia coli after addition of 2 to 3 drops of Kowacs reagent. The final reading is also taken according to the NPP table. because Escherichia coli produces both gas and indole at 44°C for 24 hours (**Labres et al., 2008**).

Note: Since faecal coliforms are part of total coliforms, it is practically impossible to find more faecal coliforms than total coliforms. Results are expressed as germs per 100 ml of water analyzed (**Labres et al., 2008**).

- **For Faecal streptococci**

Positive Rothe tubes are subcultured on EVA Litsky medium at 37°C for 24 hours. Eva-Litsky medium is simply a Rothe medium with added ethyl violet. The presence of streptococci is indicated by a more or less significant cloudiness and the formation of a purple pellet at the bottom of the tube (**Fig 6**) (**Roux, 2003**).

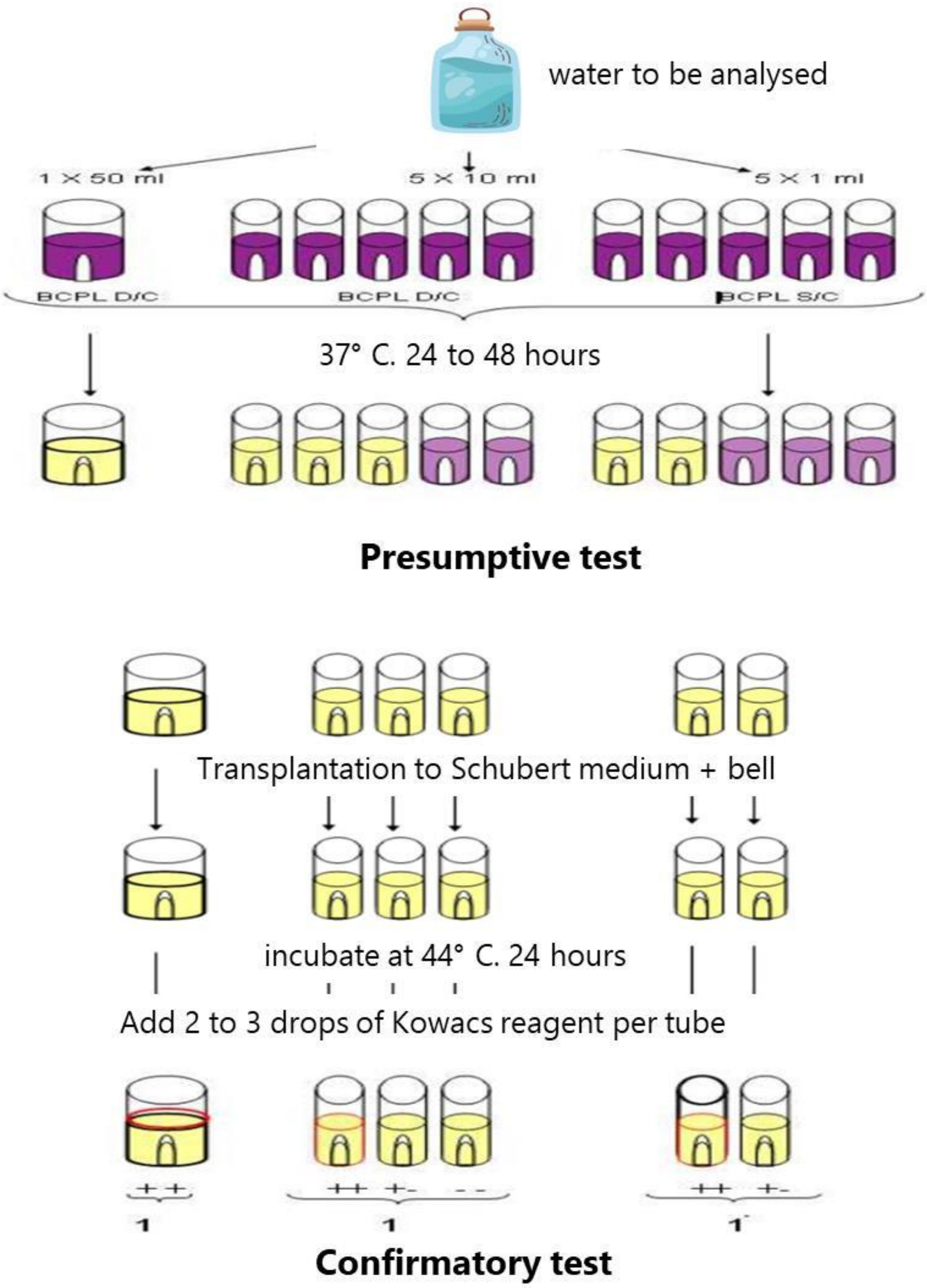


Figure 5. Enumeration of Total and Faecal coliforms

(Flow chart of the MPN).

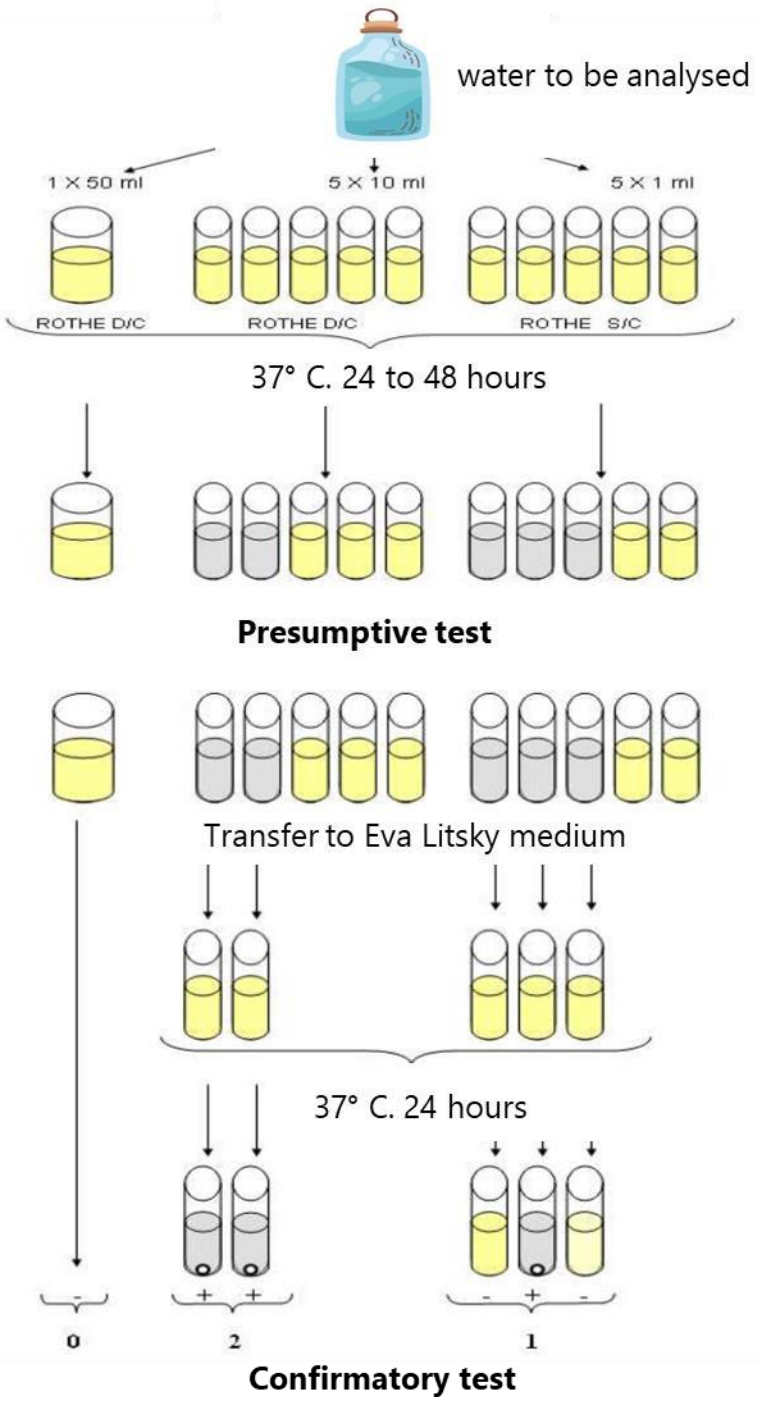


Figure 6. Enumeration of faecal streptococci

II.3. Statistical analysis

Univariate (correlation tests) and multivariate (cluster analysis and principal component analysis) statistical analyses were carried out on the data to determine the various correlations between the water parameters.

II.3.1. Multivariate statistical analysis

In recent years, various multivariate statistical techniques have been frequently employed to examine environmental and hydrogeological phenomena, especially those related to the assessment of water quality (**Ghaudhry et al.,2019**). In this research, CA and PCA, which were performed using IBM SPSS Statistics software (version 27) and Origin Pro Learning Edition for students. were applied to the study of 64 surface water samples (32 in GHT and 32 in LDO).

- **Multivariate tests (ANOVA)**

A two-way analysis of variance (ANOVA) was used to evaluate the spatiotemporal differences in physico-chemical water parameters and bacterial load values for THB, TC, FC, and FS between stations, the two study sites, and months. We then used a Tukey post hoc test to identify distinct groups among the stations and seasons with different characteristics when the ANOVA test produced a significant result ($p < 0.05$). Additionally, we used Pearson correlation tests to investigate the relationships among the water's physicochemical and bacterial parameters.

- **Cluster analysis (CA)**

CA is a statistical technique used to classify water samples according to their characteristics (**Kumar et al.,2022; Gaagai, 2017**). It is a technique frequently used to categorize observations or variables into relatively homogeneous groups and to illustrate their interactions. As part of a research project, the clustering process can be applied, which consists of gathering until a single set containing all the variables is identified.

The different levels of the dendrogram can then be broken down to generate different groups of physico-chemical and bacteriological water parameters sampled based on the most significant chemical variables. This approach is based on assessing the similarity between two models using a distance measure, the most widely used being the Euclidean distance (**Dash et al.,2021; Athamena et al.,2022**).

- **Principal component analysis (PCA)**

The use of Principal Component Analysis (PCA) in surface water quality studies is an effective and useful tool that can provide relevant insights into complex relationships and connections between variables (**Ghodbane et al.,2022; Elsayed et al.,2021**). In addition, the PCA technique facilitates the identification and expression of similarities and differences, while grouping samples according to their characteristics.

Indeed, Principal Component Analysis (PCA) uses factor analysis to determine the reasons for changes in water quality by examining the fluctuation in the various parameters analyzed (**Roubil et al.,2022; Lu et al.,2015**). The suitability of the data for factor analysis was checked using the KMO and Bartlett tests. To examine the relevance of the sample to each of the individual variables in the model. KMO values ranging from 0.8 to 1, 0.5 to 0.8 and less than 0.5 were all considered appropriate or desirable, respectively (**Patil et al., 2020**).

Chapter III : Results & Discussion

III.1. Phenology and patterns of occupation and spatiotemporal distribution of Anatidae in the Gareat Hadj Taher and Lac des Oiseaux

The distribution of birds in a body of water follows specific patterns that are almost never random. It is influenced by biological and ecological factors specific to the species and the site (**Tamisier et al., 1999**). One of the fundamental factors influencing the distribution of aquatic birds is the availability and accessibility of food resources (**Jacobsen, 1994**). According to **Brochet et al. (2009)**, it has also been established that the size of wetland habitats is the main factor influencing the diurnal distribution of ducks. They attribute this to the expansion of the diversity of feeding niches, as well as to the protection against human disturbance provided by the heart of a vast wetland ecosystem.

During our outings and after the systematic counting of Anatidae, we tried to locate them on maps using constant reference points in the two study sites to determine their mode of occupation of the body of water.

These specific and provisional maps were then transferred to other definitive monthly maps, which will make it possible to monitor the invasion and use of the wetland by waterbirds, as the graphical representations of spatial occupation do not consider the numerical importance of the birds.

III.1.1. Mallard : *Anas platyrhnchos*

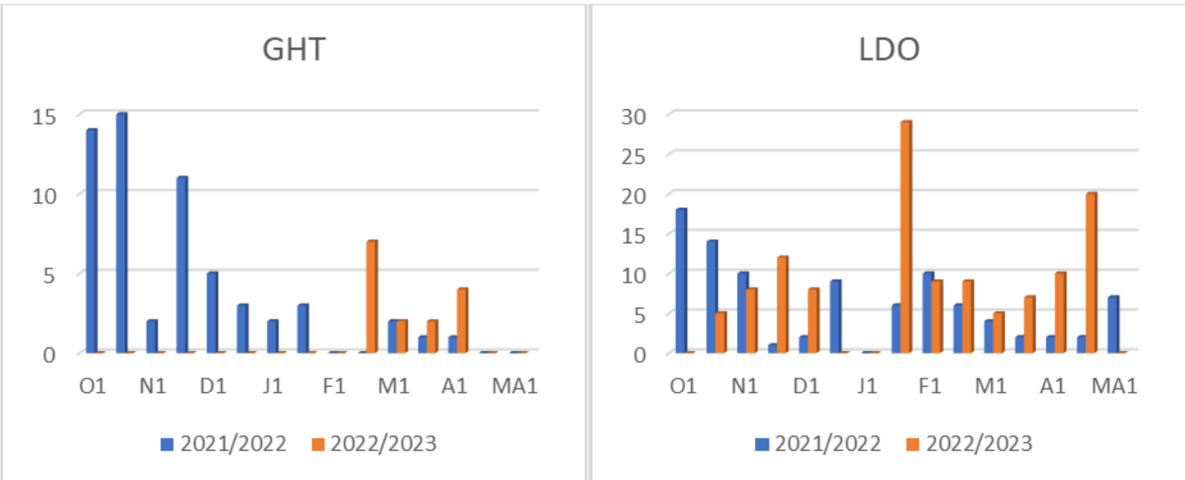


Figure 7. Fluctuation in the number of *Anas platyrhnchos* in GHT (left), LDO (right).

Seasons: 2021/2022-2022/2023

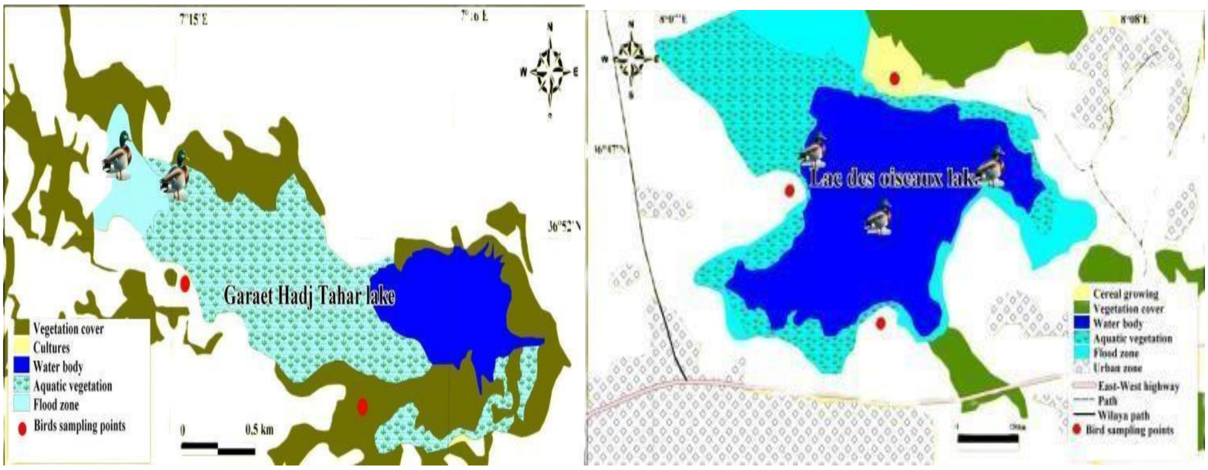


Figure 8. Spatial occupation by *Anas platyrhnchos* in GHT (left), LDO (right). Seasons: 2021/2022 and 2022/2023

The Mallard is a sedentary breeding bird in Numidia and the most commonly observed in Algeria (**Samraoui & Samraoui, 2008**). These birds do not move much between sites unless disturbed (**Dziri et al., 2014**). They feed particularly on duckweed and leaves of aquatic plants, but also on tadpoles and small fish (**Bezzalla,2019**)

Mallards are common in their natural habitat, which comprises the ponds, rivers, and streams found in artificial waterways such as parks and farms. They are also kept for aesthetic purposes in human watering holes and inland yards (**Birdlife, 2015**). As a potential epidemic detector, Anas platyrhynchos is endangered due to pesticide contamination and lead shot ingestion (**Memon, Q., 2023**).

The mallard is a wintering species at GHT and LDO. At GHT, a maximum of 14 individuals were observed in the northwest on October 20, 2021. After that, the number of individuals decreased until the end of the first wintering season (**Fig 7**).

Regarding the second period, from October to February, it was noted that there are days when there are no individuals, probably due to the drought in GHT. The second wintering season, or January, was when the greatest numbers at LDO were observed, with a maximum of 29 individuals recorded on January 31, 2023.

After that, collapses were recorded until the end of the wintering season. This dabbling duck uses the central, north-eastern, and north-western sectors of the lake (**Fig 8**).

III.1.2. Northern shoveler: *Anas clypeata*

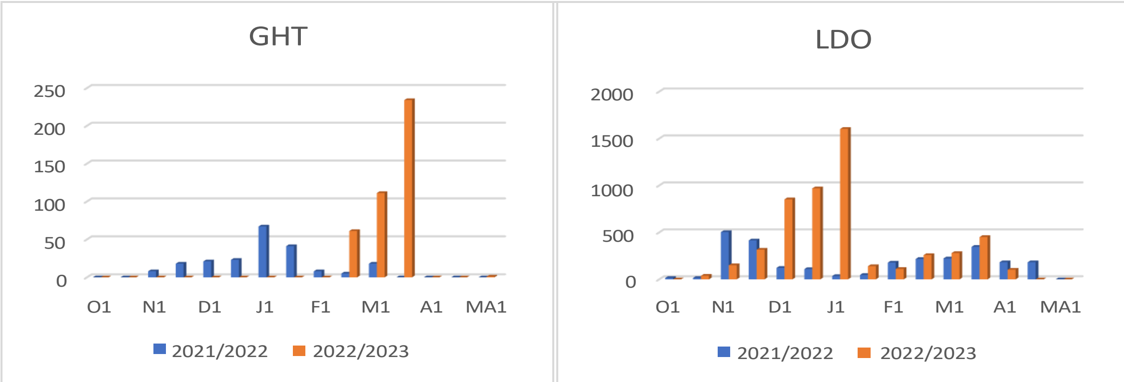


Figure 9. Fluctuation in the number of *Anas clypeata* in GHT (left), LDO (right). Seasons 2021/2022 and 2022/2023

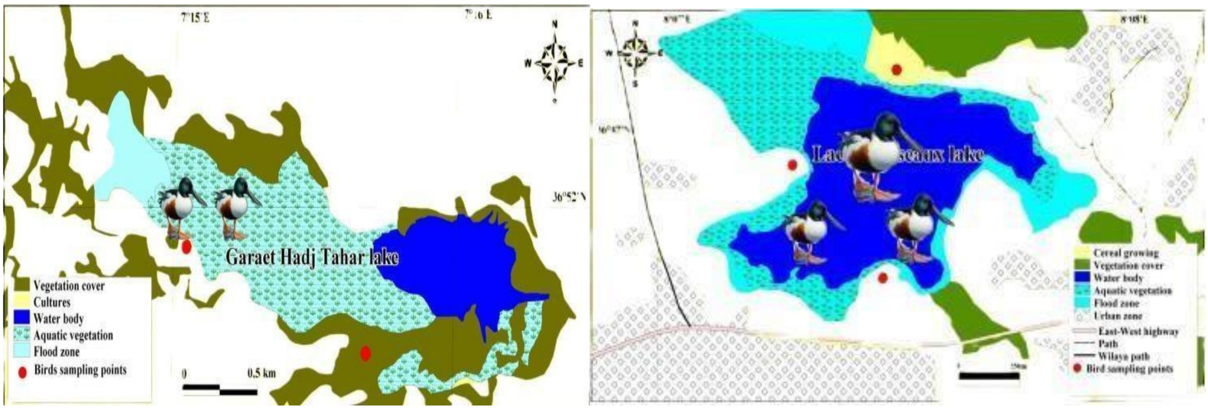


Figure 10. Spatial occupation by *Anas clypeata* inGHT (left), LDO (right). Seasons 2021/2022 and 2022/2023

The Northern Shoveler is an extremely prevalent species in Algeria (**Isenmann and Moali, 2000, Metallaoui et al., 2014, Tabouche et al., 2016, Khemis et al., 2018**). It is a regular winter visitor to the country's extreme northeast and primarily resides in the population that breeds in central Europe (**Ruger et al., 1987**). In the wetlands of eastern Algeria, this duck species' life history features have been extensively studied in recent years by the following researchers: **Tabouche et al., 2017, Bendjedid et al., 2020 and Touarfia et al.,2022.** Recently, **Slimane et al.,2023** confirmed the first breeding of the Northern Shoveler *Spatula clypeata* in Algeria.

The Shoveler, like most Anatidae, was mainly observed in the centre of Lac des Oiseaux and in the western part of the GHT (**Fig 10**). According to **Tabouche (2017)**, this duck is generally distributed in the central area of the Garaet Hadj-Tahar, mainly in areas devoid of any vegetation and away from disturbances caused by water pumping.

This species is observed throughout the wintering season. It is much more present in LDO than in GHT (**Fig 9**). The first observations of shoveler ducks began in October in the LDO, where their numbers reached a maximum of 1602 individuals in 04.01.2023. According to **Khemis et al. (2016)**, around 485 individuals can be seen nearby in the El-Feid marsh. In the GHT, this dabbling duck is poorly represented. The maximum recorded is 234 individuals observed during the second wintering season (17/03/2023). After this date, the numbers of these Anatidae are suddenly cancelled.

III.1.3. Eurasian wigeon: *Anas Penelope*

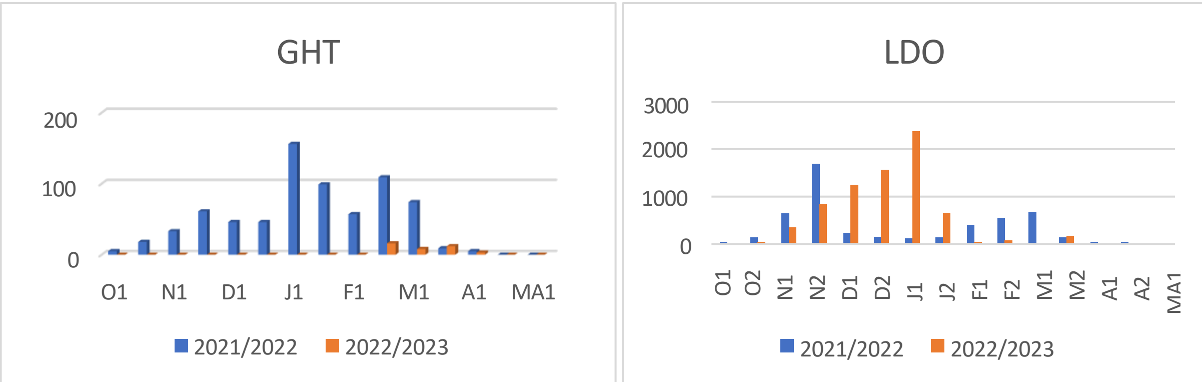


Figure 11. Fluctuation in the number of *Anas Penelope* in GHT (left) and LDO (right). Seasons 2021/2022 and 2022/2023

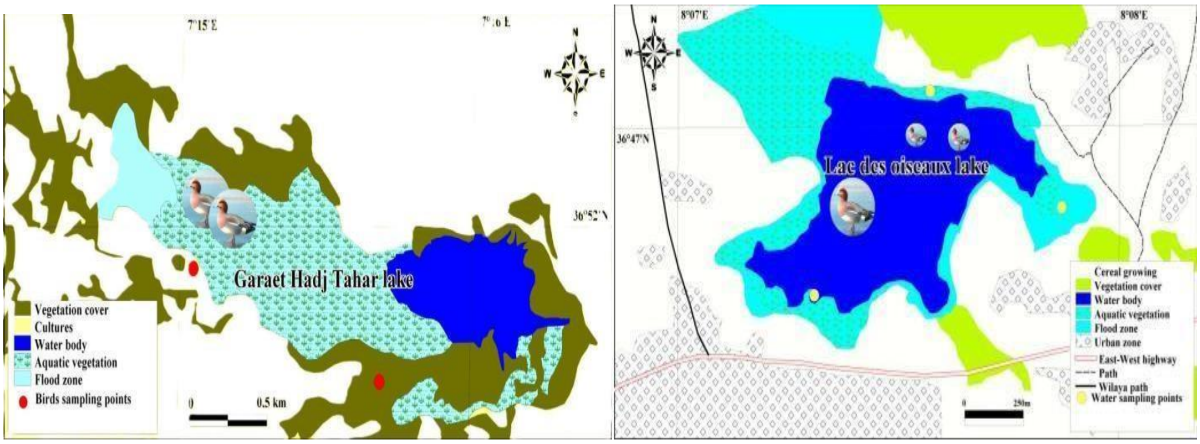


Figure 12. Spatial occupation by *Anas Penelope* in GHT (left) and LDO (right). Seasons 2021/2022 and 2022/2023

Wigeons are social birds that only live in groups. Their wintering grounds extend over the entire Mediterranean basin. (**Houhamdi and Samraoui, 2003**). *Anas penelope* is a dabbling duck that has been the subject of a great deal of research on the northern shores of the Mediterranean but is still little studied in North Africa. Little is known about the ecology, spatial and temporal distribution, and dynamics of this area of the Mediterranean basin.

This species is observed throughout the period of our study with considerable numbers in LDO compared with GHT. It is the most represented species in our study sites. The Wigeon has a wintering status and a Gaussian graph where the largest number recorded at GHT is 156 individuals observed on 14.01.2022 whereas 2387 individuals were recorded on 04.01.2023 at LDO. The numbers then decline until the end of the wintering period (**Fig 11**).

The majority of the wigeon populations are found in the central Lac des Oiseaux regions, close to the *Scirpus lacustris*-dominated northwest bulrush, which is most likely where they get most of their food (**Fig 12**). These are shallow and remote from any disturbance (RN44 and the village). Furthermore, the wigeon colonizes the western portion of the GHT, just like any other dabbling duck.

III.1.4. Gadwall: *Anas stepeara*

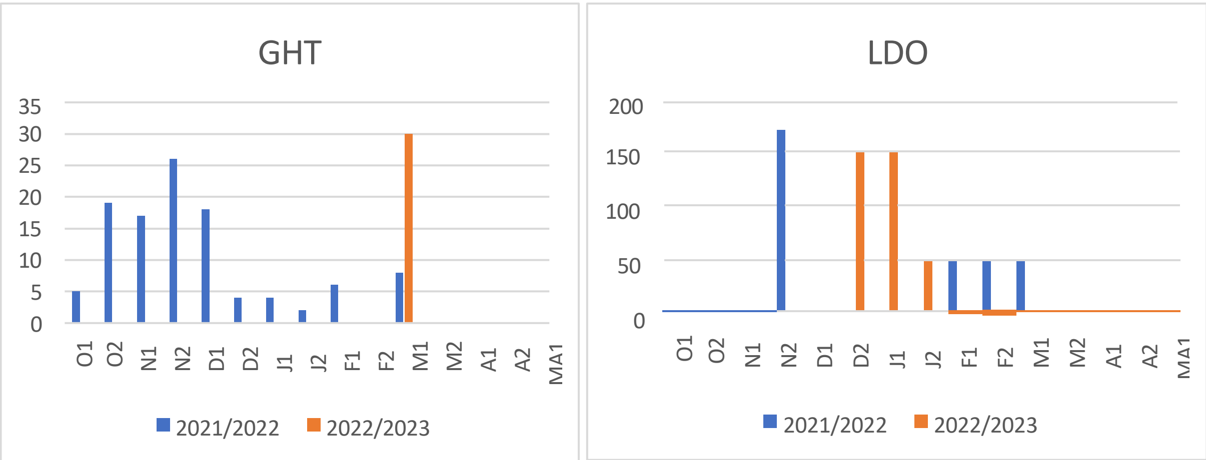


Figure 13. Fluctuation in the number of *Anas stepeara* in GHT (left) and LDO (right). Seasons 2021/2022 and 2022/2023

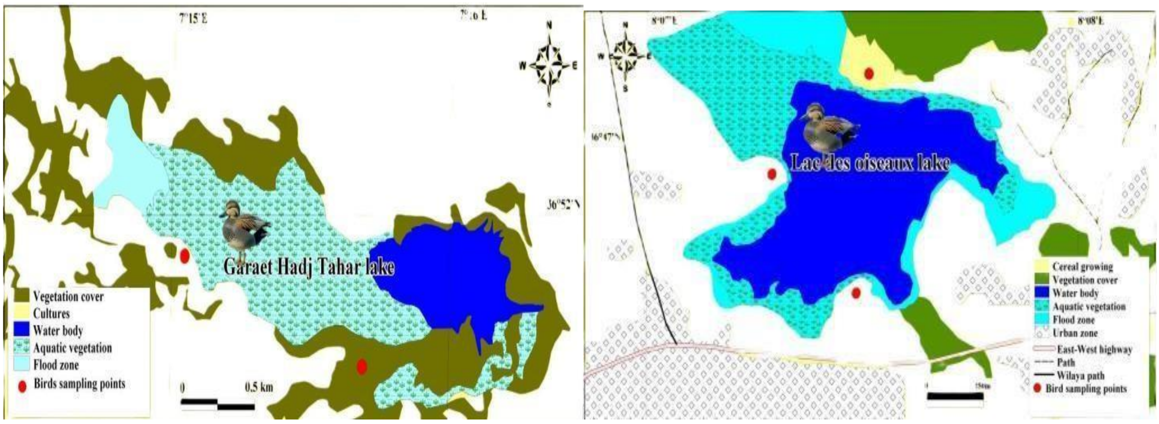


Figure 14. Spatial occupation by *Anas stepeara* in GHT (left), LDO (right).
Seasons: 2021/2022-2022/2023

The Gadwall is a species of Anatidae that regularly winters in the wetlands of Algerian Numidia (**Merzougue, 2015**). Although some authors consider this duck to be an occasional breeder in Algeria (**Isenmann and Moali, 2000**). It is a dabbling duck that frequents mainly loose environments and feeds mainly on plants such as roots, leaves, stems and tubers, but also on aquatic insects, molluscs, small amphibians and poisons (**Elagbani, 1997**). In Algeria, this species has not been the subject of many studies on its wintering strategy (**Merzougue, 2015**).

The Gadwall is a species that has begun to colonise the GHT with very low numbers compared to the LDO. Five individuals of this species were observed during our first outings. Subsequent arrivals of wintering populations brought the total number to 26 individuals recorded on 20.11.2021. By the end of the winter, in March, numbers had fallen to a very low level of 8 individuals.

During the first winter, the Gadwall occupied the LDO at the beginning of October with 12 individuals, then a maximum of individuals was observed at the end of November (27.11.2021) with 170 individuals (**Fig 13**).

After this peak, the species left the site until the beginning of February, when it recolonized the lake with 41 individuals. This value remained stable until it fell completely at the end of March.

III.1.5. Eurasian teal: *Anas crecca*

During our study, Eurasian teal was observed during both wintering seasons, but there were very large numbers in the LDO.

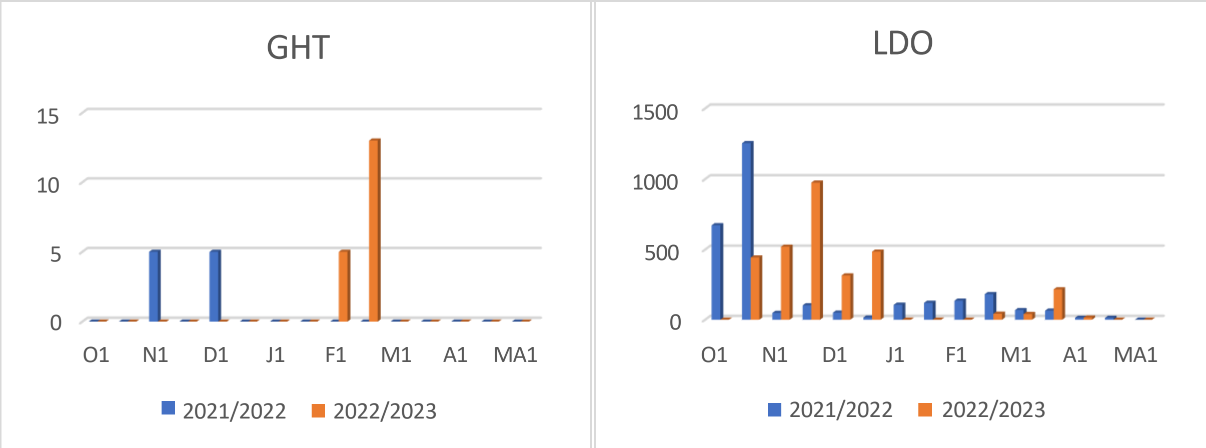


Figure 15. Fluctuation in the number of *Anas crecca* in GHT (left) and LDO (right). Seasons 2021/2022 and 2022/2023

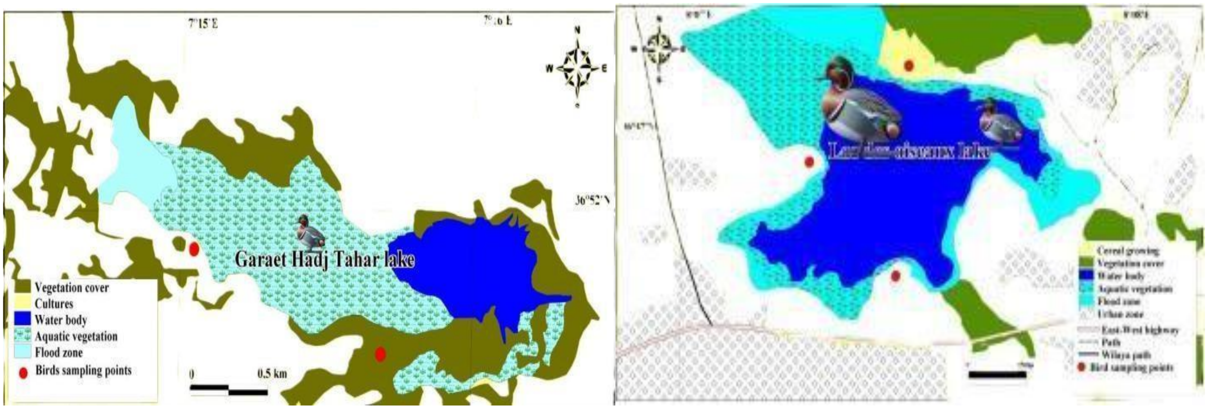


Figure 16. Spatial occupation by *Anas crecca* in GHT (left), LDO (right). Seasons: 2021/2022 and 2022/2023

Eurasian teal is a widespread species in northern Europe (**Cramp & Simmons, 1977**). Within this vast area, two large wintering populations can be distinguished: that of north-western Europe, estimated at 400,000 individuals, and that of the Mediterranean Black Sea (part of which winters in Morocco), of the order of 1,000,000 individuals (**Bezzalla, 2019**). It breeds mainly in the northern to temperate latitudes of the western Palearctic. Its preferred breeding habitats are the forested areas of Scandinavia, the coasts of the Tundra, and the vicinity of small, relatively eutrophic ponds, marshes, lagoons, and slow-flowing streams in the steppic to desert areas of Siberia (**Guergueb, 2016**).

During our study, Eurasian teal Anas crecca crecca was observed during both wintering seasons, but there were very large numbers in the LDO. The species frequented the LDO throughout the wintering season but was only observed in the GHT on two occasions during the two seasons, with a total of no more than 13 individuals (25/02/2023). It therefore has the status of a wintering bird in the LDO and a bird of passage or transit in the GHT (**Fig 15**). However, according to **Charchar (2018)**, this species is the most widespread, with a maximum of 506 individuals observed in the Garaet Hadj-Tahar. In LDO, the first observations were recorded in October and continued until the beginning of April. The maximum numbers observed during the two wintering seasons were 1254 (30/10/2024) and 975 (25/11/2022) successively. Nearby, in the El-Feid marsh, **Khemis et al. (2016)** observed a maximum of 637 individuals.

III.1.6. Northern pintail: *Anas acuta*

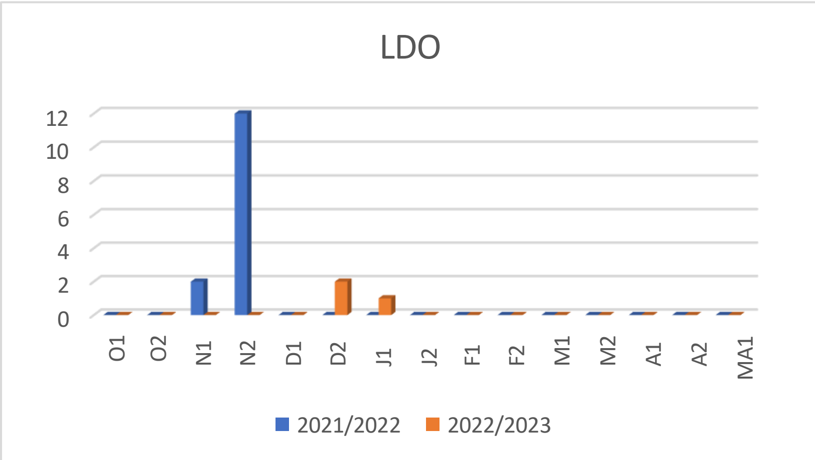


Figure 17. Fluctuation in the number of *Anas acuta* in LDO for the seasons: 2021/2022and 2022/2023

Figure 18. Spatial occupation by *Anas acuta* in LDO for the seasons: 2021/2022 and 2022/2023

The northern pintail is a high-latitude breeding Anatidae. It winters in Western Europe and sub-Saharan Africa. It prefers spacious, shallow wetlands and generally frequents estuaries and mudflats, where it feeds mainly on seeds and grazes on the shoots of aquatic plants. Insect larvae and small crustaceans are only incidental foods. Very little is known about the status of the species in Algeria, but recent studies indicate that large numbers winter in the high plains of Constantinois, where more than 20,000 individuals have been counted in this area (**Boukrouma et al., 2011**).

The pintail was only observed in the LDO on two occasions during the two wintering seasons, when a maximum of 12 individuals were recorded at the end of November (**Fig 17**). Regarding the spatial occupation of this species, we agree with **Houhamdi et al, 2009**, who indicate that pintails frequently occupy the central areas of bodies of water close to other Anatidae such as Eurasian teal *Anas crecca*, Northern shoveler *Anas clypeata*, Eurasian wigeon *Anas Penelope*, Common pochard *Aythya ferina* and Ferruginous duck *Aythya nyroca* (**Fig 18**).

III.1.7. Marbled duck : *Marmaronetta angustirostris*

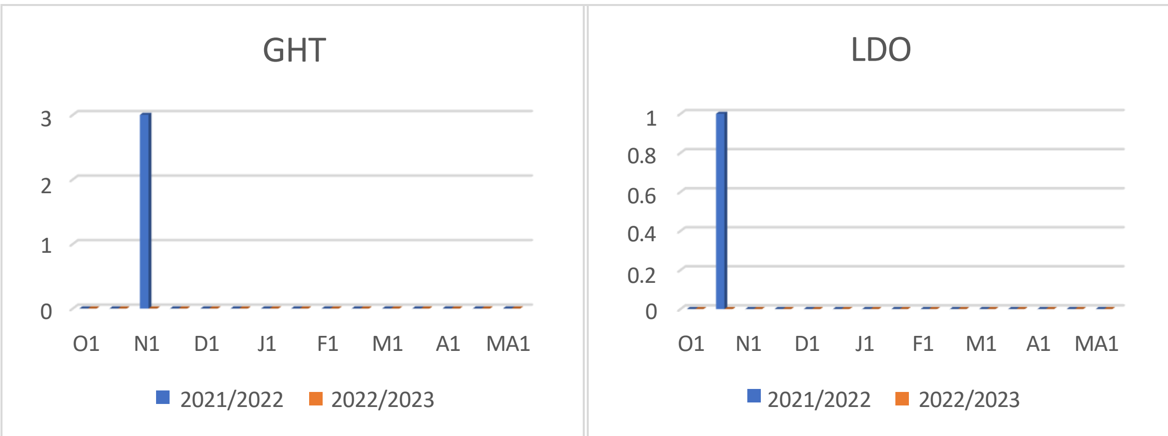


Figure 19. Fluctuation in the number of *Marmaronetta angustirostris* in GHT (left) and LDO (right). Season 2021/2022

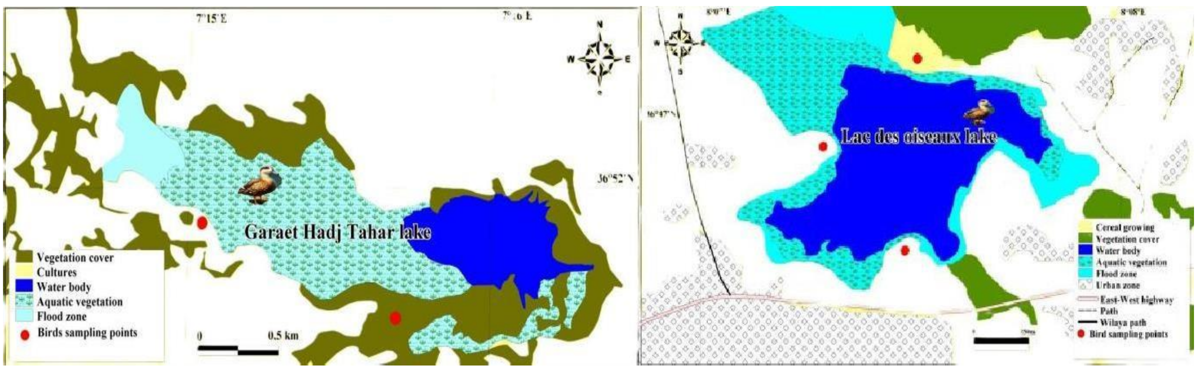


Figure 20. Spatial occupation by *Marmaronetta angustirostris* GHT (left), LDO (right). Season 2021/2022

Marmaronetta angustirostris, commonly known as the Marbled Duck or Marbled Teal, is on the International Union for Conservation of Nature's red list as ‘vulnerable’.In Algeria and the Western Palearctic, it has this status.

The marbled teal exhibits notable variations in population around the world, primarily as a result of yearly fluctuations in rainfall, forcing the species to adjust to shifting environmental conditions (**Charchar, 2018**). **Dodman (2002)** estimates that there are between 50,000 and 55,000 people on the planet, with the majority living in South Asia at least 44000, West Africa at 1000, the western Mediterranean at 3000-5000, and East Africa at 1000. According to **Bouzegag et al. (2013)**, marbled duck populations in Algeria can be found in arid, semi-arid, and coastal wetlands.

As per **Charchar (2018)**, the Marbled duck's annual stay was relatively brief. Three individuals of this species were found in the western portion of the GHT and one individual in the eastern portion of the LDO (Fig 20), according to our research, which only included one recording of the species in each of the two bodies of water.

III.1.8. Garganey: *Spatula querquedula*

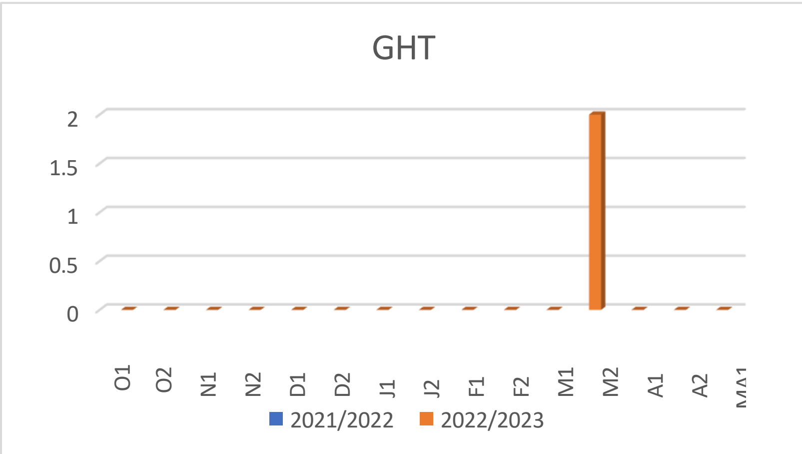


Figure 21. Fluctuation in the number of *Spatula querquedula* in GHT for the season 2022/2023

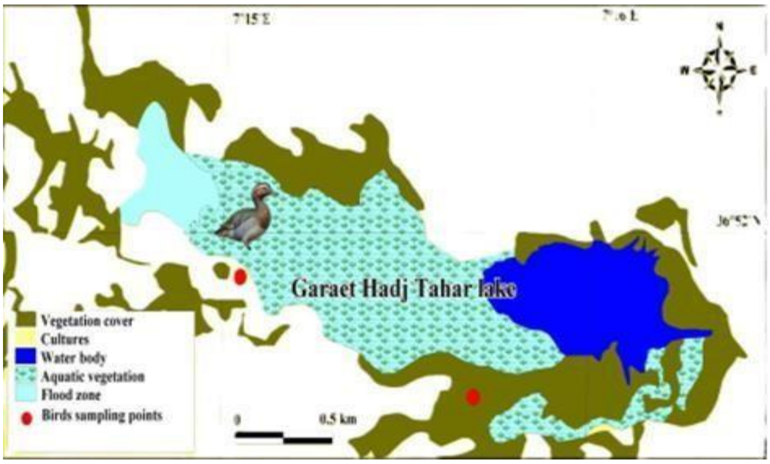


Figure 22. Spatial occupation by *Spatula querquedula* in GHTfor the seasons 2022/2023

The Garganey is an omnivorous bird and prefers to eat plant prey (seeds) and animal prey (insects, molluscs, crustaceans, annelids, etc.) (**Bouzegag et al., 2013**). According to **Houhamdi (2002)**, the summer teal affects flood plains, rice fields, coastal lagoons, marshes, and freshwater lakes in its African wintering grounds. In Algeria, the species is not very common. It is found in humid regions (Saharan chotts and sebkhas) and in the high plateaux before moving on to the usual wintering areas in the Sahel countries (**Isenmann and Moali, 2002**).

This species only visited GHT once, at the end of March, during the 2022/23 season of our study. Only two individuals were noted in the western part of the lake.

III.1.9. Common shelduck: *Tadorna tadorna*

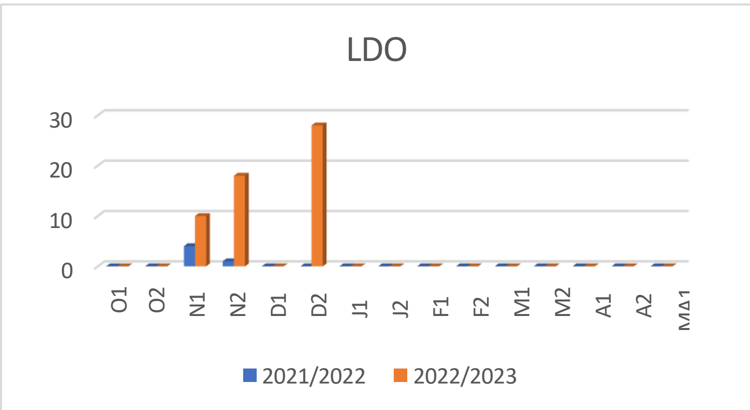


Figure 23. Fluctuation in the number of *Tadorna tadorna* in LDO for the seasons:2021/2022 and 2022/2023

Figure 24. Spatial occupation by *Tadorna tadorna* in LDO for the seasons2021/2022 and 2022/2023

The Common shelduck is a very abundant species in the wetlands of the high plains of eastern Algeria (**Bouchrit, 2014**). In Algeria, the species is concentrated in the great Sebkhet of Oran, the Macta marshes and the Arzew salt pans in the west and Garaet Tarf, Ank Djemel and Baghai in Constantinois (**Bezzalla, 2019**).

This species was only observed in the Lac des Oiseaux on 3 occasions in November and December on the banks in the western part of the lake. The maximum observed during the second wintering season was 28 individuals, recorded at the end of December.

III.1.10. Common pochard: *Aythya ferina*

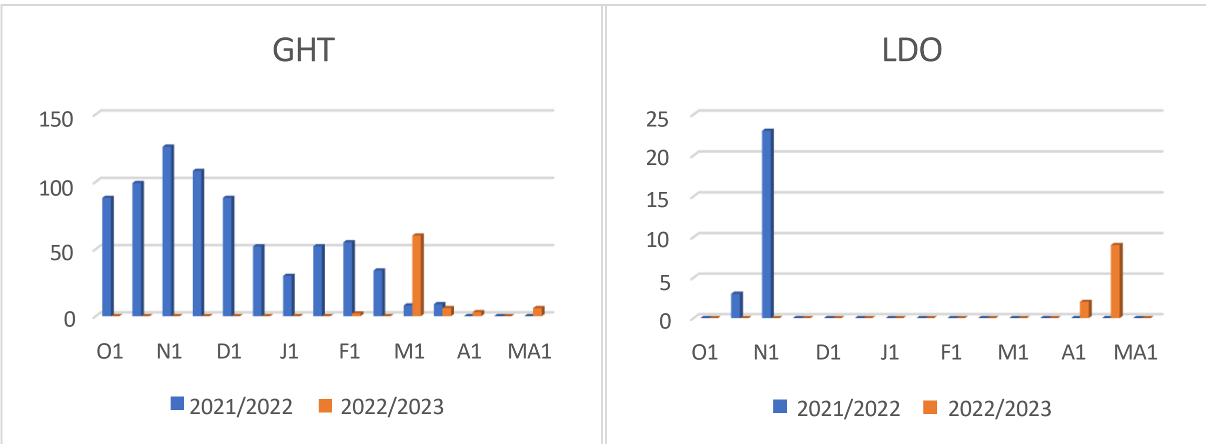


Figure 25. Fluctuation in the number of *Aythya ferina* in GHT (left) and LDO (right). Seasons 2021/2022 and 2022/2023

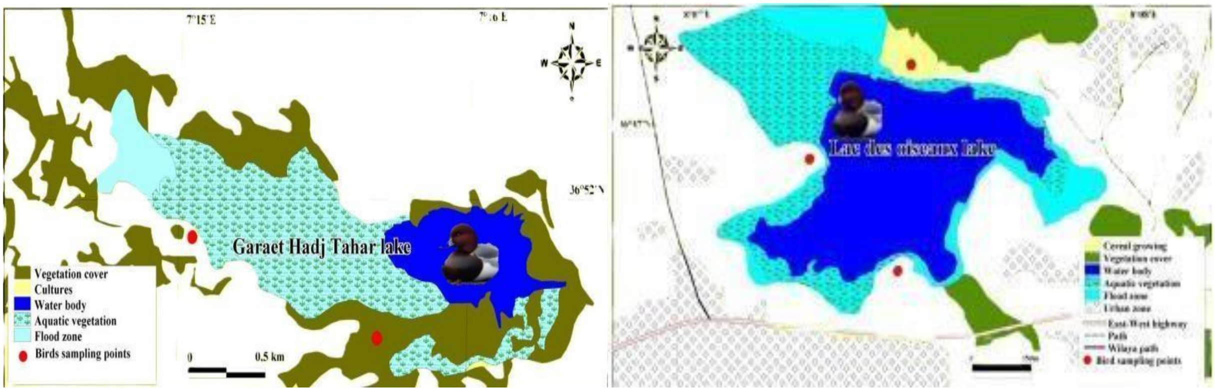


Figure 26. Spatial occupation by *Aythya ferina* in GHT (left) and LDO (right). Seasons 2021/2022 and 2022/2023

The Common pochard is a medium-sized diving duck. According to **Saidi et al. (2017)**, this bird feeds mainly on the bottom of the mud or vegetation growing there, to a depth of up to 3 meters. Its diet can therefore be described as omnivorous.

The Common pochard is partly migratory and is present on its breeding grounds throughout the year. Breeding grounds throughout the year in western and southern Europe, but northern populations are highly migratory, and a few ringing recoveries suggest that wintering populations in the Mediterranean region come mainly from southern Europe, southern Russia and the southern regions of western and central Siberia (**Cramp and Simmons, 1977, Monoval and Pirot, 1989**), and that the birds that winter in southern Asia probably come mainly from the republics of central Asia. This anatid is found in Algeria in all freshwater and saltwater areas, from the coast to the Sahara, via the high plateaux (**Houhamdi 2002**).

This species is generally observed in Lac des Oiseaux only 4 times during the study period, twice during the first season with a maximum of 23 individuals: one was observed on 13/11/2021 and 9 individuals observed on 28/04/2023. As far as the GHT are concerned, the species is more present, particularly during the first season (**Fig 25**). In this body of water, the change in numbers is Gaussian, from the start of the wintering season (October) to the end of March, reaching a maximum in November (126 individuals).

As a result, this duck is a wintering waterfowl. Its distribution in the two areas depends on the depth of the water. This species frequents the deep, unvegetated sectors of the two bodies of water close to the Ferruginous Duck (**Fig 26**).

III.1.11. Ferruginous duck: *Aythya nyroca*

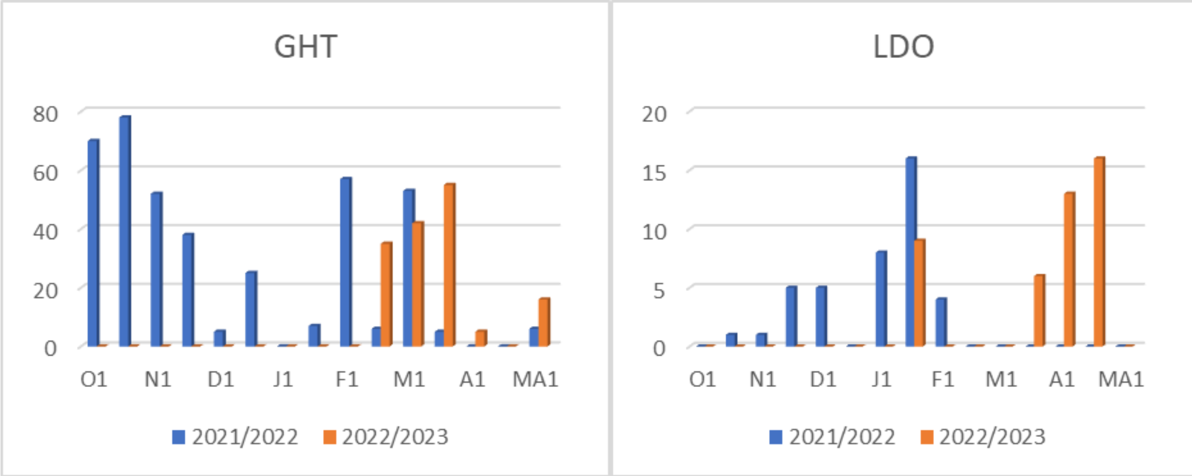


Figure 27. Fluctuation in the number of *Aythya nyroca* in GHT (left) and LDO (right). Seasons 2021/2022 and 2022/2023

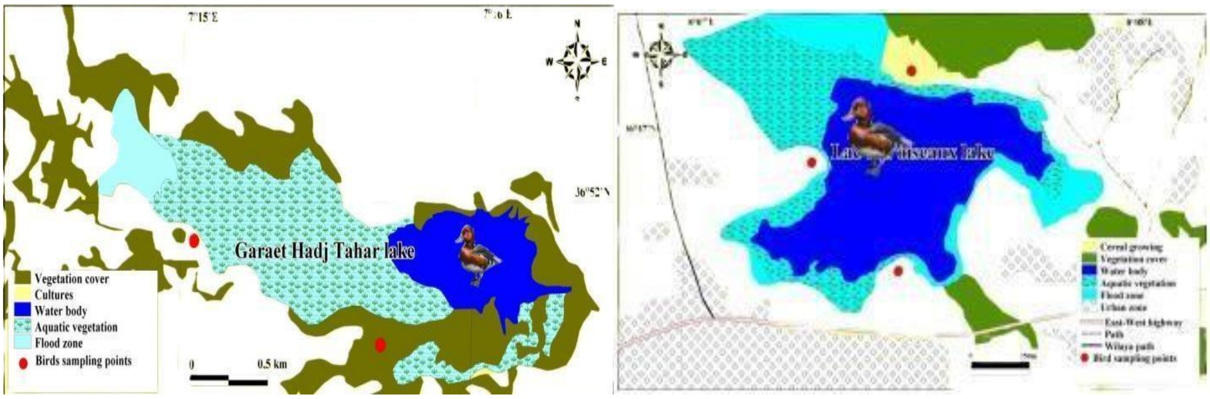


Figure 28. Spatial occupation by *Aythya nyroca* in GHT (left) and LDO (right). Seasons 2021/2022 and 2022/2023

The Ferruginous Duck is a palearctic species with a fragmented breeding range in temperate latitudes below 54°N (**Scott and Rose, 1996**). The main breeding area is in Eastern Europe (Romania, Hungary, Russia, Ukraine, Moldova, and Turkey), and the main wintering areas are in the Black Sea, the Caspian Sea, the Mediterranean, and West Africa (**Petkov et al., 2003**).

The Ferruginous Duck is also a diving duck, feeding mainly on seeds and aquatic plants that it gathers at the surface or on banks (**Houhamdi and Samraoui, 2008; Lardjane-Hamiti et al., 2013; Abdi et al., 2015**). The Ferruginous Duck is classified as a low-threat species by the IUCN. It is a breeding species in Algeria, and the first study on its reproduction was carried out by **Boumezbeur. (1993)** at Lake Tonga (PNEK).

At Garaet Hadj Tahar, the first sightings of this species can be seen at the beginning of

October. There were very large numbers of up to 70 individuals, reaching a peak of 78 at the end of the same month. This abundance then declined until the beginning of May, when around ten individuals were counted, representing the size of the breeding population.

As a result, like all Anatidae, it exhibits a late wintering status during the second wintering period. The species is more represented in the GHT, and only around ten individuals have been observed in the Lac des Oiseaux, where the largest number was recorded at LDO on 28.01.2022, with just 16 individuals.

During the period of its presence, the Ferruginous Duck occupied exclusively the central part of the two lakes. This part of Garaet Hadj-Tahar is characterised by a surface of open water sparsely covered with clumps of vegetation, providing shelter for certain activities such as daytime resting. This part also seems to offer sufficient food resources for these individuals (**Atoussi et al., 2013**)

III.1.12. Tufted Duck: *Aythya fuligula*

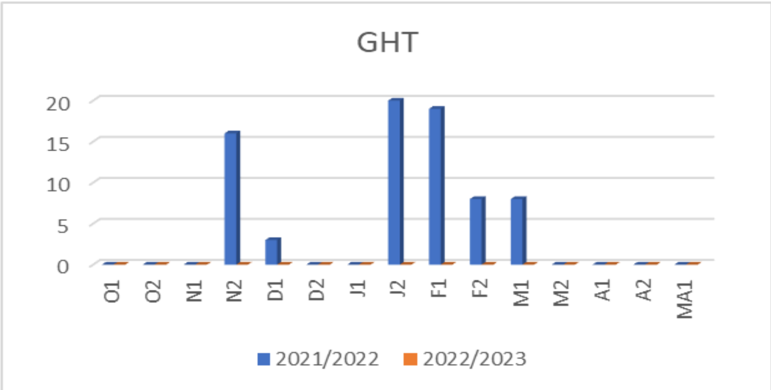


Figure 29. Fluctuation in the number of *Aythya fuligula* in GHT for the seasons 2021/2022

Figure 30. Spatial occupation by *Aythya fuligula* in GHT for the season 2021/2022

Tufted Duck is a diving duck formerly known as the ruddy duck. Its diet includes roots, aquatic plants, invertebrates, molluscs and crustaceans.

This species, which is only seen in the GHT during the first wintering season, is observed in the eastern part of the lake, where the first individuals were recorded during the second half of November, with a total of 16 specimens.

The peak was recorded in January, with 20 individuals. A gradual decline was noted, reducing the number of individuals to 8 in March. These birds were mainly observed in the company of the common pochard in areas cleared of vegetation (figure 30), where it is accustomed to deep areas of the site (**Bouchrit, 2014**).

III.1.13. Red-crested Pochard*: Netta rufina*

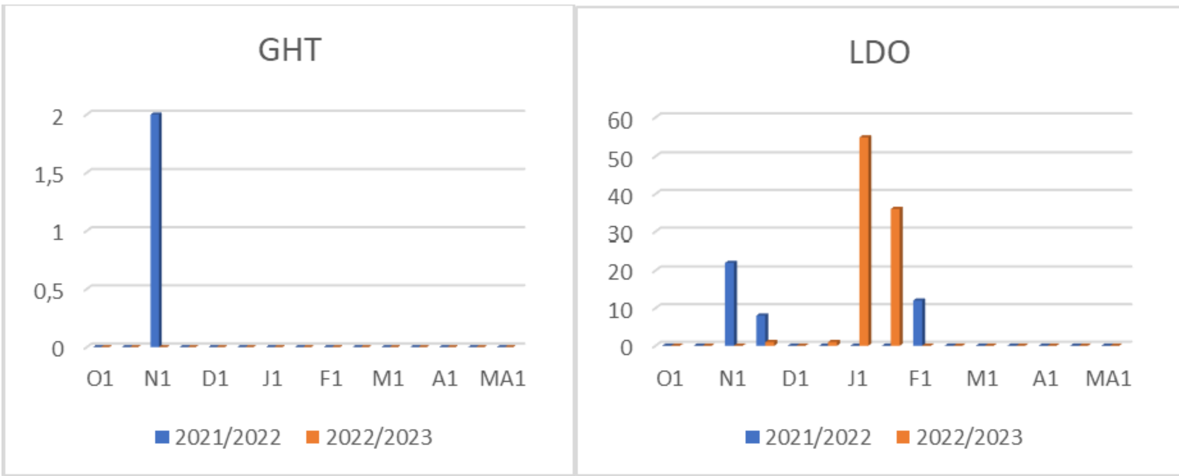


Figure 31. Fluctuation in the number of Netta rufinain GHT (left) and LDO (right). Seasons 2021/2022 and 2022/2023

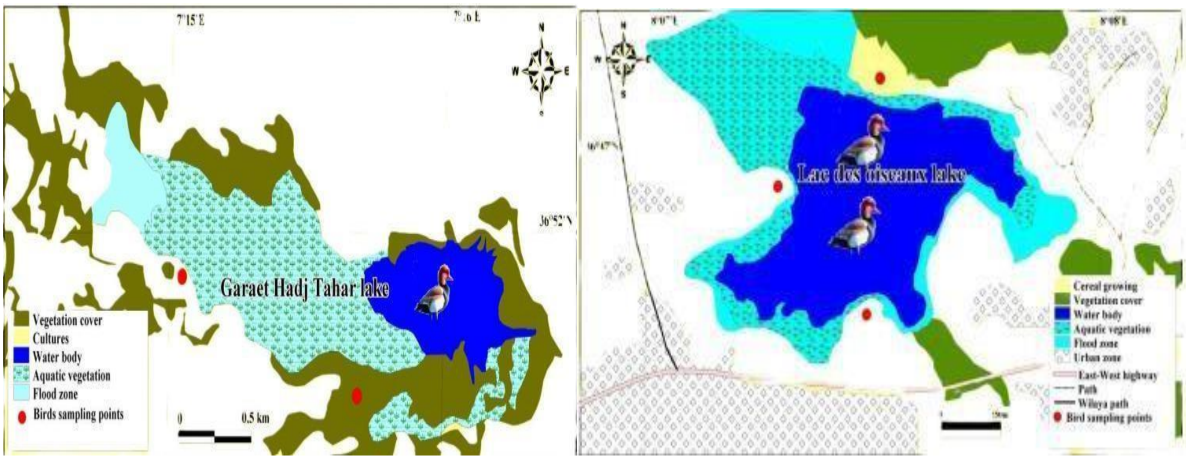


Figure 32. Spatial occupation by Netta rufina in GHT (left) and LDO (right). Seasons 2021/2022 and 2022/2023

The Red-crested Pochard is one of the few diving ducks in Algeria (**Isenmann & Moali, 2000**). The red-crested Pochard holds the status of least concern globally, according to the latest IUCN classification of threatened animal species (**IUCN, 2016**). However, it is thought to be almost extinct in Algeria (**Ledant et al., 1981; Isenmann & Moali, 2000**) and endangered in Morocco (**El-Agbani & Qninba, 2011**).

However, **Oudihat et al. (2017)** reported nesting at Dayet El-Ferd (700 ha) in the wilaya of Tlemcen, in north-western Algeria, where almost 500 individuals were counted during the wintering period. The species' habitat consists mainly of chotts, sebkhas, salt pans, and dams (**Oudihat et al., 2017**). In the east of the country, this species was first recorded (1 pair) in the Garaet Hadj-Tahar wetland (Guerbes-Sanhadja complex, wilaya of Skikda) by **Metallaoui and Houhamdi (2008)**.

Throughout the study period, a solitary pair was observed in the GHT, whereas the species is significantly more prevalent in the LDO. The maximum number of individuals observed on 13/11/2021 was 22, and during the second wintering season, that number increased to a maximum of 55 (comprising 25 males and 30 females) on 04/01/2023 (**Fig 31**).

The red pochards are typically found in groups or pairs and are friendly toward other members of the Anatidae family. Generally, red pochards prefer the southeast side and the center of the lake. However, most individuals congregate in the southeast of Lac des Oiseaux (**Fig 32**).

III.1.14. White-headed Duck: *Oxyura leucocephala*

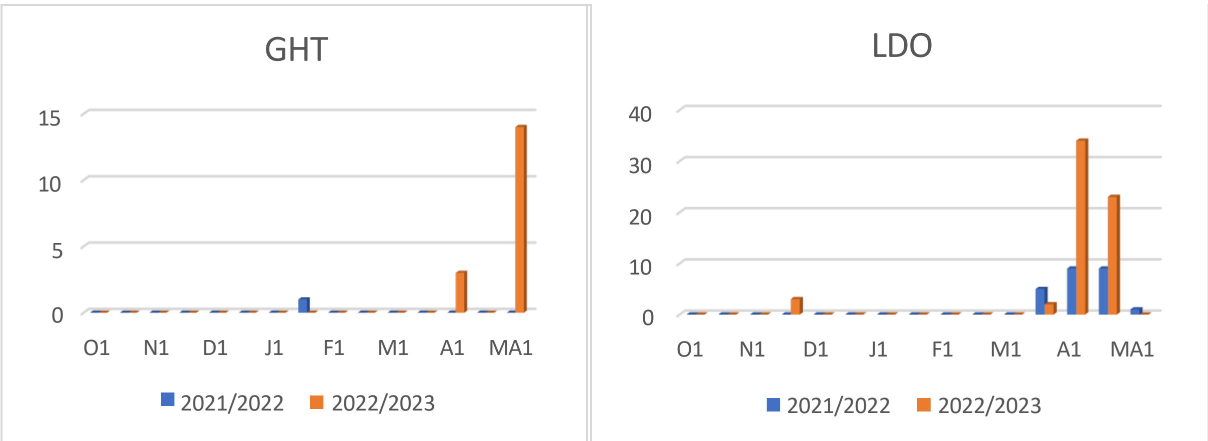


Figure 33. Fluctuation in the number of *Oxyura leucocephala* in GHT (left) and LDO (right). Seasons 2021/2022 and 2022/2023

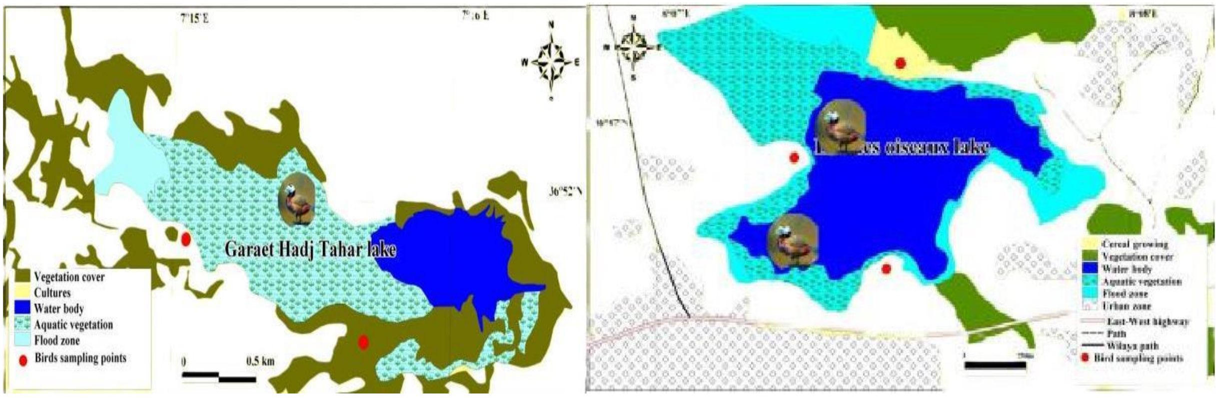


Figure 34. Spatial occupation by *Oxyura leucocephala* in GHT (left) and LDO (right). Seasons 2021/2022 and 2022/2023

The International Union for Conservation of Nature has listed the white-headed duck as endangered, making it a globally threatened species. It can be found in a range of wetland habitats, including freshwater, brackish to saline, temporary or permanent wetlands, and humid to arid regions. (**Atoussi et al., 2017; Hannouni et al., 2021**).

This diving duck is both an overwinterer and a sedentary breeder in the Numidie region of Algeria, particularly in the Tonga and Oiseaux lakes (**Chalabi 1990, Maazi 1992, Samraoui et al. 1992, Boumezbeur. 1990/1993, Boukhalfa. 1996, Houhamdi and Samraoui. 2002**).

The distribution of the white-headed duck is fragmented, with small resident populations stretching from the Mediterranean to south-west Asia (**Green, Anstey, 1992**). Its numbers are endangered by various factors such as habitat degradation, pollution, agriculture, climate change, hybridization, and competition with its fellow Ruddy Duck (O. jamaicensis) (**Torres et al., 1994**). In Algeria, the species was very common in the middle of the 19th century (**Heim De Balzac, Mayaud, 1962**).

The white-headed duck was known to live in Algeria in the previous century (**Ledant et al., 1981**). The primary habitats for this species were Lake Fetzara (Annaba region), Lake Holloula (Algiers region), and the El Kala wetland complex (Lake Tonga, Lake des Oiseaux, and Lake Oubeira) in northeastern Algeria. (**Heim de Balzac, Mayaud, 1962**).

Numbers have fluctuated over the years but have increased substantially over the last four decades, from 40 individuals in 1976 to 1,045 in 2010 at Lake Tonga (**Lazli et al., 2011; Hennouni et al., 2021**).

It only visited the GHT water body between April and May, in very limited numbers, with a maximum of 14 individuals gathering in the north-west of the water body. In the LDO, this species was observed on 09/04/2022 with a total of 9 individuals. During the second wintering season, a maximum of 34 individuals was recorded on 08/04/2023. This was followed by a sharp fall in numbers to 23 at the end of the month (**Fig 33**).

It is important to note that these individuals spend their days in the western part of the lake, near the *Typha angustifolia* and *Scirpus lacustris* that border the two lakes. They are rarely found in the water (**Fig 34**). According to **Matellaoui et al. (2009)**, this species congregates in the middle section of the Garaet, the deepest and most vegetation-free zone.

III.2. Evolution of ecological parameters

III.2.1. Study of population structure and balance

❖ **Abundance**

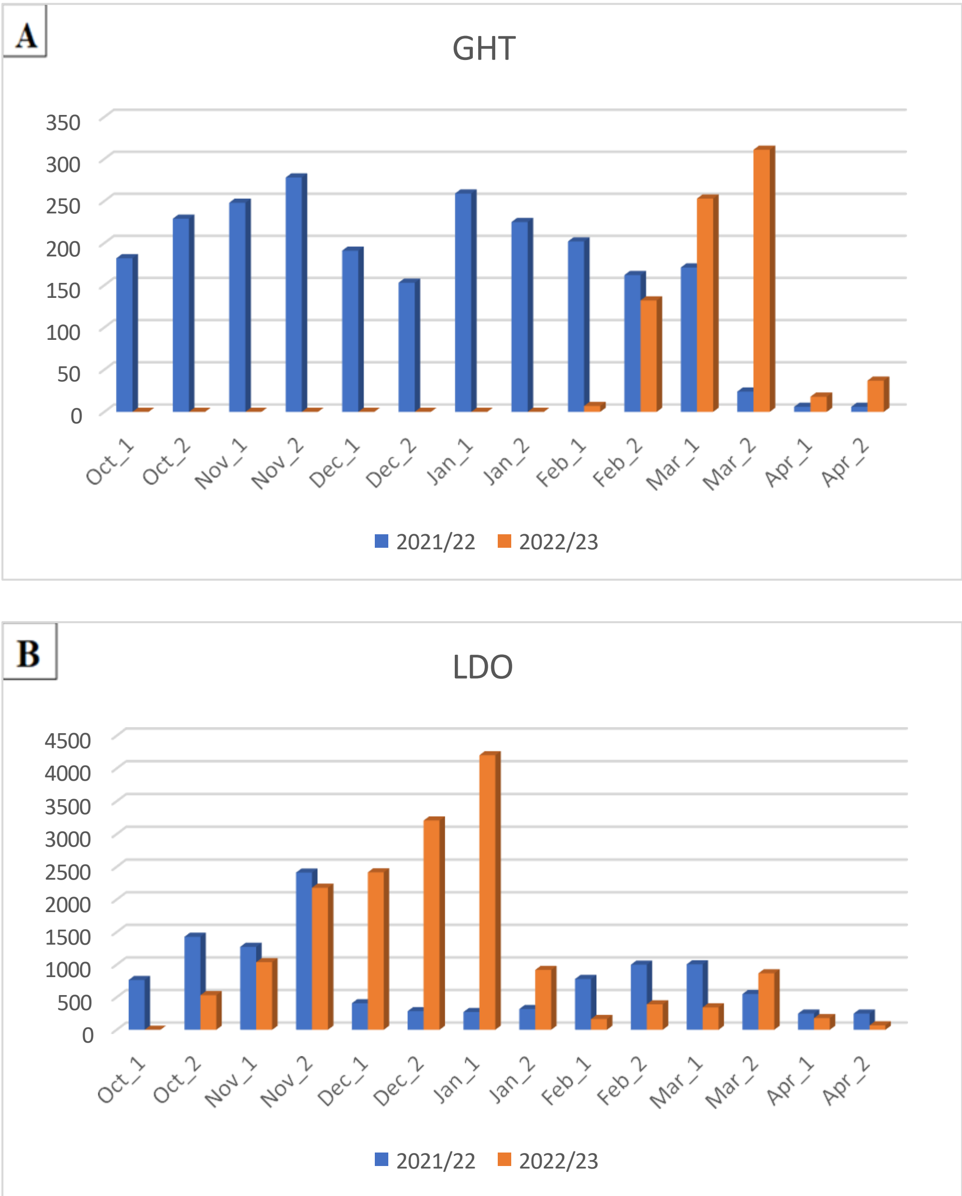


Figure 35. Total abundance of Anatidae individuals at Garaet Hadj Tahar (A) and lac des oiseaux (B), northeast Algeria. Blue columns, 2021/22; Orang columns, 2022/23.

Since the beginning of October 2021, GHT has been home to 182 individuals, mainly common pochard and ferruginous duck. This number rose steadily to reach 278 individuals at the end of November, due to a sudden increase in the number of Eurasian wigeon, Northern shoveler and Tufted duck. Numbers then began to decline gradually.

The second wintering season of 2022 started too late, at the beginning of February, with just 7 individuals, including 5 Eurasian teal and 2 Common pochard. The numbers then rose to reach maximum values of 311 individuals towards the end of March, only to fall back gradually. Therefore, the abundance curve in GHT can be divided into two distinct parts.

The first runs from October to the beginning of February, when values are nil. The second marks the end of February and March, when values gradually increase from 130 individuals to 311individuals.

At LDO, from October 2021, 763 individuals attached to 5 species (Eurasian teal, Eurasian wigeon, Northern shoveler, Mallard, and Gadwall were recorded. This number increased rapidly to reach 2411 individuals at the end of November, mainly due to the increase in the number of Eurasian teal and Eurasian wigeon. After this period, we saw a free fall in the numbers of Eurasian Teal.

As for the second 2022 season, LDO began hosting Anatidae in October with 531 individuals (including 443 Eurasian Teal). This number gradually increased to reach a maximum of 4201 birds in January, mainly Eurasian wigeon, Northern shoveler, Gadwall and Red-crested Pochard. After this period, numbers fell gradually to a low of 68 individuals at the end of April (**Fig 35**).

❖ **Specific richness**

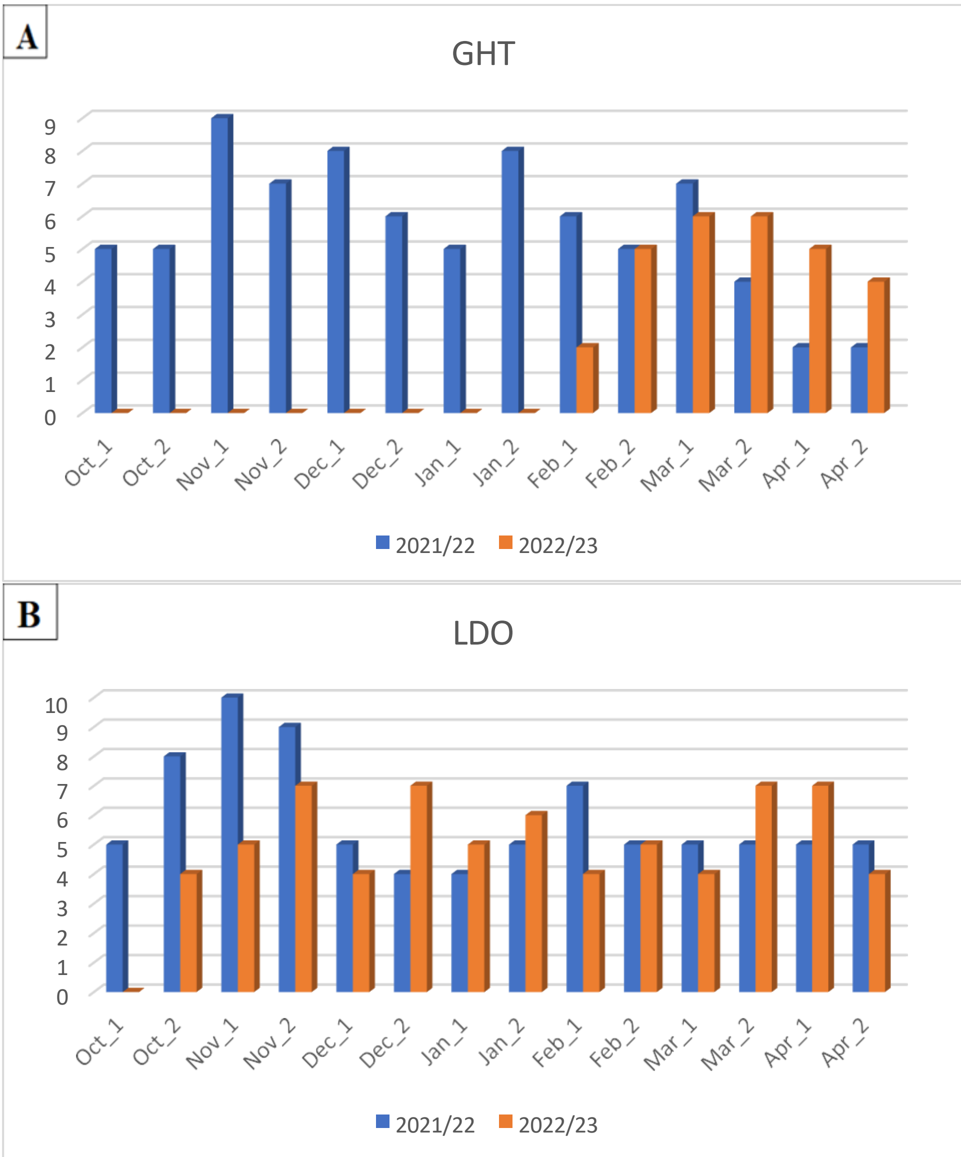


Figure 36. Specific richness of Anatidae individuals at Garaet Hadj Tahar (A) and lac des oiseaux (B), northeast Algeria. Blue columns, 2021/22; Orang columns, 2022/23.

The graph of the species richness of the 2021/2022 wintering season shows that the GHT Anatidae showed a curve with a peak observed during the month of November with a richness of 9 species, consisting mainly of common pochard and ferruginous duck, etc.

The 2022/2023 wintering season was characterized by a species richness of only 6 species observed during the month of March, consisting mainly of common pochard and ferruginous duck, etc.

At LDO, the graph of the species richness of the 2021/2022 wintering season for Anatidae showed a curve that began in October and continued until the end of April, when it was characterized by a gradual sawtooth rise, peaking in November with a richness greater than GHT.

There were around 10 species, consisting mainly of Eurasian wigeon, Northern shoveler, etc. The second wintering season 2022/2023 is characterized by a richness curve with several peaks of 7 species observed at the end of November, end of October, end of March and beginning of April. We mainly found Eurasian teal, Eurasian wigeon and Northern shoveler, etc. (**Fig 36**).

Because of the nearly climatic conditions in the Mediterranean region in general and Algerian Numidia in particular, the second wintering season exhibits a regression in species richness in both study areas. Most wetlands, like Garaet Hadj Tahr and Mekhada, completely dried up due to this climate (personal observation).

❖ **Shannon's Index**

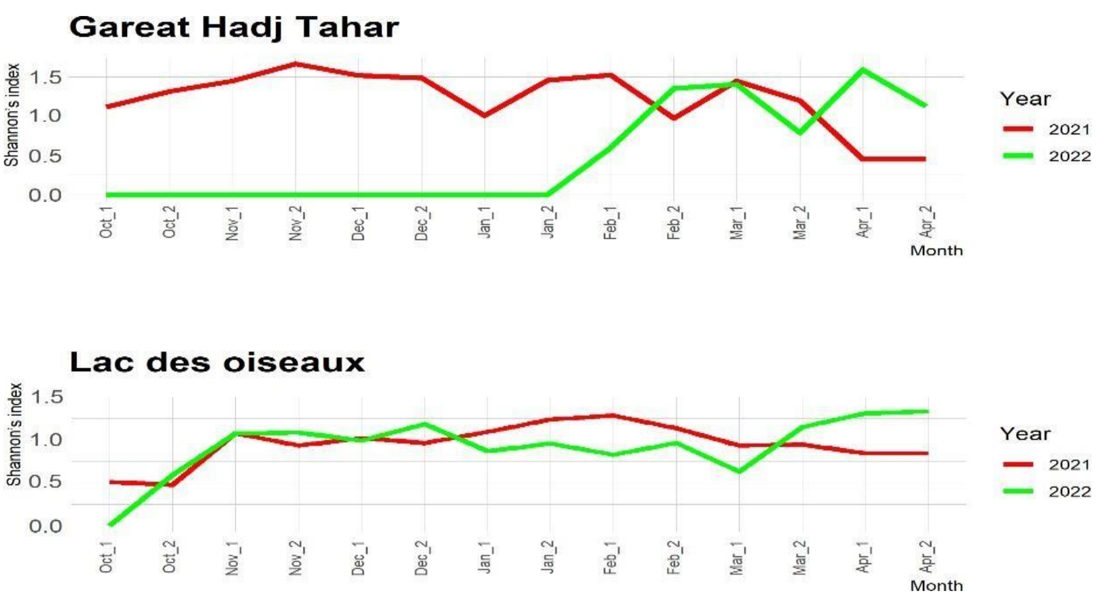


Figure 37. Temporal variation in the Shannon's Index of Anatidae in the two water bodies (Gareat Hadj Tahar and Lac des oiseaux) during two wintering seasons (2021/22 and 2022/23).

At the GHT, for the 2021/2022 season, the highest values of the Shannon diversity index are observed at the end of November, when this index exhibits maximum values of 1.66 for a species richness of 07 with several 278 individuals shared mainly between Common pochard, Ferruginous duck and Eurasian wigeon.

The minimum was recorded in April with a value of 0.45. During this month, the species richness was of the order of 02 and a representativeness of 06 individuals (05 Ferruginous duck individuals and 01 single Mallard individual). It should be noted that there are two distinct populations of Ferruginous Duck, one wintering and the other breeding (personal observation of 6 individuals on 12/05/2022).

For the 2022/2023 season, the highest values of the diversity index were observed at the beginning of April, when the index reached 1.58, shared between Mallard, Eurasian wigeon, Common pochard, Ferruginous duck, and White-headed duck.

The minimum is noted at the beginning of february with a value of 0.59 for a specific richness of 02 and a representativeness of 07 individuals, dominated by Common pochard (05 individuals) and Eurasian teal (02 individuals).

At LDO, the diversity index values are lower than those observed at GHT. During the 2021/2022 season, the highest values were recorded at the beginning of February, when the index reached 1.28. This value corresponds to a species richness of 07 for a population of 779 individuals with a codominance shared between Eurasian wigeon, Gadwall, and Eurasian teal. The minimum was noted at the end of October with a value of 0.47, for a species richness of 08 and a representativeness of 1427 individuals.

The population was dominated by Eurasian teal (1254 individuals) (**Fig 37**).

❖ **Pielou's Eveness**

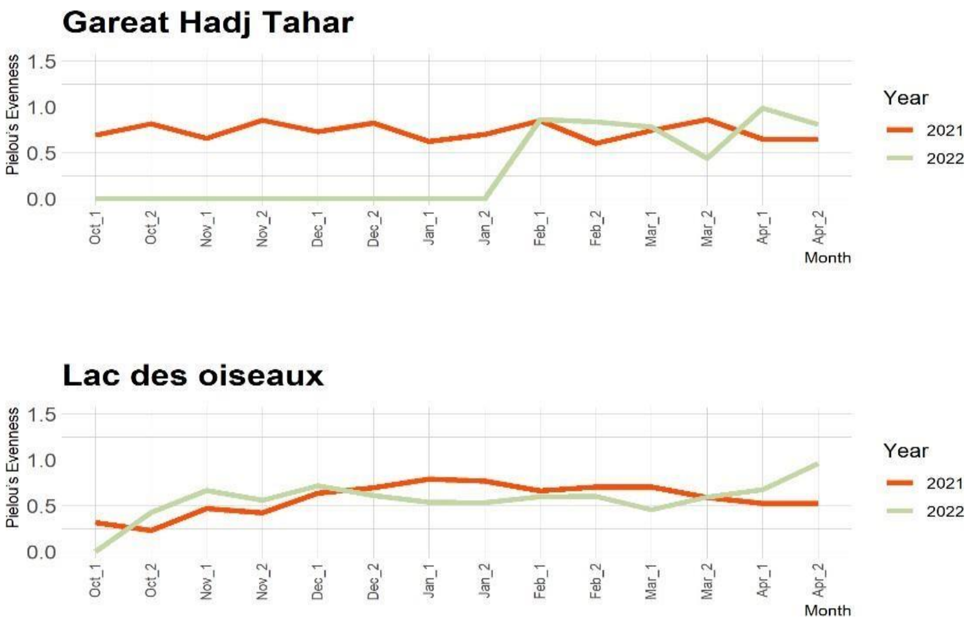


Figure 38. Temporal variation in the Pielou's Eveness of Anatidae in the two water bodies (Gareat Hadj Tahar and Lac des oiseaux) during two wintering seasons (2021/22 and 2022/23).

Throughout the study period, the Pielou regularity index shows that the highest values (E=0.98) were recorded at the beginning of 2023. At the end of the GHT's second wintering season, the graph of these indices stabilized around (E=0) until the end of January 2023.

The end of the second season also shows the maximum value of this index at LDO (E=0.96), which was recorded at the end of April. At the end of 2021 (end of October), LDO led to an imbalance in species abundance within the community, where two species dominated total abundance: *Anas crecca* with 1,254 individuals and *Anas penelope* with 131 individuals. This phenomenon was reflected in the value of the Pielou regularity index (E=0.22) (**Fig 38**).

In general, the permanence of the water in Lac des Oiseaux could explain the greater abundance of Anatidae observed at this site. However, the large surface area and availability of accessible nutrients at Garaet Hadj Tahr make it a more balanced ecosystem, as shown by the higher values of the Shannon-Weaver diversity index and Pielou equitability index compared with Lac des Oiseaux.

Although the species richness is identical between the two study sites, their main compositions differ. At Garaet Hadj Tahr, diving ducks, Common pochard Aythya ferina and Ferruginous Duck *Aythya nyroca*, are the best represented. while at Lac des Oiseaux, dabbling ducks dominate, among them: Eurasian teal *Anas crecca*, Eurasian wigeon *Anas Penelope* and Northern shoveler *Anas clypeata*.

From another point of view, a notable difference was observed between the two wintering seasons due to the disruption in climatic conditions. In 2022 and until February 2023, the North African region was marked by a period of drought, leading to a significant drop in the water level at Lac des Oiseaux and almost complete desiccation of the shallow wetlands, particularly Garaet Hadj Tahr and Mekhada (personal observation).

A previous study of Anatidae wintering in Tonga and Bird Lake showed similar results when comparing ecological indices. Although Anatidae abundance was higher in Bird Lake (A = 5755) than in Tonga Lake (A = 1890), species richness, Shannon-Weaver diversity index, and equitability were higher in Tonga Lake.

III.2.2. Winter phenology of the Anatidae species frequenting the site GHT and LDO

In terms of Anatidae, both lakes were home to 12 species each at LDO and GHT over the entire study period. At GHT, 6 out of 12 species (*Anas platyrhynchos*, *Anas clypeata*, *Anas* *penelope*, *Anas strepera*, *Aythya ferina*, and *Aythya nyroca*) were present throughout the wintering season, representing 50%. Only one species (*Aythya fuligula*) remained for 3 months, accounting for 8%. The remaining 5 species (*Marmaronetta angustirostris, Anas crecca*, *Netta rufina*, *Oxyura leucocephala*, and *Spatula querquedula*), representing 42%, were rarely seen at the site.

LDO hosted 4 species (*Anas platyrhynchos, Anas clypeata*, *Anas penelope*, and *Anas crecca*) throughout the entire wintering season, comprising 33%. Two species (*Anas strepera* and *Aythya nyroca*) were present for only 3 months, representing 17%. The remaining 6 species (*Marmaronetta angustirostris, Aythya ferina, Netta rufina, Oxyura leucocephala*, *Tadorna tadorna,* and *Anas acuta*) rarely visited the site, accounting for 50%. (**Fig 39**).

Figure 39. Winter phenology of the Anatidae species frequenting the site GHT and LDO (2021/2022 and 2022/2023)

III.2.3. Bioecological status of Anatidae at Garaet Hadj Tahat and Lac des oiseaux

III.2.3.1. Systematic inventory and Phenological categories

In Garaet Hadj Tahar and Lac des Oiseaux, fourteen (14) species of Anatidae were systematically listed during the study period (2021/2022/2023). Eleven and twelve species, respectively, visited GHT and LDO during the first wintering seasons (2021–2022). In the second season, both sites show a decrease in the number of species, with only 9 species found in GHT and 11 species in LDO (**Tab 6**).

This number of species is comparable with other wetlands: 14 species in Lake Tonga (willaya of El-Tarf) (**Bouchrit, 2014**), 13 species in the wetlands of Souk-Ahras (Bouali et all., 2021), 11 species in Lake Ayata (willaya of El Oued) (**Laabed et all., 2022**). In the same study sites, **Bara et all (2019)** found 11 species of Anatidae in Garaet, Hadj Tahar and **Bouchrit (2014)** recorded 11 species in Lac des oiseaux.

In general, throughout the study period, eight species (57%) were winter migrants, including *Anas clypeata, Anas penelope, Anas strepera, Tadorna tadorna, Aythya ferina, Aythya fuligula, Netta rufina,* and *Anas crecca crecca.* Three species (21%) were occasional visitors (passing visitors), which included *Anas acuta, Marmaronetta angustirostris,* and *Spatula querquedula.* Additionally, three species (22%) were winter migrants with sedentary populations, namely *Anas platyrhynchos, Oxyura leucocephala*, and *Aythya nyroca.*

Table 6. The Phenological status (**Ph.S.**) of Anatidae in our two wetlands; Gareat Hadj Tahar (**GHT**) and Lac des oiseaux (**LDO**). **OV**: occasional visitor, **WM**: winter migrant, **WMSP**: winter migrant with sedentary population.

Species	*GHT*	*Max observed [DD/MM/AA]*		*LDO*	*Max observed [DD/MM/AA]*	
	Ph.S	**2021/2022**	**2022/2023**	**Ph.S**	**2021/2022**	**2022/2023**
Anas platyrhynchos (Linnaeus, 1758)	WMSP	15[20/10/2021]	07[25/02/2023]	WMSP	18[12/10/2021]	29[31/01/2023]
Anas clypeta (Linnaeus, 1758)	WM	67[14/01/2022]	234[17/03/2023]	WM	503[13/11/2021]	1602[04/01/2023]
Anas penelope (Linnaeus, 1758)	WM	156[14/01/2022]	16[25/02/2023]	WM	1698[27/11/2021]	2387[04/01/2023]
Anas stepera (Linnaeus, 1758)	WM	26[20/11/2021]	30[11/03/2023]	WM	170[27/11/2021]	156[04/01/2023]
Anas crecca (Linnaeus, 1758)	WM	5[12/11/2021]	13[25/02/2023]	WM	1254[30/10/2021]	975[25/11/2022]
Anas acuta (Linnaeus, 1758)	–	–	–	VO	12[27/11/2021]	02[23/12/2022]
Marmaronetta angustirostris (Ménétries, 1832)	VO	03[12/11/2021]	–	VO	01[30/10/2021]	–
Spatula querquedula (L. 1758)	VO	–	02[17/03/2023]	–	–	–
Tadorna tadorna (Linnaeus, 1758)	–	–	–	WM	04[13/11/2021]	23[23/12/2022]
Aythya ferina (Linnaeus, 1758)	WM	126[12/11/2021]	60[12/03/2023]	WM	23[13/11/2021]	09[28/04/2023]
Aythya nyroca (Güld, 1770)	WMSP	78[22/10/2021]	55[17/03/2023]	WMSP	16[28/01/2022]	16[28/04/2023]
Aythya fuligula (Linnaeus, 1758)	WM	20[30/01/2022]	–	–	–	–
Netta ryfina (Pallas, 1773)	VO	02[02/12/11/2021]	–	WM	22[13/11/2021]	55[04/01/2023]
Oxyura leucocephala (Scopoli,1769)	WMSP	01[30/01/2022]	14[16/04/2023]	WMSP	09[09/04/2022]	34[08/04/2023]

III.2.3.2. Protection categories

In both study sites, most of the species identified were classified as species of least concern according to the IUCN (International Union for Conservation of Nature) red list, with 10 species (72%) falling into this category. Two species (14%) were classified as Near Threatened (Ferruginous duck *Aythya nyroca* and Marbled duck *Marmaronetta angustirostris*), one species (7%) was classified as Vulnerable (Common pochard *Aythya ferina*) and only one species (7%) was classified as Endangered (White-headed Duck *Oxyura leucocephala*).

As regards protection status, 4 species recorded at Garaet Hadj Tahr and Lac des oiseaux are protected under Algerian law in accordance with decree no. 12-236 of May 28, 2012, on protected non-domestic animal species, including marbled duck, ferruginous duck, common shelduck, and white-headed duck (**Tab 7**).

The first and second species are listed as “Near threatened” and the fourth as “Endangered” on the International Union for Conservation of Nature's Red List of Threatened Species (Birds Life International, 2025).

In my study areas, the first species is presented with low numbers: a maximum of 03 individuals of marbled duck observed on November 12, 2021, at GHT and a single individual observed on October 30, 2021, at LDO. The second species is presented with a relatively high number: a maximum of 78 individuals of ferruginous duck observed on October 22, 2021, at GHT and a maximum of 16 individuals observed on January 28, 2022, at LDO. a maximum of 14 individuals of white-headed duck observed on April 14, 2023, at GHT and a maximum of 34 individuals observed on April 8, 2023, at LDO (**Tab 7**).

At GHT and LDO, 6 species are listed in the Washington Convention (CITES). The Bonn Convention and the AEWA agreement place all the Anatidae species recorded in the vicinity of the two lakes (14 species) on its list of species to be protected (**Tab 7**).

Table 7. Binomial, English, and French nomenclature of Anatidae recorded in the vicinity of Gareat Hadj Tahar and Lac des oiseaux and its protection category (**Pr.C**) and IUCN Red List categories (**Rl.C)**

Subfamily	Genus	Scientific name	English name	French name	PrC	Rl.C
Anatinea Dabbling ducks	*Anas*	*Anas platyrhynchos*	Mallard	Canard colvert	N2, W, R3	LC
	Spatula	*Spatula clypeata*	Northern shoveler	Canard souchet	C3, N2, W, R3	LC
	Anas	*Anas penelope*	Eurasian wigeon	Canard siffleur	C3, N2, W, R3	LC
	Anas	*Anas stepera*	Gadwall	Canard chipeau	N2, W, R3	LC
	Anas	*Anas crecca*	Eurasian teal	Sarcelle d'hiver	C3, N2, W, R3	LC
	Anas	*Anas acuta*	Northern pintail	Canard pilet	C3, N2, W, R3	LC
	Marmaronetta	*Marmaronetta angustirostris*	Marbled duck	Sarcelle marbrée	D, N1, N2, W, R2	NT
	Spatula	*Spatula querquedula*	Garganey	Sarcelle d'été	N2, W, R3	LC
	Tadorna	*Tadorna tadorna*	Common shelduck	Tadorne de Belon	D, N2, W, R2	LC
Aythyinea Diving ducks oxyurinea	*Aythya*	*Aythya ferina*	Common pochard	Fuligule milouin	N2, W, R3	VU
	Aythya	*Aythya nyroca*	Ferruginous duck	Fuligule nyroca	D, C3, N1, N2, W, R3	NT
	Aythya	*Aythya fuligula*	Tufted Duck	Fuligule morillon	N2, W, R3	LC
	Netta	*Netta rufina*	Red-crested Pochard	Nette rousse	N2, W, R3	LC
	oxyura	*Oxyura leucocephala*	White-headed Duck	Erismature à tête blanche	D, C2, N1, W, R2	EN

Protection categories (PrC): C: Washington Convention (CITES), **D**: Algerian laws, **N**: Bonn Convention, **R**: Berne Convention, **W**: AEWA.**IUCN Red List categories** (**LC**: least concern, **VU**: vulnerable, **NT**: Near threatened and **EN**: endangered), 1: Annex I, 2: Annex II, 3: Annex III.

III.2.4. Study of the diurnal activity rhythms of Anatidae

In general, throughout the study period, the diurnal time budget of Anatidae was dominated by sleeping activity (59% in GHT et 71 % in LDO), which accounted for more than half of the total time budget, followed by swimming activity (30% in GHT et 24% in LDO) (**Fig 40**).

According to **Boumezbeur (2005)**. Sleep is the most frequent behaviour of waterbirds in wintering areas during the day and an essential step in gaining mass, reducing energy expenditure, and preparing for reproduction (for sedentary species) or migration (for migratory species).

In addition, sleep enables these birds to reduce body heat loss (**Tamisier, 1972**) to cope with the occasional cold temperatures in the region during a sub-humid bioclimatic stage in a cold winter.

The predominance of sleep at our study sites suggests that the environmental conditions required for wintering waterbirds are met. We obtained results like those obtained by (**Bouali et all., 2021**) in the wetlands of Souk-Ahras and (**Laabed et al., 2022**) in Lake Ayata, concerning the diurnal behaviour of all Anatidae species.

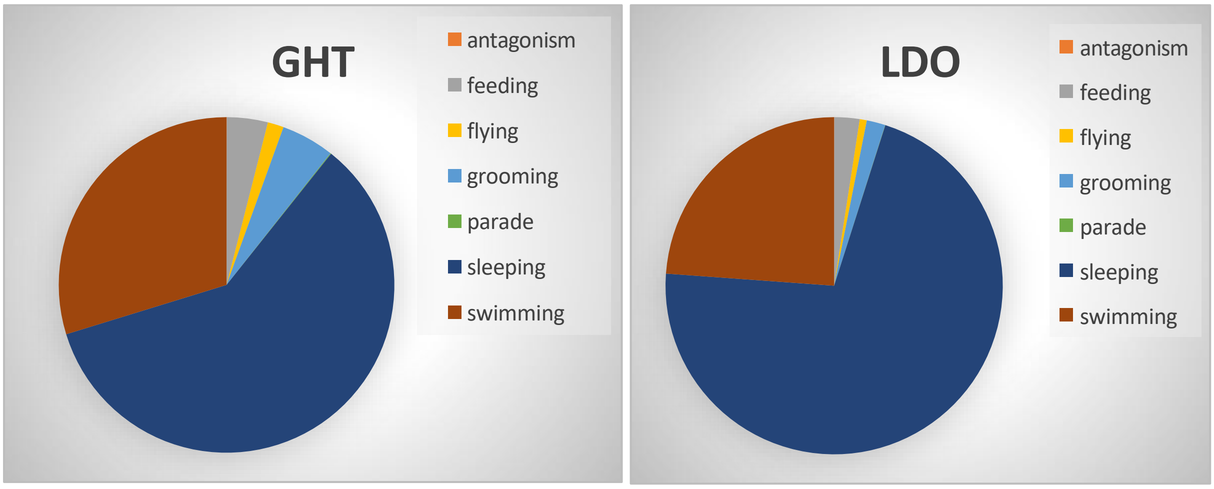


Figure 40. Proportions of daytime Anatidae activity over two wintering seasons 2021-2023 in GHT and LDO

When we separate our results for the two wintering seasons, sleeping activity reached its highest value during the first wintering season at LDO, while the highest values for swimming activity were recorded during the second wintering season (**Fig 41**). Time devoted to feeding and grooming was relatively minor at GHT, with percentages of 9% in the 2022/2023 season and 7% in the 2021/2022 season. At LDO, these activities were equally uncommon, with feeding and grooming each accounting for 9% in both the 2021/2022 and 2022/2023 seasons. Interestingly, antagonism and parade activities were completely absent at both sites during the two wintering seasons.

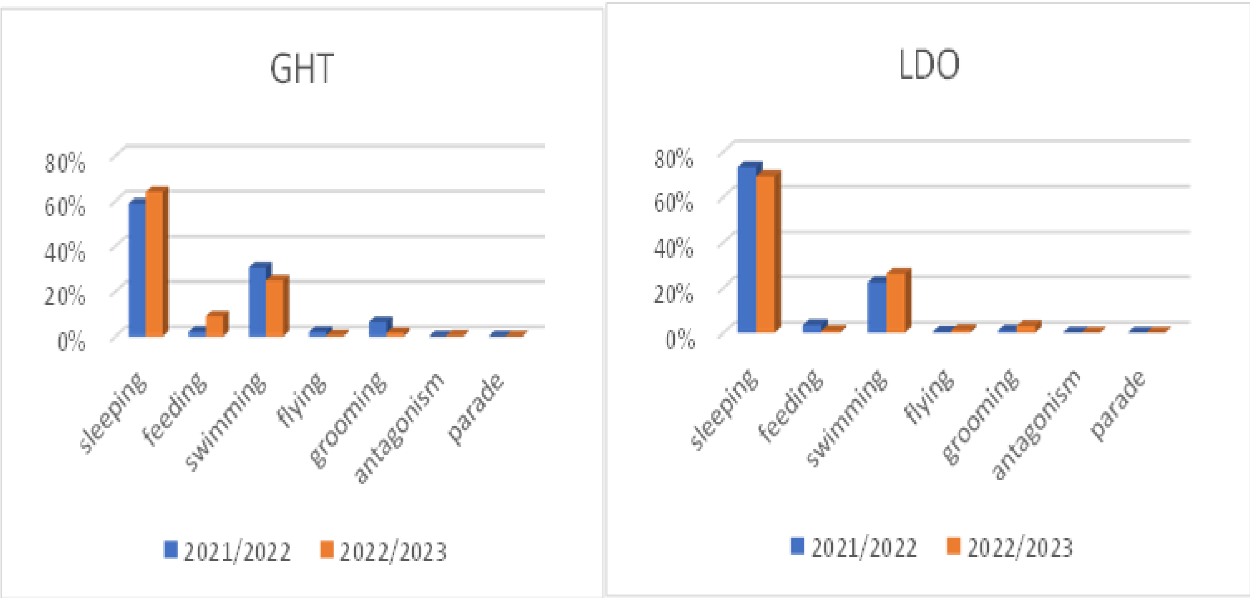


Figure 41: Diurnal time budget of Anatidae at GHT and LDO during tow wintering season (2021/2022 and 2022/2023).

III.2.4.1. Variation in diurnal activity patterns of wintering Anatidae species

In our study and at the level of these two wetlands, the diurnal behavior of the Anatidae monitored is briefly described below (**Fig 42**).

Sleeping is the main activity observed in the two bodies of water. In the ducks, it represents a phase of energy recovery on the one hand and a reduction in the number of hours of sleep on the other. secondly, a reduction in their energy consumption (**Tamisier and Dehorter, 1999**). In both lakes, this is the main activity, with rates generally varying between10% for *Spatula querquedula* and 71% for Spatula clypeata in GHT (**Fig. 42A**). At LDO, it varies between 44% for *Aythya nyroca* and 79% for *Anas crecca* (Fig 42 B).

Swimming is a basic behavior that often accompanies other activities (feeding, courtship). But it is, of course, a means of moving around the water and a way for the bird to avoid drifting induced by wind and waves.

It occupies second place in the monitoring of these time budgets, and it was recorded in both wetlands with rates fluctuating between 16% for *Anas stepera* to 60% for *Spatula clypeata* (**Fig 42 A**), while at LDO the rate fluctuated between 15% for *Anas crecca* and 49% for *Tadorna tadorna* (**Fig 42 B**), with the exception of *Marmaronetta angustirostris* and *Netta rufina*, where it was observed at a rate of 100% in both study sites for the former species but only in GHT for the latter (**Fig 42**).

Food provides calories, but looking for them also costs energy. For this reason, food intake must exceed energy expenditure. During the wintering period for Anatidae, this activity is mainly nocturnal (**Houhamdi and Samraoui, 2001, 2003, 2008**). It is observed during the day following probable disturbance at night by predators or poachers (**Houhamdi and Samraoui, 2003**). The rate of this activity reaches its maximum value of 28% for *Anas stepera* at GHT (**Fig. 42 A**) and 49% for *Tadorna tadorna* at LDO (**Fig. 42 B**).

Grooming is a behaviour that has a dual function. On the one hand, it cleans damaged feathers, eliminates ectoparasites, removes old feathers and replaces new ones, particularly during pre- and post-nuptial migrations and during the moulting period. It is also used to grease feathers with the product of the uropygial gland (located on the rump) to make them waterproof (**Tamisier and Dehorter, 1999**).

The rate of grooming varies from one species to another, reaching a maximum of 30% for *Spatula querquedula* in GHT, and only 9% for *Anas acuta* in LDO.

Parade activity was only observed in *Anas platyrhnchos* and *Aythya nyroca* at LDO and reached 10% for Anas crecca at GHT.

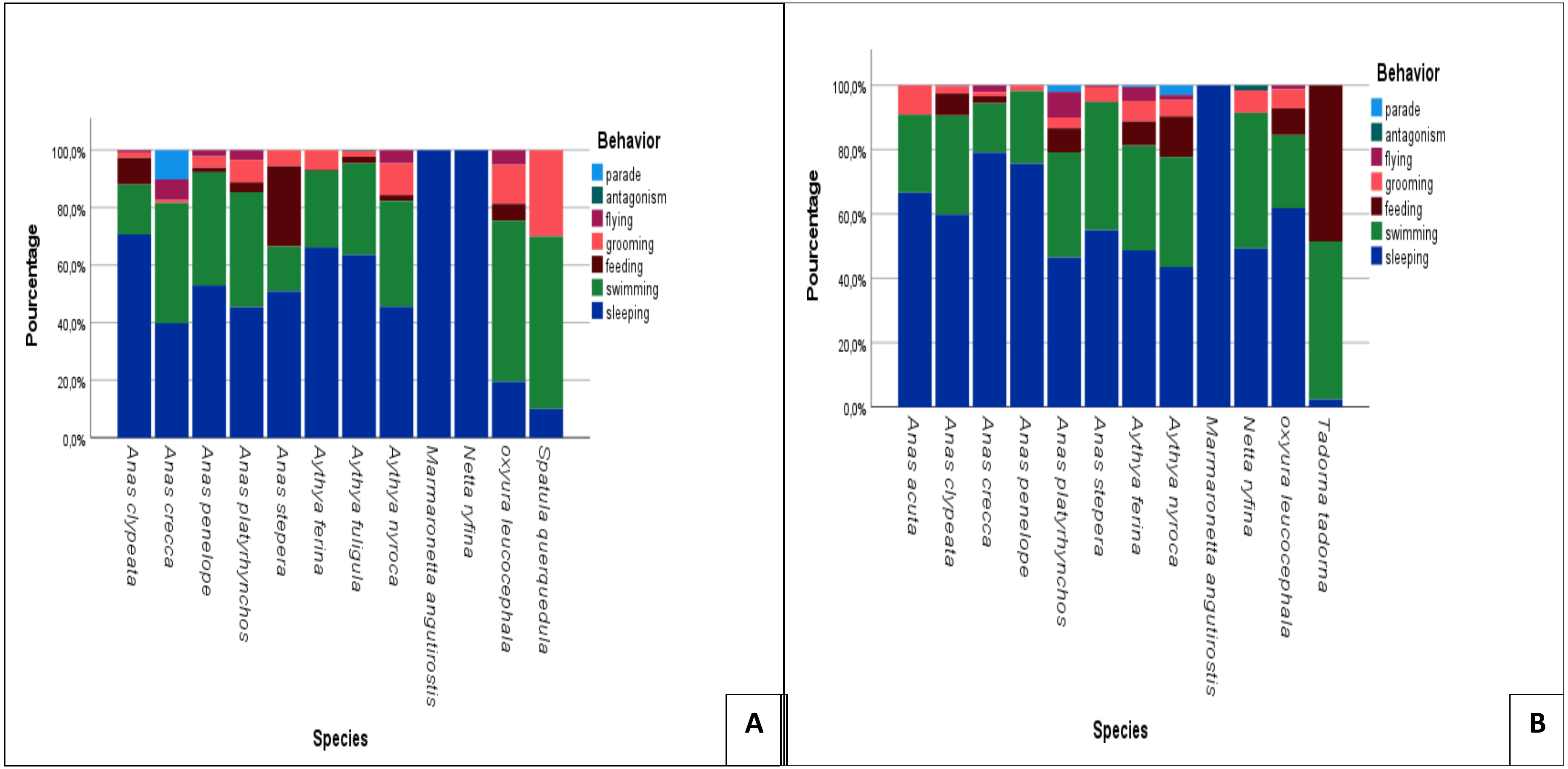


Figure 42. Diurnal activity patterns of all wintering Anatidae species in GHT (A) and LDO (B): wintering seasons 2021-2022 and 2022-2023.

III.2.4.2. Bimonthly variation in daytime activity of Anatidae

Thus, the daily activity of ducks is influenced by the nycthemeral cycle (day/night), but for certain species and in certain places, it can also be determined by the tidal cycle. For instance, in the Gulf of Morbihan, the Whistling Duck *Anas Penelope* frequently uses the foreshore (**Mahéo, 1982**).

Contrastingly, sleep, which represented a large part of the daily time budget of Anatidae at GHT at the start of the wintering period, with 80% observed at the end of January. This rate then decreased progressively and significantly until the end of the wintering season, reaching a rate of 28% at the end of March (**Fig 43.A**). In LDO, where this activity recorded a higher rate than in GHT, all the Anatidae species dedicated up to 96% of their sleep activity during the month of October (start of the wintering period); on the other hand, the lowest (19%) was observed during the month of March (**Fig 43.B**). Following long journeys, the need for rest and daytime sleep is vital for aquatic birds, particularly Anatidae (dabbling and diving ducks) (**Charchar, 2017**).

Daytime rest is also considered to be a way of reducing energy consumption (**Boumezebeur et al., 2005; Merzoug et al., 2013**). It is also a method of recovering and replenishing energy reserves (**Tamisier and Dehorter, 1999; Houhamdi and Samraoui, 2008; Merzoug et al., 2013**).

Swimming is an important part of the diurnal behaviour of Anatidae, with rates ranging from 69% at the end of April to 10% at the beginning of November at the first study site (the GHT). On the other hand, during the same month, this activity reached its lowest levels (14%), while its highest level was observed at the beginning of March (66%).

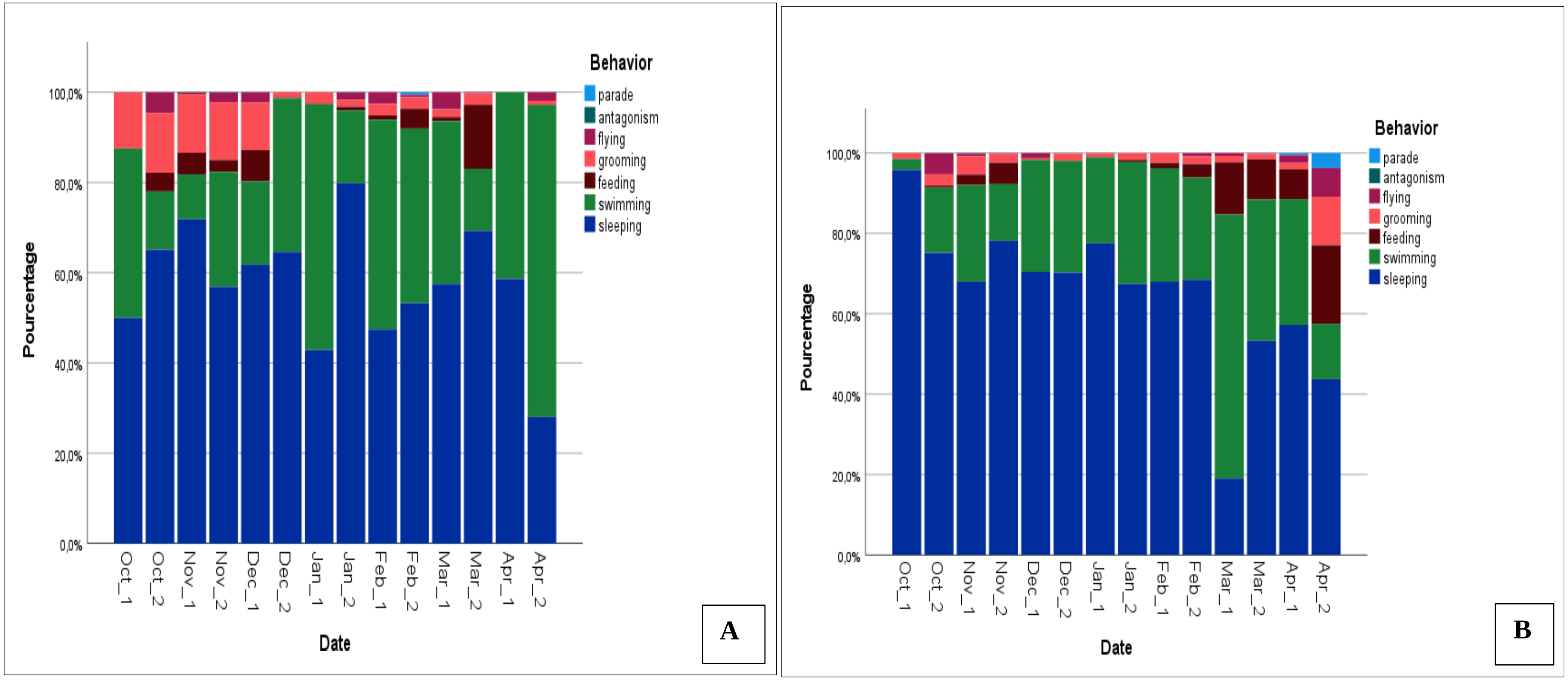


Figure 43. Bimonthly variation in daytime activity of Anatidae in GHT and LDO: wintering seasons 2021-2022 and 2022-2023.

III.2.4.3. Activity rhythms expressed in hours

The time an individual spends per hour is a means of evaluating the use of space and the organization of activities by waterfowl, mainly during the day. In fact, the study of eight (8) hours of observation of the diurnal behavior of all the Anatidae species at Garaet Hadj-Tahar and Lac des Oiseaux, gave us a better understanding of the evolution and distribution of the various activities throughout the day.

Sleep takes up most of the time allocated to daytime activities. At GHT, we observed that these values ranged from 79% at the start of the day (8am) to 63% towards the end (4pm). Thus, more than half of the time per hour during the day (more than 80%) is dominated by sleep, with a daily average of 6 h and 24 min per day (**Fig 44A**). At LDO, we observed that these percentages vary from 70% at the beginning of the day (8 am and 9 am), then decrease to 48% at the end of the day (2 pm). Therefore, more than half of the time per hour during the day (65.87%) is dominated by sleep, with a daily average of 5 h and 12 min per day (**Fig 44B**).

After sleep comes swimming, which takes second place in the time allocated during the day by Anatidae. At GHT, this activity is observed in the mornings (8 h) with 22% and in the afternoons (14 h), with 39%, giving a daily average of 2 h 42 min (**Fig 44A**). At LDO, we observed that these percentages vary from 15% at the start of the day (8 am), then increase to 33% at the end of the day (4 pm). Thus, more than a quarter of the time per hour during the day (26.37%) is dominated by swimming, with a daily average of 2 h and 6 min per day (**Fig 44B**).

Feeding was observed during all eight hours of observation, with a high percentage at GHT compared with LDO. At GHT, this activity was highest in the afternoons, when we recorded a maximum of 8% between 2 pm and 3 pm. The daily average was 24 minutes (4.86%) (**Fig 44A**). This average is estimated at just 14 minutes (2.87%) in LDO, where we recorded a maximum of 4% at 9 a.m. (**Fig 44B**). Also, **Charchar (2017)** showed that feeding was accomplished mostly during the morning period before noon rather than in the evening.

The grooming activity of this family of waterbirds at GHT shows slightly higher values compared to the values recorded at LDO and even compared to the other sleeping and swimming activities recorded on the same bodies of water.

It should be noted that at GHT, grooming was carried out mainly in the evening (7%) rather than in the morning (1%).

In both areas, we reported very low averages for flying, parade and antagonism (**Fig 44**). Generally, except for sleep, which is high in LDO, we observe higher rates for all other activities (feeding, swimming, and grooming) in GHT compared with LDO.

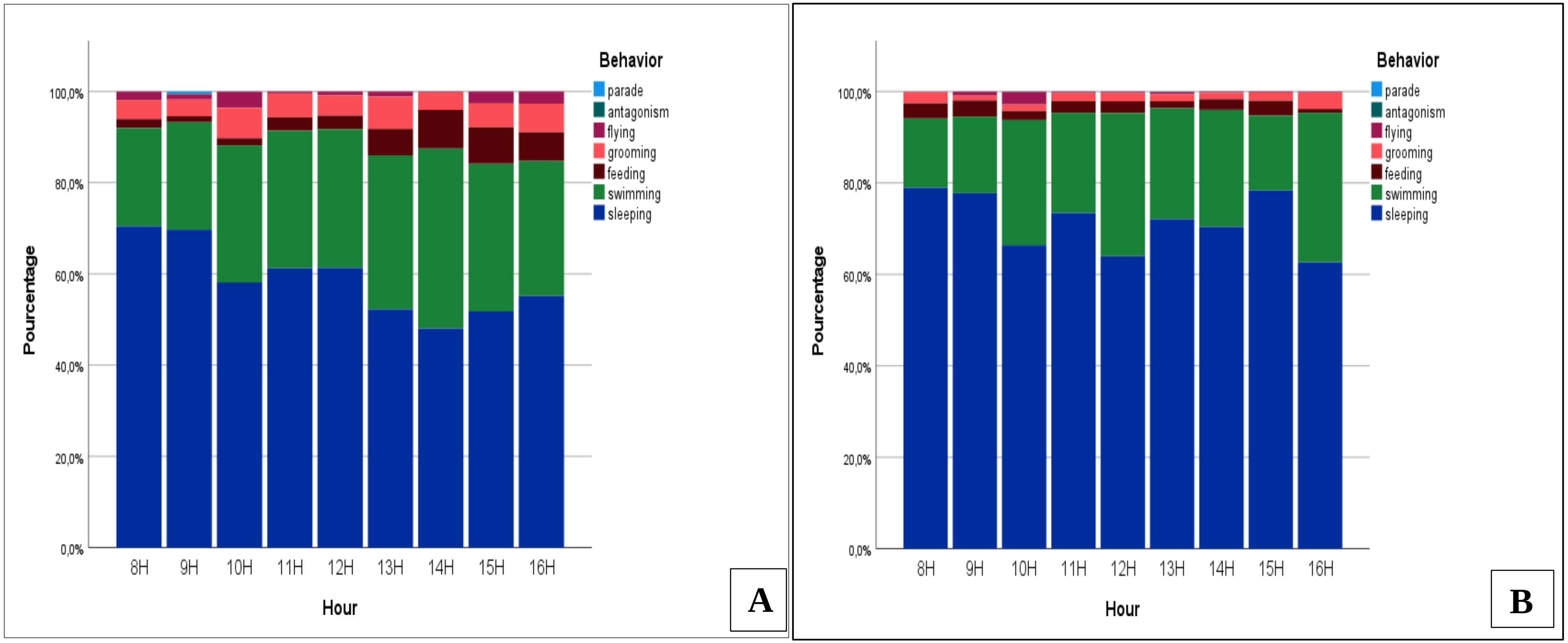


Figure 44. Changes in diurnal activity rhythms per hour of wintering Anatidae at GHT (A) and LDO (B): 2021-2022 and 2022-2023 wintering seasons.

III.3. Characterization of the biotope

III.3.1. Spatial and temporal variations of water physicochemical parameters

The assessment of surface water quality in the Algerian Numidian wetland complex was studied in relation to two parameters: a time factor represented by the months and a space factor represented by the two study sites. The detailed results of the physicochemical analyses of the water at the two study sites (GHT: Garaet Hadj Tahr and LDO: Lac des oiseaux) are illustrated in the **figures 45,46,47,48,49,50,51** and **52.**

A. Electrical conductivity 'EC'

Electrical conductivity shows very significant spatio-temporal fluctuations. In GHT, they vary from 1235.63 µS/cm to 1404 µS/cm (**Fig 45**). Whereas in LDO, their values vary from 1278.57 µS/cm to 1459.84 µS/cm. The average electrical conductivity content during our study was 1311.11 µS/cm for GHT and 1338.90 µS/cm for LDO, which is three times higher than the threshold (400 µS/cm) set by the **WHO (2017)**.

The highest values are observed in our study sites during the summer season, which is marked by high temperatures and intense mineralization. Whereas the minimum electrical conductivity levels observed during the rainy period (November 2021) may be consistent with the dilution phenomenon.

In general, high values of electrical conductivity are caused by an increase in temperature that leads to evaporation of water and concentration of dissolved salts. Moreover, this also differs depending on the geological substrate crossed (Bouchaala et al., 2019).

On the same study sites, similar results were reported by **Bara Y (2021)** and **Toumi (2016)** in Garaet Hadj Tahr and Lac des oiseaux, respectively. This high mineralization was attributed to geological and anthropogenic origins linked to high concentrations of housing and very dense agricultural activities. In other regions, the results of **Kerief. (2018)** in the Béni Haroun dam in Jijel (**Guergueb, 2016**) and **Bouleknafet et al. (2017)** at the mouth of Oued El Kebir Est are also similar.

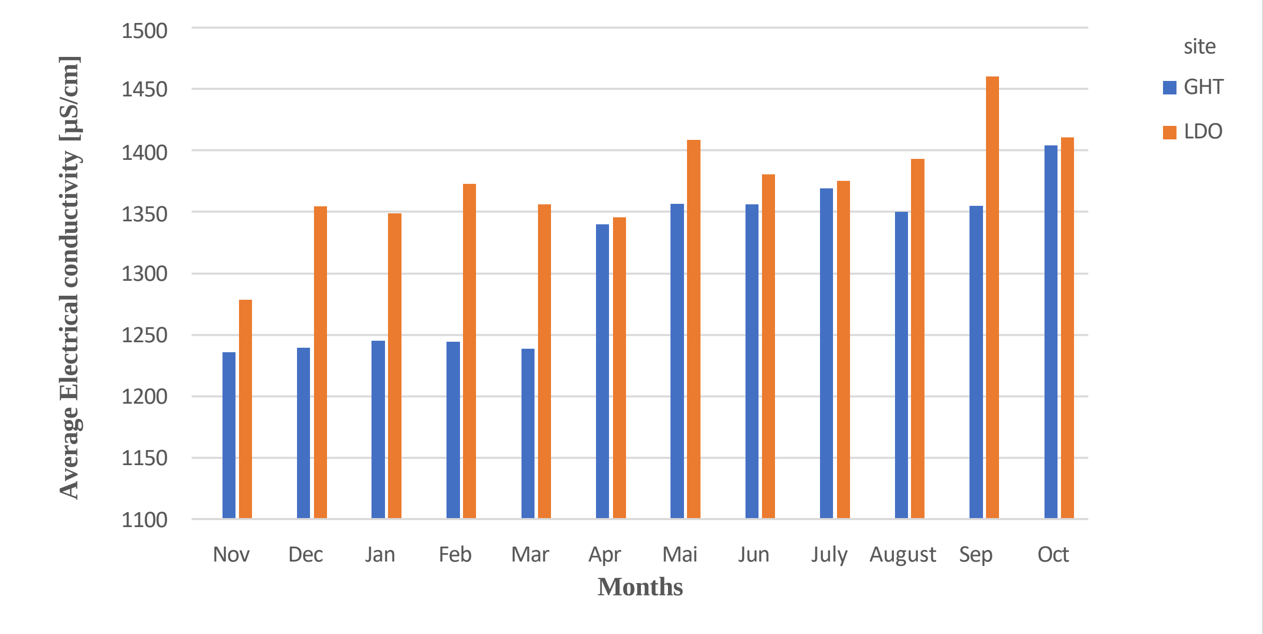


Figure 45. Monthly variation in electrical conductivity of Garâet Hadj Tahar and Lac des oiseaux from (November 2021 to October 2022).

B. Dissolved oxygen 'DO'

Oxygen concentrations measured during the study period are highly variable both temporally and spatially. The average dissolved oxygen levels obtained at GHT and LDO are 0.76 mg/l and 0.55 mg/l respectively. Throughout the study period, the water at both sites showed low oxygenation, with DO concentrations below the thresholds established by the WHO (2017), which are greater than 5 mg/L. Dissolved oxygen reached its maximum value (0.97 mg/l) in September at LDO, while the minimum value (0.12 mg/l) was observed at the same site in December (**Fig 46**)

It should be noted that our results show a clear deterioration at these sites compared with previous studies, where in 2012 values for this parameter ranged from 5.1 mg/l to 7.8 mg/l at GHT (**Kouti et al., 2016**). Furthermore, **Toumi et al (2016)** recorded values between 3.5 mg/l and 4.2 mg/l in LDO during the same period. Thus, long-term monitoring of these stations is essential to better understand the underlying elements that contribute to the low DO concentrations observed.

When dissolved oxygen levels are low, microorganisms that break down organic matter are encouraged to grow and develop, this makes dissolved oxygen a great indicator of water quality (**Merzoug s, 2015**). Water is considered polluted if its dissolved oxygen content is less than 3 mg/l, according to **Beaux (1998).**

The abundance of organic matter in untreated urban waste and the presence of oxygen-consuming bacterial activity, which lowers these waters' capacity for self-purification, are the reasons for the low values, according to **Bisimwa et al. (2022 a)**.

In addition, variations in DO levels are directly associated with variations in temperature and decomposed organic matter in these waters, leading to a significant drop in the solubility of oxygen in the water and revealing organic pollution (**Guemmaz et al., 2020**). According to **Bouchaala et all (2019)**, the increase in water temperature and the decomposition of large quantities of organic matter, which generally comes from animals and domestic waste, cause an increase in the oxygen content of the water. Long-term monitoring of these sites

Is therefore necessary to gain a better understanding of the underlying factors contributing to the low DO concentrations observed.

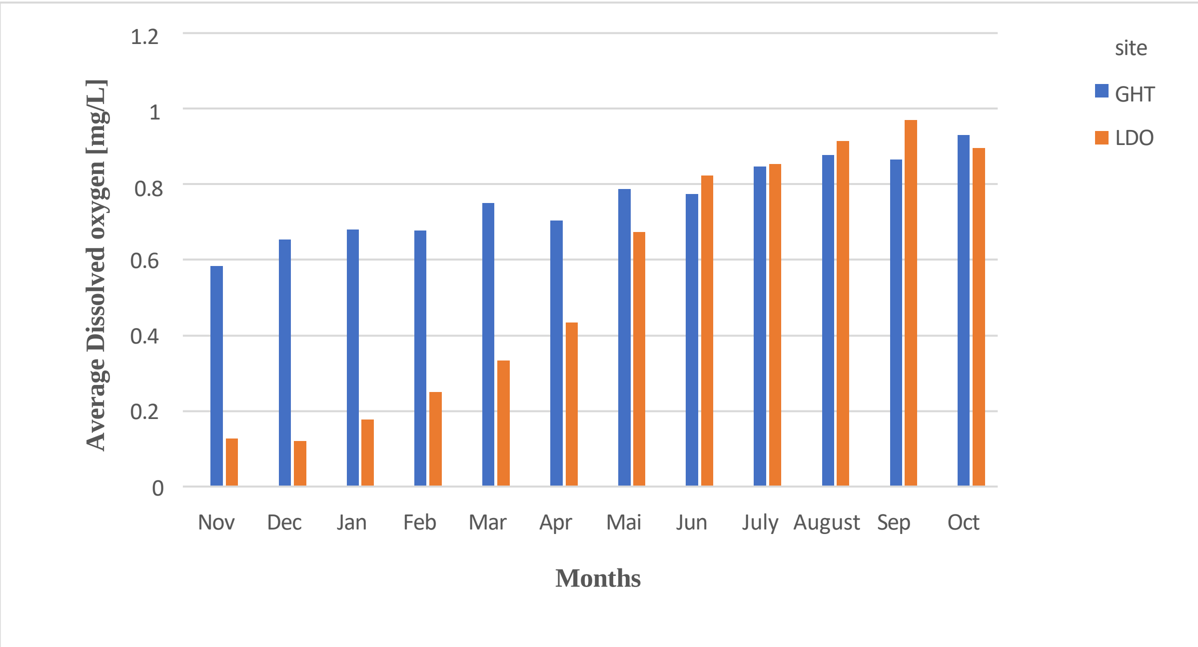


Figure 46. Monthly variation in Dissolved oxygen of Garâet Hadj Tahar and Lac des oiseaux from (November 2021 to October 2022).

C. Five-day biochemical oxygen demand ‘BOD5’

BOD5 is an indicator of the presence of labile organic matter in the water (**Wang et al., 2007**). The average amount of oxygen required by microorganisms to degrade the organic matter present in the two water bodies under aerobic conditions is 6.02 mg/L in GHT and 8.63 mg/L in LDO (**Fig 47**).

Our results exceed the limit established by the **WHO (2017)**, which is 5 mg/L. This increase is due to the release of accumulated organic matter (**Buhungu et al.,2018**). According to **Boyd (2020)**, natural waters usually have a BOD5 of between 1 and 10 mg/L, while domestic wastewater has a much higher BOD5 of between 100 and 300 mg/L.

Oxygen consumption is the main effect of releasing biodegradable organic matter into the natural environment. Due to the accumulation of organic matter at both sites, BOD5 values increase and DO decreases.

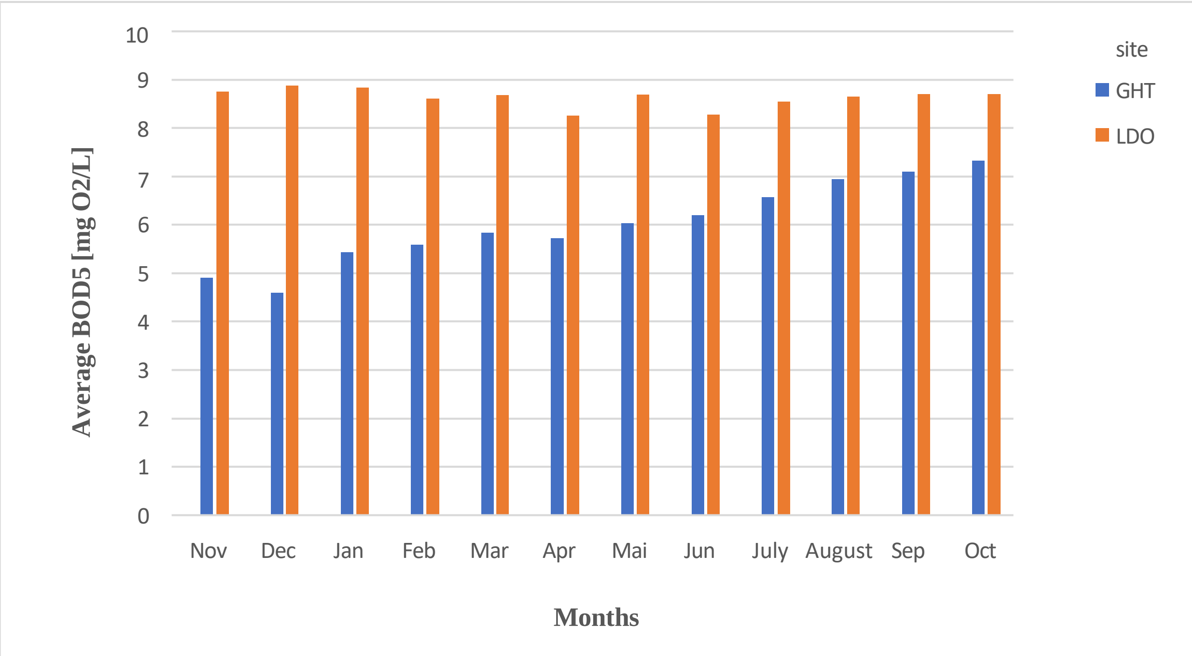


Figure 47. Monthly variation in DBO5 of Garâet Hadj Tahar and Lac des oiseaux from (November 2021 to October 2022).

D. Nitrates ‘NO_3^-’

Nitrates come from agriculture, whether through the spreading of fertilizers or the rearing of livestock, following the leaching of agricultural land. According to **Lalami et al. (2010)**, they also come from the mineralization of organic nitrogen and the oxidation of ammonium. Since NH3 can linger in aquatic environments for a long time and endanger aquatic life and humans, it is one of the main pollutants found in leachates (Parvin and Tareq, 2021).

The nitrate ion concentration in the waters of Garâet Hadj Tahar varies between a minimum of 12.60 mg/l observed in November and a maximum of 13.75 mg/l observed in August. LDO was marked by a wide range, reaching 24.94 mg/l in September and October, while the lowest concentrations were recorded in April, at 21.61 mg/l.

According to the results of the analyses carried out during our study, **Figure 48** shows that nitrate levels are relatively lower than the threshold value (50 mg/l) proposed by **J.O.R.A. (2011)**. With a large difference (almost double) between the two study sites.

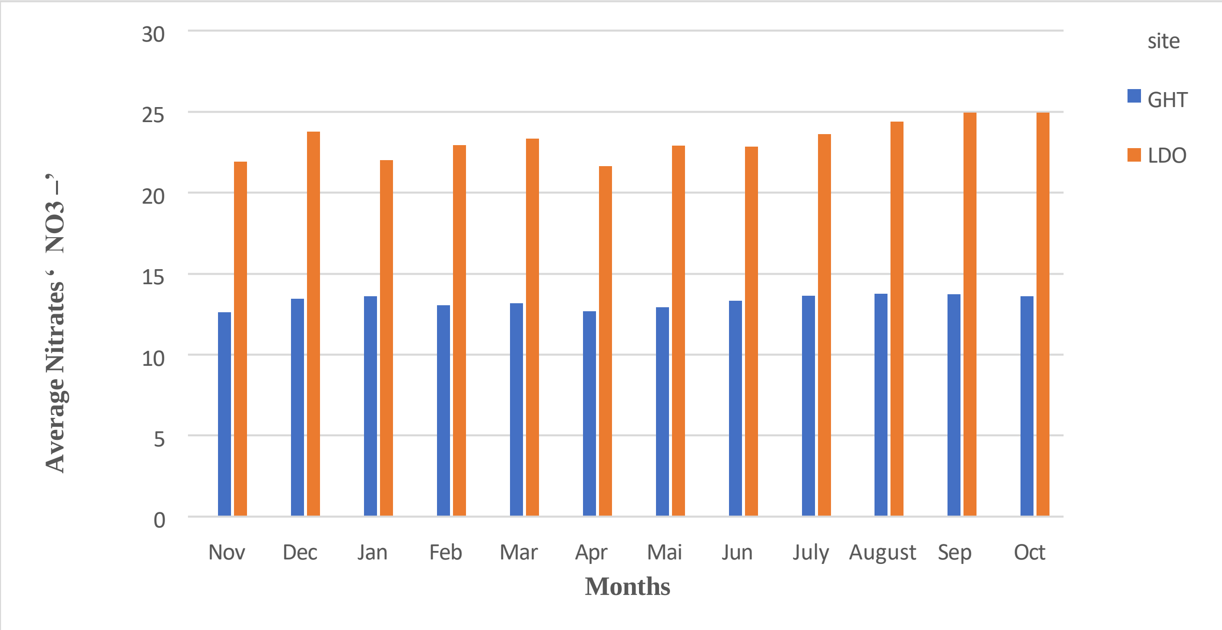


Figure 48. Monthly variation in Nitrates of Garâet Hadj Tahar and Lac des oiseaux from (November 2021 to October 2022).

E. Nitrites 'NO$_2$'

Nitrites (NO2-), a less oxygenated and less stable form, represent the transition between nitrates and ammonium and are toxic. As far as GHT is concerned, the highest levels were recorded in August (0.97 mg/l), while the lowest levels were recorded in December (0.45 mg/l) (Fig). LDO reached maximum levels in October and minimum levels in November, respectively (1.38 mg/l and 0.65 mg/l). However, nitrite concentrations were high, well above the threshold (0.1 mg/L) set by the **WHO (2017)** and **JORA (2011)**.

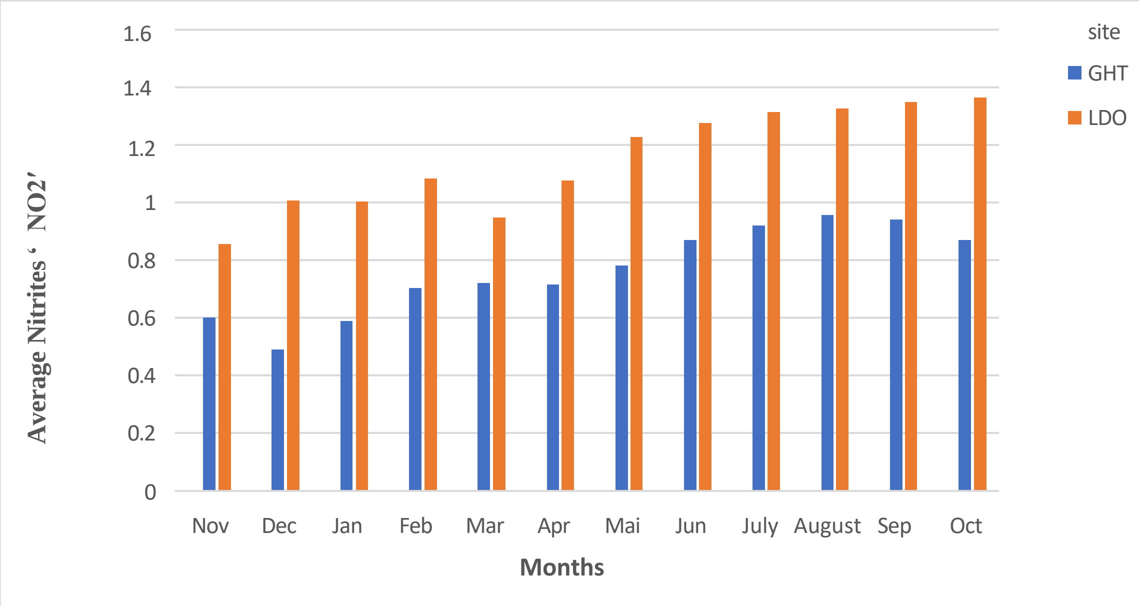


Figure 49. Monthly variation in Nitrites of Garâet Hadj Tahar and Lac des oiseaux from (November 2021 to October 2022).

F. Ammonium 'NH_4^+'

Our results in the (**Fig 50**) show that the ammoniacal nitrogen concentration in LDO ranged from 5.26 to 7.18 mg/l. On the other hand, at GHT, the average monthly NH4 + content was 4.51 mg/l. Except for September, when we recorded a significant peak of around 5.65 mg/l.

Compared with the classification of surface waters established by (**Belhaouari et al, 2017**), these values considerably exceed the limit value (0.1 to 3 mg/l and > to 3 mg/l) and indicate highly polluted water. According to **WHO (2017)** and **JORA (2011)** data, our results exceed the threshold (0.5 mg/L) by 20 times. Furthermore, according to **ANRH (2003)**, the pollution is significant (>3 mg/L).

We agree with the results of **M'ehounou et al. (2016)** in Benin and **Bisimwa et al. (2022a)** in Congo. According to **Ould Sidi et al. (2019)**, this increase can be attributed to animal use of lake water. Ammonia in surface waters comes mainly from sources of chemical fertilisers containing nitrates and nitrites, industrial and domestic wastewater, erosion of natural deposits, and microbial decomposition of organic matter containing nitrogen (**Aydin et al., 2021**). Sufficient oxygenated water contains only ammonia residues (**Sayad et al., 2009**).

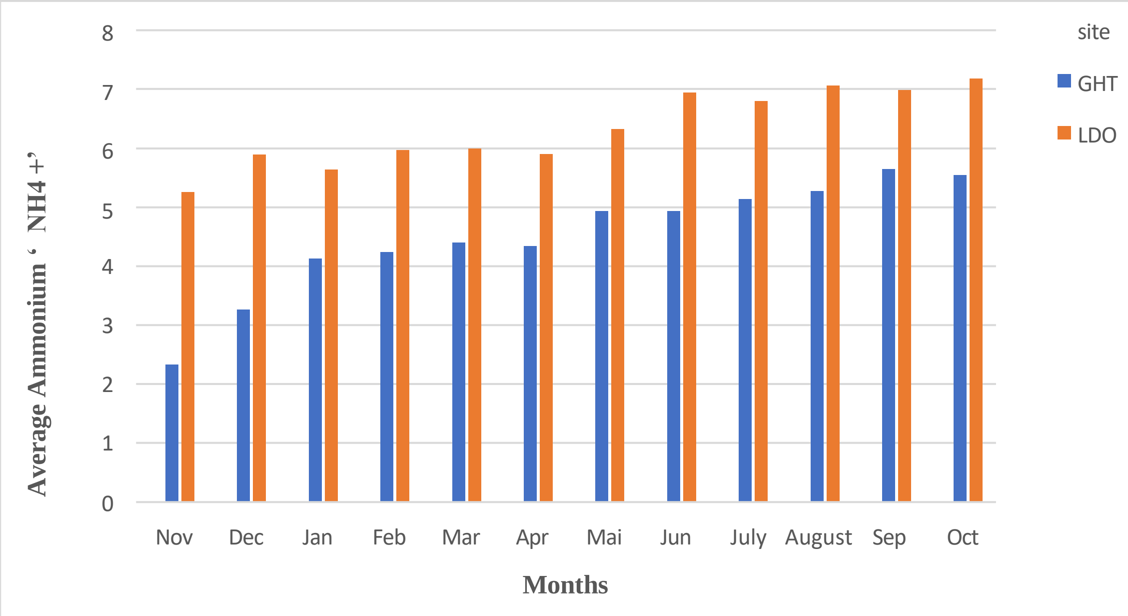


Figure 50. Monthly variation in Ammonium of Garâet Hadj Tahar and Lac des oiseaux from (November 2021 to October 2022).

G. Phosphate 'PO_4^{3-}'

The input of phosphorus into watercourses or water bodies can have a positive impact on primary production, as it can promote the growth of plants and algae (**Aounallah, 2016**). According to **Nechad et al. (2014)** a high concentration of orthophosphate may reflect pollution caused by the leaching of fertilizers in agriculture. In particular, high concentrations of this compound in surface waters may cause eutrophication.

Orthophosphate concentrations in GHT vary from 6 to 7.59 mg/l, as shown in the figure. As for LDO, all the values recorded range from 8.20 mg/l to 8.66 mg/l. Similarly, and based on its results obtained in GHT and LDO, we can clearly conclude that orthophosphate in both study sites has greatly exceeded the tolerance bar established by **Belhaouari et al. (2017)**. In addition, this gives us the opportunity to classify these waters as polluted as they also exceed the 5 mg/L standard recommended by **Rodier et al. (2009)** and the **WHO (2017)**. This is in line with the findings of **Bisimwa et al. (2022b)** and **Brahimi and Chafi (2014)**.

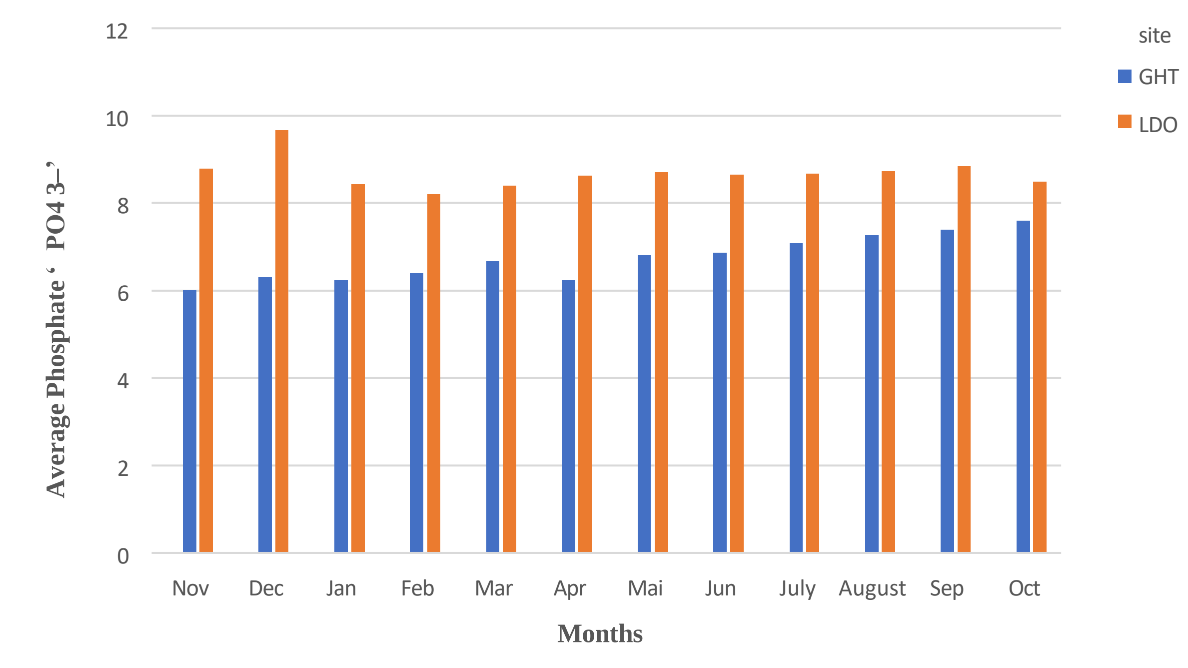


Figure 51. Monthly variation in Phosphate of Garâet Hadj Tahar and Lac des oiseaux from (November 2021 to October 2022).

Previous research by (**Merzoug, 2009**; **Abdi, 2013**; **Kouti, 2016**; **Bouchaala, 2017**; and **Bara Y, 2020**) carried out in GHT and by (**Sayad et al., 2009**; **Halassi, 2010**; **Toumi et al., 2016**; and **Mezbour et al., 2018**) in LDO allows us to follow the evolution of nutritional salts (NO_3^- , NO_2^- , NH_4^+ , and PO_4^{3-}) in the waters of the two study sites.

A comparison of these values with those from this study shows a significant and worrying increase. The unexpected increase in these levels has prompted us to express our concerns about the health of the two specific sites and the wetlands of the Algerian Numidia region in general. It could be linked to an increase in human activity.

As indicated by **Bara Y (2021)**, the high quantity of nutrient salts, especially ammoniacal nitrogen and orthophosphate, in Garaet Hadj Tahr is linked to the faecal excrement of the cattle herds that live in the area, the uncontrolled expansion of agriculture and the excessive use of plant protection products. Added to which are the wastewater discharges from the Daïra of Ben Azzouz and the villages located upstream (**D.G.F, 2001**).

III.3.2. Spatial and temporal variations of bacterial load

The mean heterotrophic bacteria load in GHT is 456.63 × 10^3 CFU/100 mL (range: 366.33 × 10^3–554 × 10^3), in total coliforms: 328.50 × 10^3 CFU/100 mL (range: 287 × 10^3–

382.67 × 10^3), faecal coliforms 257 × 10^3 CFU/100 mL (range: 198.33 × 10^3–279 × 10^3) and in faecal Streptococci: 76.36 × 10^3 CFU/100 mL (range: 32.33 × 10^3–158× 10^3).

The LDO revealed a total microbial load of 771.88 × 10^3 CFU/100 mL (range: 660 × 10^3–848.50 × 10^3); TC: 538.54 × 10^3 CFU/100 mL (range: 446 × 10^3–610.67 × 10^3); FC: 413.14 × 10^3 CFU/100 mL (range: 350 × 10^3– 469 × 10^3) and of FS: 161.76 × 10^3 CFU/100 mL (range: 132.33 × 10^3– 198 × 10^3) (**Fig 52**).

The trend in the number of total germs counted at the two study sites (GHT and LDO) shows a gradual increase from the first month of sampling (November 2021) to the last (October 2022). As the temperature increased, so did the number of faecal coliforms. The graphs for total coliforms and faecal coliforms follow the same pattern as those for total germs (**Fig 52**).

The highest densities were recorded during the summer period. These microscopic organisms, which can break down lactose in a variety of environments, have varying levels of demand and reproduce easily in aquatic environments. They are indicators of persistent faecal pollution (**Toumi et al., 2016; Reggam et al., 2017; Mezbour et al., 2018; Hamli et al., 2019**).

The detection of faecal streptococci in each environment indicates recent pollution of that environment, as these microscopic organisms reside exclusively in the digestive system of animals and do not survive external conditions (**Carluer et al., 1996**). These microorganisms are also present in the environment (**Toumi et al., 2016, Mezbour et al., 2018, Hamli et al., 2019**). The levels measured are very high and show that the environments are subject to constant pollution. Maximum values were recorded during July, the hottest month (**Fig 52 C**), while minimum values were observed during the coldest months of the year (December, January and February).

It was noted that, except for DO, the values recorded for nutrients (NO3 -, NO2 -, NH4 +, and PO4 3-), EC, BOD5 and faecal bacteria in our study were all higher than those documented in other studies. It is important to note that a rise in the lake's nutrient concentrations may cause fecal bacteria to proliferate and become more active, which in turn lowers DO levels (**Bisimwa et al., 2022b**).

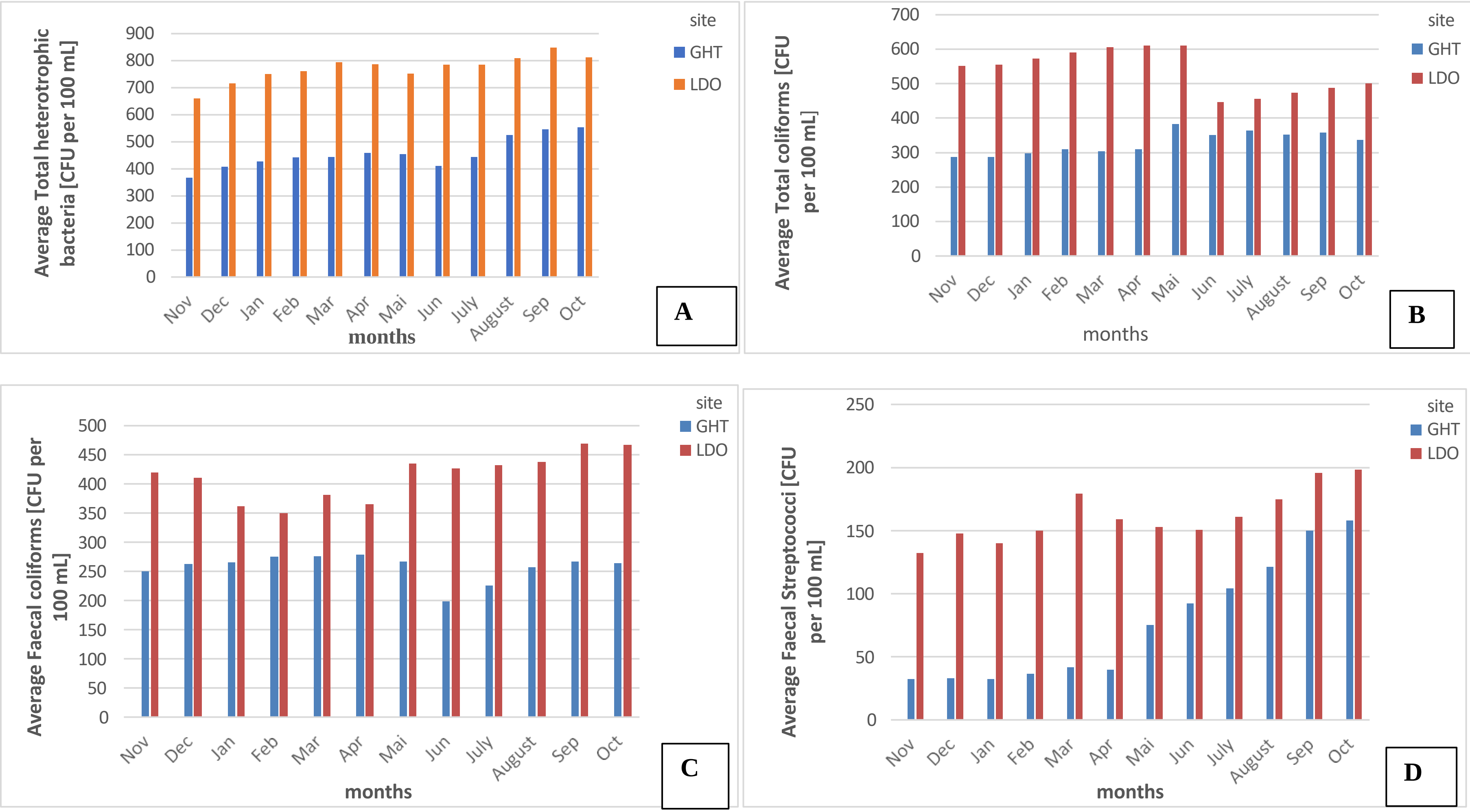


Figure 52. Monthly in Total heterotrophic bacteria 'THB' (A), Total coliforms 'TC'(B), Faecal coliforms 'FC'(C) and Faecal Streptococci 'FS'(D) of Garâet Hadj Tahar and Lac des oiseaux from (November 2021 to Octob

III.3.3. Multivariate Statistical analysis

To establish a relationship between the various physico-chemical and bacteriological parameters, and to better assess the effect of human activities on the water quality of two wetlands in the Algerian Numidia, we carried out a statistical treatment to define the parameters.

A. Two-way ANOVAs

Analysis of variance with a classification criterion (ANOVA) ($\alpha \leq 0.05$) showed a very highly significant difference between the two study sites (Gariet Hadj Tahr and Lac des Oiseaux) and the months ($p < 0.001$). The ANOVA showed no significant difference between the three sampling stations (**Tab 8**).

Table 8. Two-way ANOVAs testing the effects of sites, months, and stations on the variation of water physical parameters and bacterial loads measured in the water of GHT and LDO.

Effet		Valeur	F	ddl de l'hypothèse	Erreur ddl	Sig.
Station	Trace de Pillai	,309	,730	22,000	88,000	,797
	Lambda de Wilks	,710	,729[b]	22,000	86,000	,798
	Trace de Hotelling	,381	,727	22,000	84,000	,800
	Plus grande racine de Roy	,287	1,150[c]	11,000	44,000	,348
Months	Trace de Pillai	4,407	3,221	121,000	583,000	<,001
	Lambda de Wilks	,000	8,817	121,000	353,083	<,001
	Trace de Hotelling	153,538	52,256	121,000	453,000	<,001
	Plus grande racine de Roy	138,999	669,720[c]	11,000	53,000	<,001
Sites	Trace de Pillai	,998	1687,535[b]	11,000	43,000	<,001
	Lambda de Wilks	,002	1687,535[b]	11,000	43,000	<,001
	Trace de Hotelling	431,695	1687,535[b]	11,000	43,000	<,001
	Plus grande racine de Roy	431,695	1687,535[b]	11,000	43,000	<,001

Sig.: statistical significance of p-value, ***: $p < 0.001$, **: $p < 0.01$, *: $p \leq 0.05$, NS: $p > 0.05$)

B. Principal component analysis (PCA)

Principal component analysis is a statistical method. Its aim is to present in graphical form the maximum amount of information contained in a table of data (**Diday et al., 1982;**

Philipeau, 1992). The rows of the table are made up of individuals on whom quantitative variables are measured (**Diday et al., 1982; Philipeau, 1992**).

The aim of using PCA of hydrochemical data in our study area is to:

- Characterize water chemistry over an observation period.
- Highlight any relationship between human activities and surface water quality.
- To compare the two study sites (GHT and LDO)
- To give a preliminary idea of the elements and sites of pollution

B.1. Correlation matrix

The correlation matrix gives us an initial idea of the associations existing between the various variables such as DO, EC, BOD5, NO_3^-, NO_2-, NH4+, PO43-, THB, TC, FC, and FS. These parameters are relatively well correlated with each other. Numerous substantial positive and negative correlations were found between the physicochemical and bacteriological parameters of the water in Garaet Hadj Tahar and Lac des Oiseaux (**Tab 9**).

We note that most of the correlations are positive, or only 9 negative correlations are noted at GHT and 22 at LDO. Also, out of 55 correlation tests, 38 very strongly significant positive correlations ($p < 0.001$) were found at GHT, but only 20 were recorded at LDO.

In the GHT, there is a very strong positive correlation between DO-NH_4^+, PO_4^{3-} and DBO5, between DBO5-NO_2 and PO_4^{3-} and between FS-PO_4^{3-} and DBO5. This relationship between faecal indicators and concentrations of physico-chemical parameters should be the subject of future experimental research. Furthermore, in the LDO, DO showed a highly significant positive correlation with NH4+ and NO_2^-. The (DO-NH_4^+) pairs showed positive correlations in both study sites. Conversely, (DO--BOD5) showed a positive correlation at GHT and a negative correlation at LDO.

According to **Sayad (2009)**, ammonia is typically present in trace amounts in well-oxygenated water. It has been demonstrated that nitrogen derivatives, including nitrites, nitrates, and ammoniacal nitrogen, are important contributors to water pollution, having a major impact on oxygen concentrations and, eventually, eutrophication (**Mutlu et al., 2018**). The strong positive correlation between these elements in our study can be explained by the fact that rising temperatures encourage the breakdown of organic matter into nutrient salts (NO_3^-, NO_2^-, and NH_4^+), and rising concentrations of these elements in water raise pH (**Belhouchet et al., 2024**).

In our situation, there is a negative correlation between BOD5 and DO because a significant amount of organic matter builds up in LDOs, which raises BOD5 values and lowers DO.

Table 9: Correlation matrix showing the interrelationships between the physicochemical and bacteriological parameters of the water in Garâet Hadj Tahar from November 2021 to October 2022). Pearson correlation tests are presented as correlation coefficient and p-value.

Correlations											
	EC	**DO**	**NO_3^-**	**NO_2^-**	**NH_4^+**	**PO_4^{-3}**	**BOD5**	**THB**	**TC**	**FC**	**FS**
EC	1	0,799**	0,279	0,801**	0,788**	0,764**	0,803**	0,600**	0,770**	-0,275	,823**
DO	< 0.001	1	0,587**	0,867**	**0,908****	**0,943****	**0,929****	0,822**	0,730**	-0,110	0,898**
NO_3^-	0,110	< 0.001	1	0,401*	0,530**	0,639**	0,515**	0,479**	0,257	-0,231	0,590**
NO_2^-	< 0.001	< 0.001	0,019	1	0,831**	0,837**	**0,910****	0,635**	0,739**	-0,315	0,846**
NH_4^+	< 0.001	< 0.001	0,001	< 0.001	1	0,868**	0,899**	0,777**	0,745**	-0,082	0,793**
PO_4^{3-}	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	1	**0,930****	0,779**	0,690**	-0,193	**0,951****
BOD5	< 0.001	< 0.001	0,002	< 0.001	< 0.001	< 0.001	1	0,815**	0,686**	-0,157	**0,913****
THB	< 0.001	< 0.001	0,004	< 0.001	< 0.001	< 0.001	< 0.001	1	0,530**	0,347*	0,752**
TC	< 0.001	< 0.001	0,142	< 0.001	< 0.001	< 0.001	< 0.001	0,001	1	-0,067	0,666**
FC	0,116	0,534	0,189	0,069	0,644	0,275	0,376	0,044	0,706	1	-0,264
FS	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0,131	1

**The correlation is significant at the 0.01 level.

* The correlation is significant at the 0.05 level.

Tab 10: Correlation matrix showing the interrelationships between the physicochemical and bacteriological parameters of the water in Lac des oiseaux from November 2021 to October 2022). Pearson correlation tests are presented as correlation coefficient and p-value.

Correlations											
	EC	**DO**	**NO_3**	**NO_2^-**	**NH_4^+**	**PO_4^{3-}**	**BOD5**	**THB**	**TC**	**FC**	**FS**
EC	1	-0,032	0,124	-0,004	-0,009	0,056	-0,049	0,087	0,168	-0,100	0,179
DO	0,859	1	0,588**	**0,914****	**0,939****	-0,105	-0,323	0,720**	-0,609	0,678**	0,632**
NO_3^-	0,484	< 0.001	1	0,631**	0,701**	0,244	0,154	0,519**	-0,405	0,601**	0,725**
NO_2^-	0,984	< 0.001	< 0.001	1	**0,903****	0,011	-0,367	0,691**	-0,552	0,592**	0,575**
NH_4^+	0,958	< 0.001	< 0.001	< 0.001	1	-0,050	-0,259	0,741**	-0,669	0,642**	0,648**
PO_4^{3-}	0,754	0,555	0,164	0,953	0,780	1	0,138	-0,271	-0,128	0,339*	-0,092
BOD5	0,783	0,062	0,383	0,033	0,139	0,437	1	-0,314	0,091	0,096	-0,117
THB	0,625	< 0.001	0,002	< 0.001	< 0.001	0,122	0,070	1	-0,363	0,169	0,769**
TC	0,342	< 0.001	0,017	0,001	< 0.001	0,470	0,610	0,035	1	-0,495	-0,186
FC	0,575	< 0.001	< 0.001	< 0.001	< 0.001	0,050	0,587	0,340	0,003	1	0,415*
FS	0,311	< 0.001	< 0.001	< 0.001	< 0.001	0,604	0,511	< 0.001	0,293	0,015	1

**The correlation is significant at the 0.01 level

*. The correlation is significant at the 0.05 level.

B.2. Eigen values

Principal component analysis was used to analyze the data from the 68 samples and 11 variables. Two factors (PC) were retained in the PCA analysis with an Eigen value greater than one. As indicated by Hinge et al. 2022, a value close to ±1 indicates a strong correlation between the factor and the variables. These loadings are then classified into three categories: strong (>±0.75), moderate (±0.75 to ±0.50) and weak (±0.50 to ±0.30). **Tab 11** and **Fig 53** show the correlations between the variables, the factors, and the projection of the variables over time on the PC1 and PC2 axes, respectively.

For the GHT, analysis of the PC1 and PC2 factorial designs shows that more than 82% of the observations are expressed. The percentage of variance expressed by the first factor (70.69%) shows that there is a good structure in the sampling carried out. This proves that many factors affecting the structure of the samples are interrelated. The PC1 axis is expressed by EC, DO, NO2-, PO43-, BOD5, THB, and FS. The PC2 axis has a variance of 11.97% and is expressed by FC (**Tab 11** and **Fig 53 A**).

For LDO, analysis of the PC1 and PC2 factorial design shows that more than 64% of the observations are expressed. The PC1 axis has a variance of 49.18% and is expressed by DO, NO_3^-, NO_2^-, NH_4^+, THB, and FS with a moderate correlation with FC. The PC2 axis has a variance of 15.38% and is expressed by PO_4^{3-} and a moderate correlation with BOD5 and TC (**Tab 11** and **Fig 53 B**).

The evolution of nutrient salts (NO_3^-, NO_2^-, NH_4^+, and PO_4^{3-}) has been shown to contribute significantly to aquatic pollution, greatly influencing dissolved oxygen levels below and ultimately eutrophication (**Mutlu et al., 2018**). These elements promote intense microbial proliferation and multiplication. In addition, nutrients from agricultural, industrial, and municipal activities lead to an increase in the microbial load. According to **Buhungu et al. (2018)**, the major impact of discharging biodegradable organic waste into the environment is an increase in BOD5 and a decrease in dissolved oxygen.

Table 11. Correlations between variables and principal axes (PC1 * PC2), Garaet Hadj Tahar (left) and Garaet Hadj Tahar (right) (From November 2021 to October 2022).

	GHT		**LDO**	
Variables	**PC1 (70,69%)**	**PC2 (11,97%)**	**PC1 (49.18%)**	**PC2 (15.38%)**
EC	0.86	-0.13	0.02	-0.15
DO	0.97	0.06	0.94	-0.08
NO3-	0.58	-0.12	0.77	0.32
NO2-	0.91	-0.16	0.92	-0.07
NH4+	0.93	0.09	0.96	-0.03
PO43-	0.96	-0.01	0.01	0.75
BOD5	0.96	0.02	-0.25	0.60
THB	0.81	0.52	0.78	-0.45
TC	0.78	0.03	-0.64	-0.25
FC	-0.17	0.97	0.68	0.56
FS	0.94	-0.09	0.76	-0.16

The variable score diagram shows that variables are grouped within a close range of each other when a higher percentage of variables in the data are explained. The factor score diagram shows that there are clear differences between the months in the two sites.

For GHT, the first factor shows that there is a close relationship between faecal coliforms in the months of April, March, and February. While the second factor shows that the total number of heterotrophic bacteria, BOD5, PO4, NH4, DO, and TC are related to the months of May, August, September, and October. The third factor showed that there was an association between NO2, NO3, FS, and EC during the month of July.

As for LDO, the first factor showed that there was a close relationship between BOD5 and PO4 during the months of December and November. While the second factor showed that there was an association between NO3 and faecal coliforms during the months of July, August, and September. The third factor showed that the total number of heterotrophic bacteria, faecal streptococci, NH4, and DO were associated with the months of June, July, and August. The fourth factor showed that total coliforms and electrical conductivity were linked to the months of January, February, March, and April.

The rise in temperature (during the dry season) facilitates the degradation of organic matter into nutrients (NO3 -, NO2 -, and NH4 +) (**Belhouchet et al., 2024**), It is important to note that increased nutrient concentrations in water bodies can also lead to increased proliferation and activity of faecal bacteria, which in turn leads to a reduction in DO levels (**Bisimwa et al., 2022b**).

We note that, in GHT, the fourth factor does not appear to be a good grouping in relation to the first, second, and third factors. It appears that there is no close relationship between the month of November (start of the research) and the other months of the study period, perhaps due to climatic conditions (temperature and rainfall). Note that the Algerian Numidia region experienced a significant drying out of its substantial wetlands during 2022, coupled with a clear delay in the rainy season.

This explains why, in the same graph, the months of November, December, January, February, March, and April are in the same group and are separated from the other months (May, June, July, August, September, and October).We can see that reduced precipitation, lower water levels, higher temperatures, and water evaporation are factors that can influence the concentration of physico-chemical parameters and the number of bacteria in a body of water.

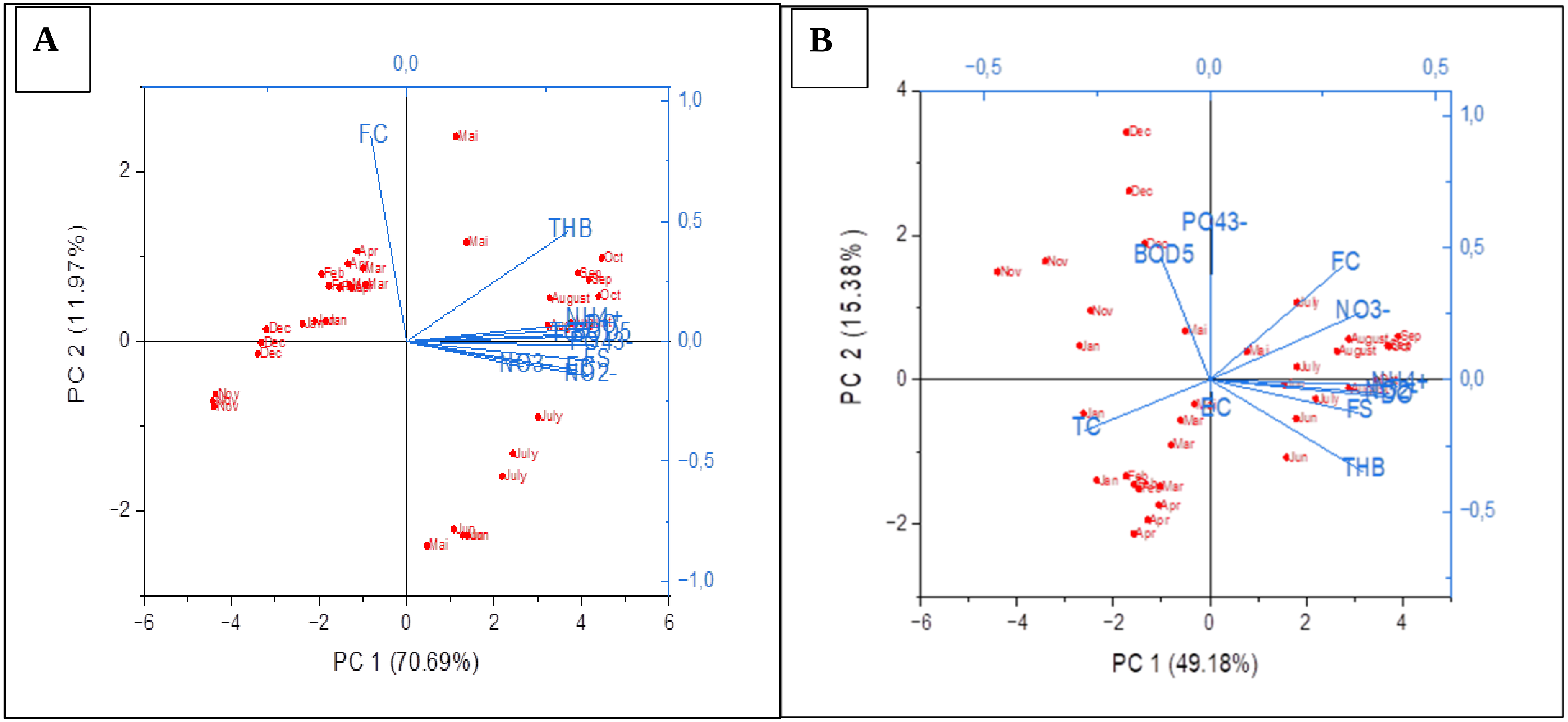


Figure 53. Principal component analysis (PCA) showing relationship between bacteriological load and physico-chemical quality of Garaet Hadj Tahr (A) and Lac des oiseaux (B) surface water.

C. Cluster analysis

To establish the similarity between the surface water samples, a method combining Ward's technique and Euclidean distance was used. In **Figure 54**, two dendrograms are displayed to classify the different physicochemical and bacteriological variables in the GHT (A) and LDO (B) surface water samples. To approximate normally distributed data, all variables were log-transformed and standard scores (z-scores) were calculated for each variable.

For each study site, the dendrogram of the eleven physicochemical and bacteriological parameters (DO, EC, BOD5, NO3-, NO2-, NH4+, PO43-, THB, TC, FC, and FS) was divided into three main groups (**Fig 54**).

For GHT, the first group (G1) showed a close association between EC, DO, BOD5, PO_43-, FS, NO4+, NO2-, THB and TC. Groups G2 and G3 showed dissociation between NO3- and CF, respectively, and other elements present in GHT surface waters, indicating an anthropogenic source. Regarding LDO, groups G1 and G2 showed a close association between only two elements. The elements EC and TC are associated with G1, while PO_4^{3-} and BOD5 showed an association with G2. Finally, the third group (G3) showed a close association between DO, NH_4^+, NO_3^-, NO_2^-, THB, FS and FC, reflecting the major predominance of oxygen.

In any aquatic ecosystem, the increase in nutrients (NO_3^-, NO_2^-, NH_4^+, and PO_4^{3-}) of agricultural, industrial and municipal origin can be correlated with the intensification of anthropogenic activities and population growth observed over the last decade. The leaching of accumulated organic matter leads to a rise in the 5-day Biochemical Oxygen Demand (BOD5) and an increase in the faecal germ load, which in turn leads to increased consumption of dissolved oxygen in the water. This process encourages the eutrophication of aquatic environments.

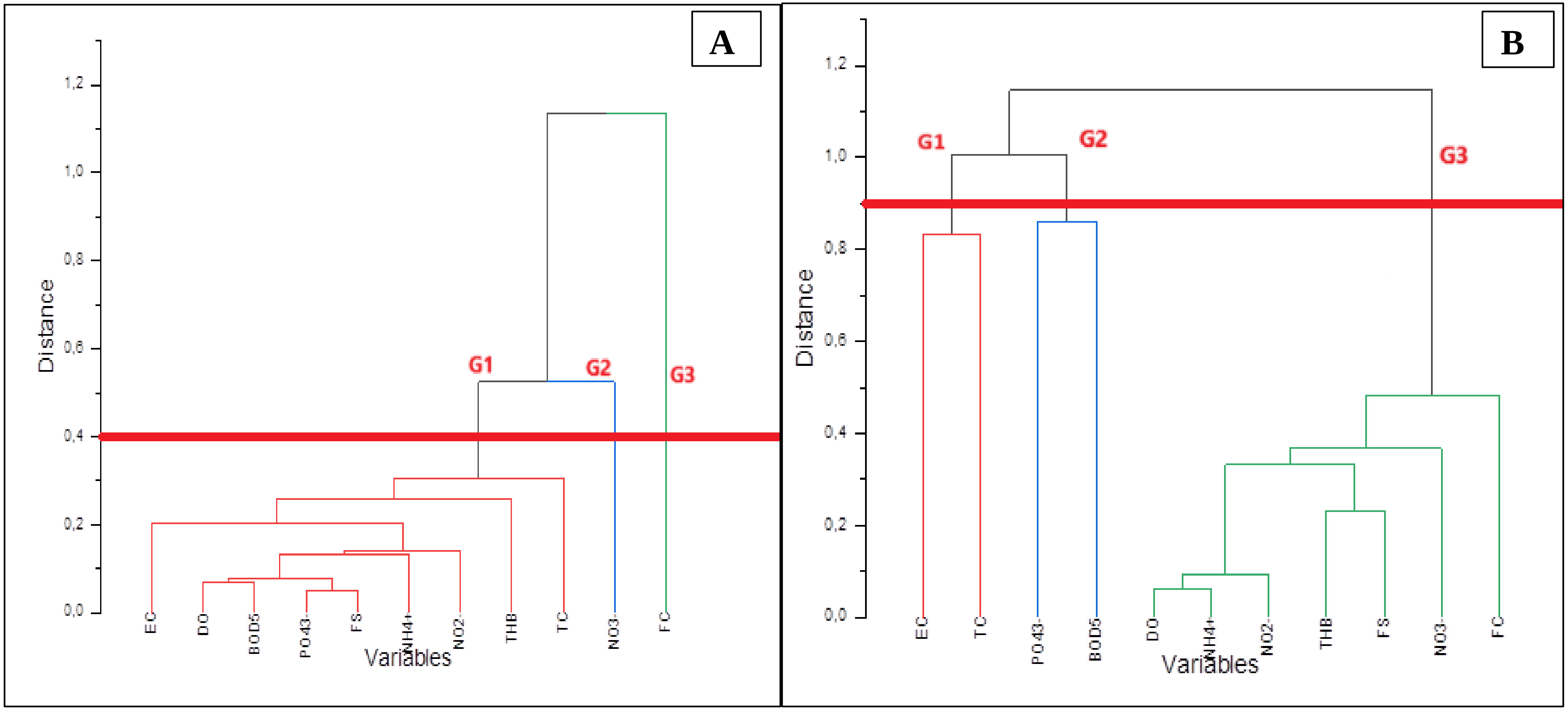


Figure 54. Cluster dendrogram for variables. (A) GHT, (B) LDO, G1 (group 1), G2 (group 2), G3 (group 3) and the groups could be distinguished in terms of their variable at the red line.

III.3.4. Effect of abiotic factors on Anatidae abundance

Environmental parameters such as water quality parameters (physico-chemical and bacteriological) and climatic conditions (temperature and precipitation) are correlated at Garaet Hadj Tahar and Lac des Oiseaux, and the significant correlation is summarized in (**Appendix 04, 05**), respectively.

At Garaet Hadj Tahar, Anatidae abundance was significantly correlated with electrical conductivity, dissolved oxygen, ammonium, Total heterotrophic bacteria, Faecal coliforms, Faecal streptococci, and precipitation (p-value < 0.05), and the correlation coefficient is summarized in **Appendix 04**. The Anatidae abundance at Lac des Oiseaux was significantly correlated with electrical conductivity, nitrite, ammonium, Faecal streptococci, and precipitation (p-value < 0.05). The correlation coefficient is summarized in **Appendix 05**.

Precipitation is known to influence water levels in aquatic ecosystems. A recent study carried out in Lake Tanga by **Loucif (2020)** shows that water depth plays a crucial role in duck reproduction. Deeper water encourages more egg-laying and better reproductive success by reducing the risk of predation and improving access to food resources. For diving ducks, this means greater mobility for feeding and escaping from predators. However, dense aquatic vegetation near the surface can hinder this mobility.

III.3.5. Relationship between physico-chemical and bacteriological water parameters and abundance of Anatidae species

Table 12 et 13, summarizes the Spearman correlation between the fortnightly abundance of Anatidae species and the physico-chemical and bacteriological parameters of the water. In both study sites, the relationship between the abundance of Anatidae and the physico-chemical and bacteriological parameters of the water was weak, significant, and highly significant (rarely).

Among the species recorded at the GHT site, the abundance of *Aythya fuligula* showed a negative correlation with electrical conductivity ($r = -0.55$, $p < 0.05$) (**Tab 12**). A similar trend was observed at the LDO site for *Anas acuta* ($r = -0.60$, $p < 0.05$). However, the abundance of *Anas platyrhynchos* ($r = 0.53$, $p < 0.05$) and *Anas crecca* ($r = 0.58$, $p < 0.05$) was positively correlated with this parameter (**Tab 13**).

Within the GHT, *Spatula clypeata* showed a single negative correlation with dissolved oxygen ($r = -0.64$, $p < 0.05$) as well as with five-day biological oxygen demand (BOD_5) ($r = -0.73$, $p = 0.003$). Similarly, within LDO, Anas acuta was negatively correlated with ammonium concentration ($r = -0.61$, $p < 0.05$). Nitrite levels were negatively correlated with *Anas penelope* at the GHT site ($r = -0.53$, $p < 0.05$). Similarly, a negative correlation was observed for *Spatula clypeata*, with values of $r = -0.83$ ($p < 0.001$) at GHT and $r = -0.57$ ($p < 0.05$) at LDO (**Tab 12, 13**). Nitrate and phosphate were not significantly correlated with any Anatidae species at either study site.

In terms of bacterial groups, *Aythya ferina* showed a negative correlation with faecal coliforms (FC) ($r = -0.75$, $p = 0.006$) in the GHT. The same was true for *Spatula clypeata*, which was negatively correlated with total heterotrophic bacteria (THB) ($r = -0.69$, $p = 0.006$), total coliforms (TC) ($r = -0.70$, $p = 0.005$), and faecal streptococci (FS) ($r = -0.76$, $p < 0.001$). At the LDO level, *Anas acuta* showed a negative correlation with THB ($r = -0.60$, $p < 0.05$) and FS ($r = -0.54$, $p < 0.05$). Similarly, *Netta rufina* correlated negatively with THB ($r = -0.54$, $p < 0.05$) and FS ($r = -0.61$, $p < 0.05$), while *Aythya nyroca* correlated negatively with FS ($r = -0.54$, $p < 0.05$). Only one positive correlation was recorded, involving *Oxyura leucocephala* ($r = 0.70$, $p = 0.005$) (**Tab 12, 13**).

Table 12. Spearman correlation between Anatidae species abundance and water physico-chemical and bacteriological parameters in Garaet Hadj Tahr

	EC	*DO*	*NO_3^-*	*NO_2^-*	*NH_4^+*	*PO_4^{3-}*	*BOD5*	*THB*	*TC*	*FC*	*FS*
Anas platyrhynchos	0,30	0,06	0,37	0,00	0,00	0,09	-0,03	-0,06	-0,14	**-0,59***	-0,04
Anas stepera	-0,22	-0,20	-0,10	-0,08	-0,19	-0,10	-0,25	-0,31	-0,32	**-0,53***	-0,18
Spatula clypeata	-0,40	**-0,64***	0,26	**-0,83****	-0,52	-0,35	**-0,73****	**-0,69****	**-0,70****	-0,37	**-0,76****
Anas penelope	-0,45	-0,48	0,23	**-0,53***	-0,24	-0,06	-0,41	-0,50	-0,40	-0,09	-0,52
Aythya ferina	-0,10	-0,34	0,02	-0,17	-0,33	-0,16	-0,35	-0,41	-0,30	**-0,75****	-0,32
Aythya nyroca	-0,18	0,30	0,04	0,41	0,30	0,36	0,27	0,23	0,26	-0,17	0,22
Aythya fuligula	-0,56	-0,20	-0,18	-0,23	-0,23	-0,21	-0,25	-0,27	-0,15	-0,04	-0,45

Note: $0.01 < p < 0.05$ *: Significant; $0.001 < p < 0.01$ **: Highly significant

Table 13. Spearman correlation between Anatidae species abundance and water physico-chemical and bacteriological parameters in Lac des oiseaux

	EC	DO	NO_3^-	NO_2^-	NH_4^+	PO_4^{3-}	BOD5	THB	TC	FC	FS
Anas penelope	-0,15	-0,51	0,11	-0,39	-0,17	-0,08	0,08	-0,43	-0,19	0,00	-0,31
Anas stepera	0,27	0,08	0,18	0,15	0,10	-0,36	-0,37	0,05	-0,19	0,00	0,01
Anas platyrhynchos	**0,53***	0,21	0,49	0,30	0,47	-0,47	0,30	0,28	-0,51	0,25	0,28
Anas acuta	**-0,60***	-0,44	-0,34	-0,36	**-0,61***	0,13	0,01	**-0,60***	-0,29	0,35	**-0,54***
Spatula clypeata	-0,50	-0,27	-0,40	**-0,57***	-0,42	-0,09	-0,27	-0,34	0,43	-0,17	-0,27
Anas crecca	**0,58***	0,31	0,46	0,51	0,39	-0,45	0,07	0,35	-0,42	0,04	0,30
Aythya ferina	-0,09	-0,02	-0,04	-0,05	0,01	-0,07	0,47	-0,05	-0,50	0,50	-0,05
Aythya nyroca	-0,47	-0,47	-0,28	0,01	-0,34	0,02	0,35	-0,51	-0,32	-0,03	**-0,54***
Netta ryfina	-0,37	-0,43	-0,30	-0,27	-0,36	-0,19	0,05	**-0,54***	-0,17	0,12	**-0,61***
Oxyura leucocephala	-0,17	0,46	-0,33	0,01	0,01	0,12	-0,47	0,32	**0,70****	-0,17	0,28

Note: $0.01 < p < 0.05$ *: Significant; $0.001 < p < 0.01$ **: Highly significant

In the present study, the physico-chemical and bacteriological parameters of the water are correlated with the majority of Anatidae species. The physico-chemical and bacteriological parameters of the water influence four (4) species of Anatidae in the GHT and seven (7) species in the LDO. These parameters are electrical conductivity, dissolved oxygen, nitrite, ammonium, BOD5, THB, TC, FC and FS. These parameters determine the availability of trophic resources for these species.

Waterbirds, particularly Anatidae, feed on aquatic plants and animals such as crustaceans, fish, macroinvertebrates, and amphibians (**Sbiki, 2017**). The availability of these food resources depends on the physico-chemical parameters of the water, variations in which influence their abundance (**Liang et al., 2002**). Good water quality thus favors the presence of biological organisms that are essential to their diet, attracting birds to these aquatic environments (**Patil et al., 2013**). In the Shekha region, bird diversity is positively related to dissolved oxygen and negatively related to salinity, while bird richness decreases with increasing temperature, conductivity, and dissolved oxygen (**Ilyas, 2021**).

In the same study sites, only five physico-chemical parameters water temperature, pH, salinity, nitrate, and nitrite influenced the assemblage of waterbird populations at Garaet Hadj Tahar (p-value$<$0.05) (**Bara.Y et al.,2020**).

Other authors have conducted similar studies to test the influence of water physico-chemical parameters on the activity of West African waterbirds, mainly of the Ardeidae family (**Sossou et al., 2024**). **Manikannan et al (2012)** also tested the influence of environmental parameters such as conductivity, pH, salinity, and water temperature on waterbird activity. The results suggest that the physico-chemical parameters of the water play a vital role in regulating the community of birds and their prey.

Conclusion

The Numidian region of Algeria contains numerous wetlands of international interest, as they play a vital role in maintaining aquatic avifauna and provide winter refuges for a wide variety of waterbirds, particularly Anatidae.

In the present work, we studied the ecology of the wintering population of Anatidae in the two Ramsar sites in Algerian Numidia, Geraet Hadj Tahr (Western Numidia) and Lac des oiseaux (Eastern Numidia). During two consecutive wintering seasons (2021/22 and 2022/23), we collected important information on the community structure, phenology, spatio-temporal distribution, and diurnal behaviour of Anatidae. In addition, during an annual cycle (November 2021 to October 2022), we attempted to establish the physico-chemical and bacteriological quality of the water in the selected wetlands.

In the first section, the wintering of all Anatidae species was observed to assess the ecological significance of the two study wetlands and investigate their ecological role. The findings indicate that both study sites are crucial for wintering.

During the two wintering seasons (2021-22 and 2022-23), more than 300 individuals were seen at GHT and more than 4000 at LDO. This abundance is distributed over fourteen species of Anatidae (12 at Garaet Hadj Tahr and 12 at Lac des Oiseaux) (Mallard *Anas platyrhynchos*, Northern shoveler *Anas clypeata*, Eurasian wigeon *Anas penelope*, Gadwall *Anas strepera*, Eurasian teal *Anas crecca*, Northern pintail *Anas acuta*, Marbled duck *Marmaronetta angustirostris*, Garganey *Spatula querquedula*, Common shelduck *Tadorna tadorna*, Common pochard *Aythya ferina*, Ferruginous duck *Aythya nyroca*, Tufted Duck *Aythya fuligula*, Red-crested Pochard *Netta rufina* and White-headed Duck *Oxyura leucocephala*).

Throughout the study period, most of species (57%) were winter migrants, only three species (21%) were occasional visitors (passing visitors), which included Anas acuta, *Marmaronetta angustirostris*, and *Spatula querquedula*. Additionally, and three species (22%) were winter migrants with sedentary populations, namely Anas platyrhynchos, *Oxyura leucocephala*, and *Aythya nyroca*.

Most of the species identified were classified as species of least concern according to the IUCN (International Union for Conservation of Nature) red list, with 10 species (72%) falling into this category. Two species (14%) were classified as Near Threatened (Ferruginous duck Aythya nyroca and Marbled duck Marmaronetta angustirostris), one species (7%) was classified as Vulnerable (Common pochard *Aythya ferina*) and only one species (7%) was classified as Endangered (White-headed Duck *Oxyura leucocephala*).

According to the Washington Convention (CITES), 6 species are listed in appendix 2 and 3, including one species listed in appendix 2 (White-headed Duck). Only four species of Anatidae are mentioned in Algerian law (decree 12-236 and order of 2012), namely marbled duck, common shelduck, ferruginous duck and white-headed duck. All the species are listed in Annexes 2 and 3 of the Bern Convention, the Bonn Convention, and on the AEWA list.

During our study, a notable change in the dispersal patterns of Anatidae, in particular the Red-crested Pochard (*Netta rufina*), was observed, with a maximum of 55 individuals (25 males and 30 females) returning to and staying longer at Lac des Oiseaux. This anomaly can be attributed to the significant drying up of the wetlands in 2022, as well as to the improved accessibility to food resources due to the drop in water levels in Lac des Oiseaux. This phenomenon is corroborated by the migration of Red-crested Pochards and other Anatidae species to other wetlands when winter conditions returned in February 2023.

A study of the spatio-temporal distribution revealed that Anatidae were mainly located in the north-western part of Garâet Hadj Tahar and in the central part of Bird Lake. Their dispersal has been conditioned mainly by several ecological factors, such as disturbance (RN44 and the village of Lac des oiseaux), the density of vegetation cover, tranquility, and, most importantly, trophic resources (near the north-west bulrush dominated by *Scirpus lacustris,* which is probably where they find most of their food).

During the wintering season, maximum abundance was recorded during the second wintering season, with 311 individuals observed at Garaet Hadj Tahr and 2411 individuals at Lac des Oiseaux. Although the species richness was identical between the two study sites (12 species for each site), their main composition differed. Garaet Hadj Tahr is mainly occupied by diving ducks, such as Common pochard *Aythya ferina* and Ferruginous Duck *Aythya nyroca*, while Lac des Oiseaux is dominated by dabbling ducks, notably Eurasian teal Anas crecca, Eurasian wigeon *Anas Penelope* and Northern shoveler *Anas clypeata*.

Lac des Oiseaux recorded low values for the Shannon-Weaver diversity index (H') and the Pielou equitability index (E), reflecting an imbalance in the abundance of species within the community. This situation is explained by the dominance of two main species, Eurasian teal *Anas crecca* with 1254 individuals and the Eurasian wigeon *Anas Penelope* with 131 individuals, which made a significant contribution to the total abundance.

Regarding its diurnal behavior in these bodies of water, sleeping followed by swimming are the dominant activities, while feeding, grooming, and flying are noted at low levels. However, antagonism and display were only observed to a very limited extent at the end of the wintering period.

In the second part of the work, which was devoted to studying the physicochemical and bacteriological quality of the water based on the determination of certain pollution indicator parameters such as EC, DO, BOD5, NO3-, NO2-, NH4+, PO43-, and the four faecal contamination indicator groups (THB, TC, FC, and FS). All the water samples studied showed results that exceeded the thresholds set by the WHO and Algerian standards, indicating significant pollution.

Spearman's correlation between the abundance of Anatidae species and physico-chemical and bacteriological water parameters shows a significant relationship between the abundance of Anatidae species in the two study sites and most water parameters, such as: electrical conductivity, dissolved oxygen, nitrite, ammonium, BOD5, THB, TC, FC and FS.

Anatidae are important subjects for tracking epidemic diseases in addition to serving as indicators of wetland quality. To conserve Anatidae and maintain biosecurity, it is essential to identify possible distribution sites and influencing factors.

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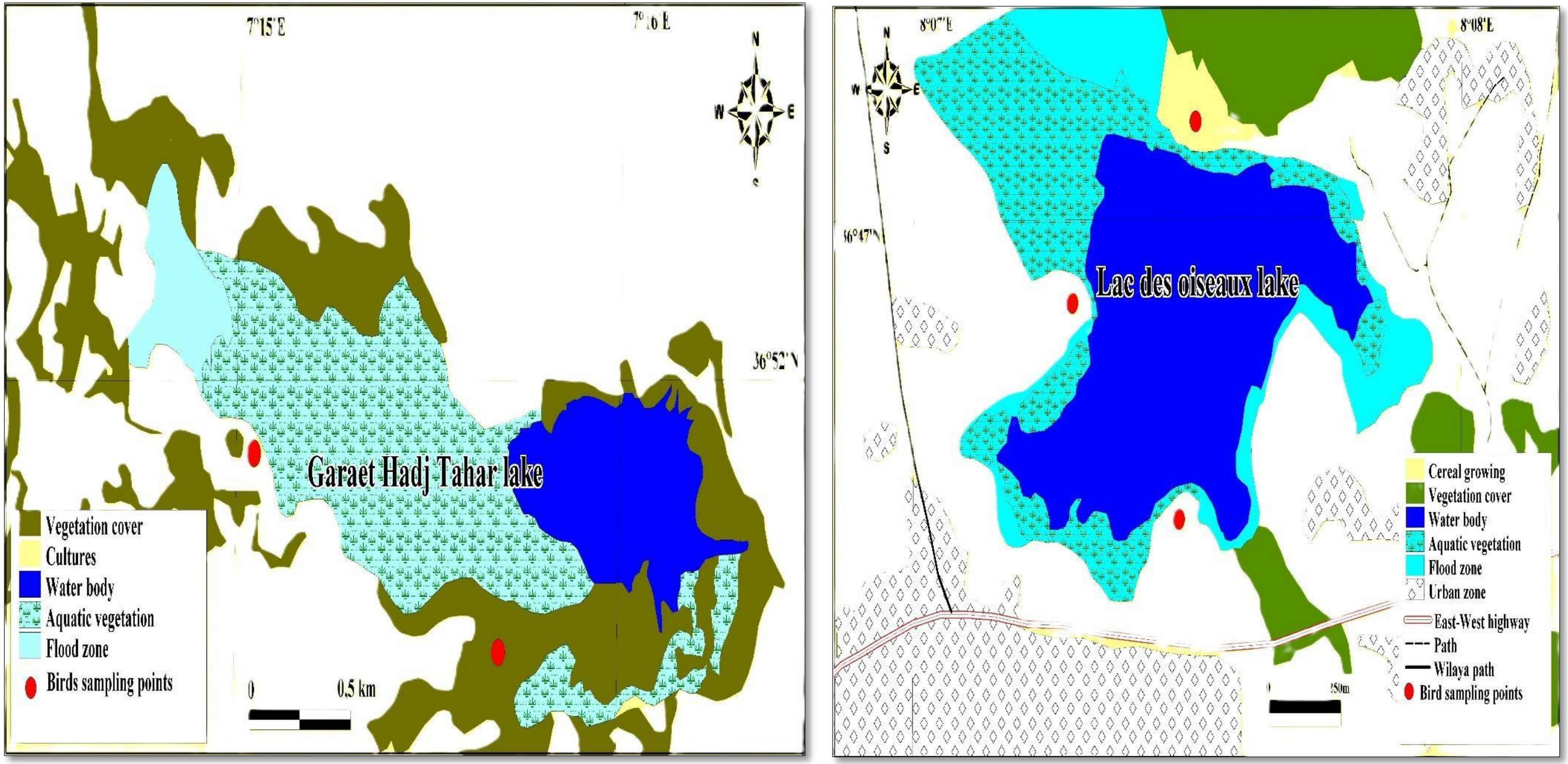
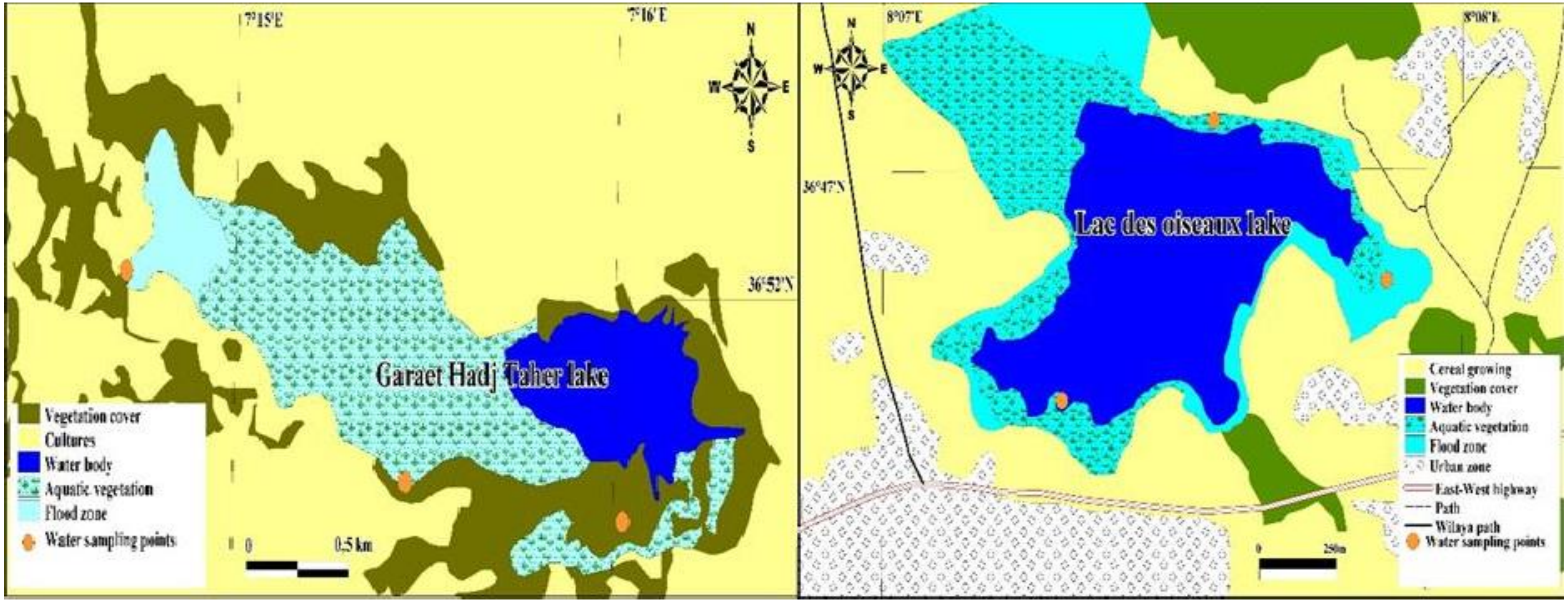
Appendixes

Appendix 01. Location of bird sampling points at Garaet Hadj Taher (right) and Lac des oiseaux (left).



Appendix 02. Location of water sampling points at Garaet Hadj Taher (right) and Lac des oiseaux (left).



Appendix 03: Liquid counting: Mac CRADY method (Mac Grady table)

3 tubes per dilution	
Characteristic number	**Number of cells**
000	0.0
001	0.3
010	0.3
011	0.6
020	0.6
100	0.4
101	0.7
102	1.1
110	0.7
111	1.1
120	1.1
121	1.5
130	1.6
200	0.9
201	1.4
202	2.0
210	1.5
211	2.0
212	3.0
220	2.0
221	3.0
222	3.5
223	4.0
230	3.0
231	3.5
232	4.0
300	2.5
301	4.0
302	6.5
310	4.5
311	7.5
312	11.5
313	16.0

320	**9.5**
321	**15.0**
322	**20.0**
323	**30.0**
330	**25.0**
331	**45.0**
332	**110.0**
333	**140.0**

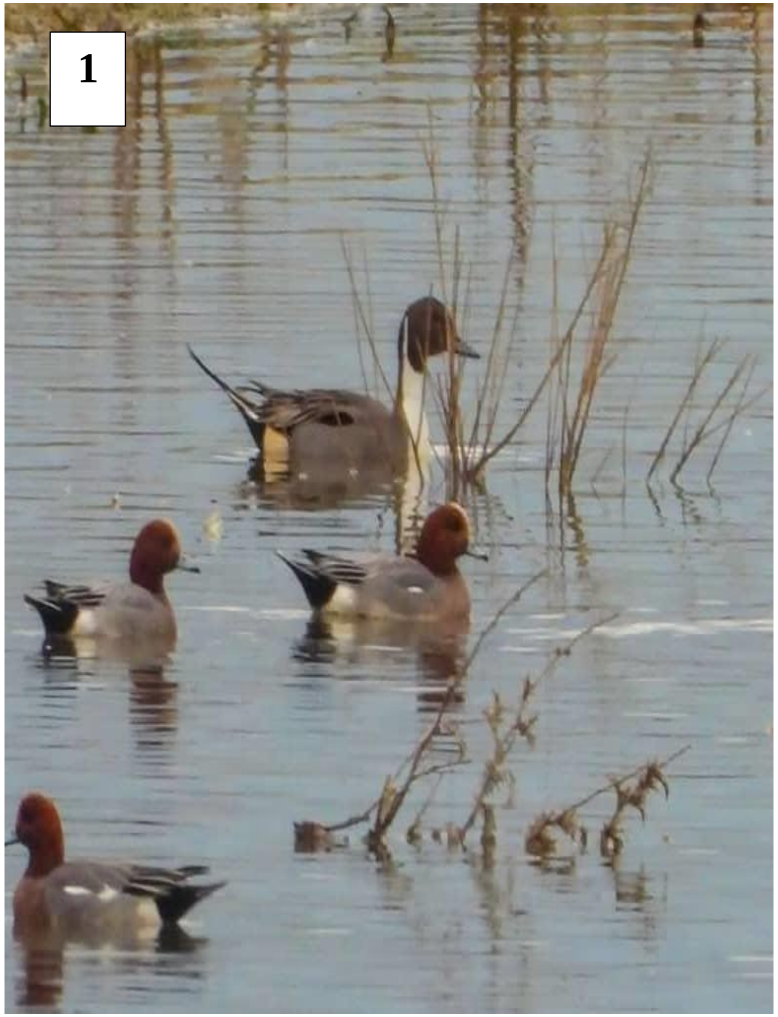
Appendix 04. Effect of abiotic factors on Anatidae abundance in Garaet Hadj Taher

Variables	***EC***	***DO***	***NO^{3-}***	***NO^{2-}***	***NH^{4+}***	***PO_4^{3-}***	***BOD5***	***THB***	***TC***	***FC***	***FS***	***Temperature***	***Precipitation***
Abundance	**-0,88**	-0,58	-0,37	**-0,85**	**-0,75**	-0,42	0,65	-0,52	-0,59	-0,01	**-0,69**	-0,01	**0,75**
EC		0,67	0,60	0,96	0,90	0,15	-0,61	0,43	0,74	0,03	0,58	0,02	-0,92
DO			0,24	0,65	0,70	-0,14	-0,58	0,11	0,98	0,28	0,57	0,70	-0,60
NO^{3-}				0,55	0,77	0,17	-0,14	0,10	0,34	0,15	0,40	-0,07	-0,39
NO^{2-}					0,90	0,32	-0,64	0,31	0,72	0,15	0,51	0,11	-0,89
NH^{4+}						0,19	-0,65	0,32	0,75	0,12	0,69	0,24	-0,78
PO_4^{3-}							-0,05	-0,17	-0,15	0,45	0,05	-0,03	0,05
BOD5								-0,69	-0,50	0,38	-0,80	-0,20	0,73
THB									0,07	-0,84	0,72	-0,44	-0,57
TC										0,32	0,49	0,62	-0,66
FC											-0,32	0,59	0,24
FS												0,17	-0,52
Temperature													0,06

Appendix 05. Effect of abiotic factors on Anatidae abundance in Lac des oiseaux

Variables	*EC*	*DO*	NO^{3-}	NO^{2-}	NH^{4+}	PO_4^{3-}	*BOD5*	*THB*	*TC*	*FC*	*FS*	*Temperature*	*Precipitation*
Abundance	**-0,86**	**-0,83**	0,06	**-0,67**	**-0,87**	-0,59	-0,64	**-0,93**	-0,67	**-0,89**	**-0,69**	-0,42	**0,77**
EC		0,54	-0,42	0,65	0,66	0,39	0,55	0,75	0,69	0,76	0,70	0,63	-0,69
DO			0,36	0,69	0,91	0,78	0,72	0,93	0,76	0,83	0,74	0,08	-0,68
NO^{3-}				-0,24	0,16	0,20	-0,22	0,15	0,01	0,03	-0,07	-0,72	0,26
NO^{2-}					0,83	0,52	0,95	0,78	0,65	0,77	0,62	0,23	-0,82
NH^{4+}						0,68	0,76	0,98	0,64	0,96	0,62	0,08	-0,85
PO_4^{3-}							0,60	0,69	0,77	0,70	0,82	0,36	-0,74
BOD5								0,71	0,66	0,67	0,66	0,30	-0,77
THB									0,72	0,97	0,70	0,18	-0,82
TC										0,64	0,98	0,47	-0,58
FC											0,65	0,25	-0,91
FS												0,59	-0,64
Temperature													-0,46

Appendix 06. Photographic appendix (Photographed by A. BOUSSAHA, 2021/2023). (1) Eurasian wigeon: Anas Penelope ;(2) Mallard : Anas platyrhnchos ; (3) Common shelduck: Tadorna tadorna ; (4) White-headed Duck: Oxyura leucocephala ; (5) Ferruginous duck: Aythya nyroca ; (6) Marbled duck : Marmaronetta angustirostris.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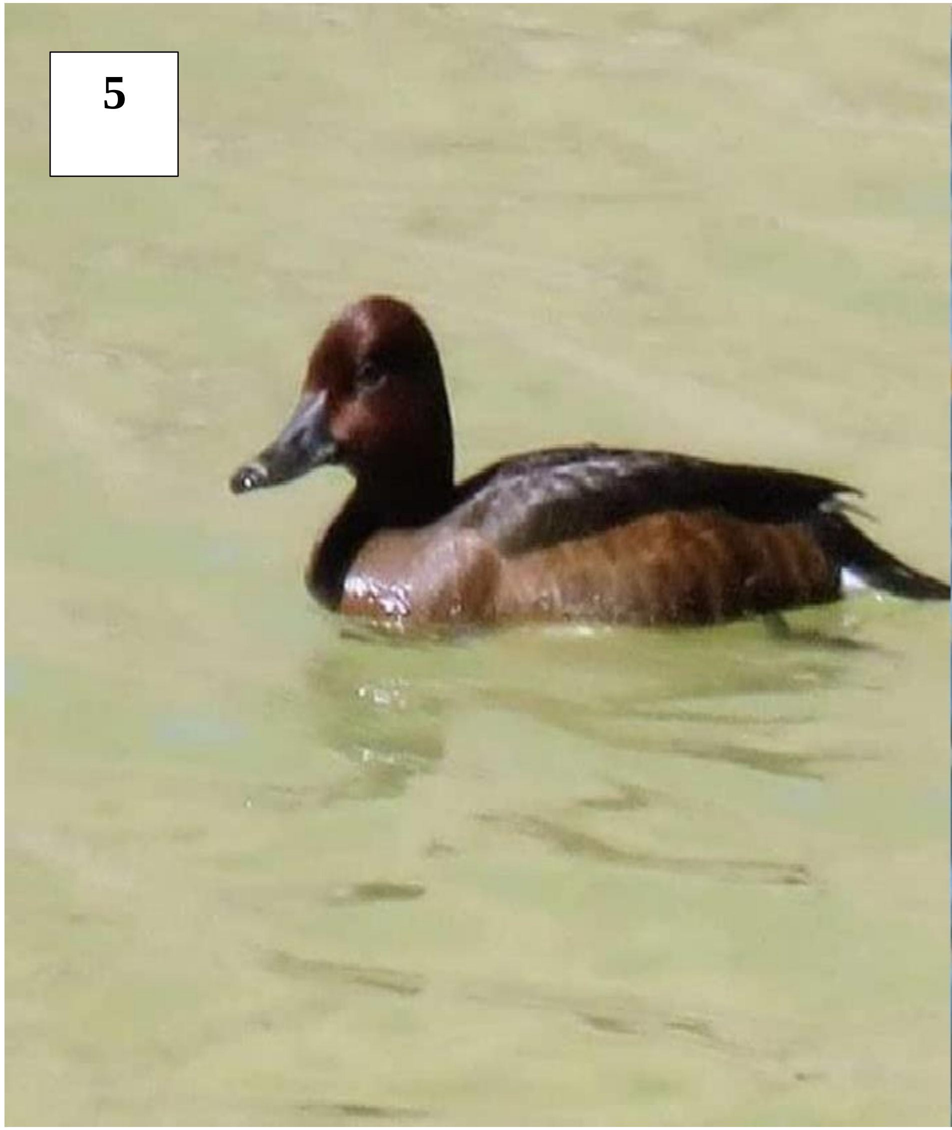
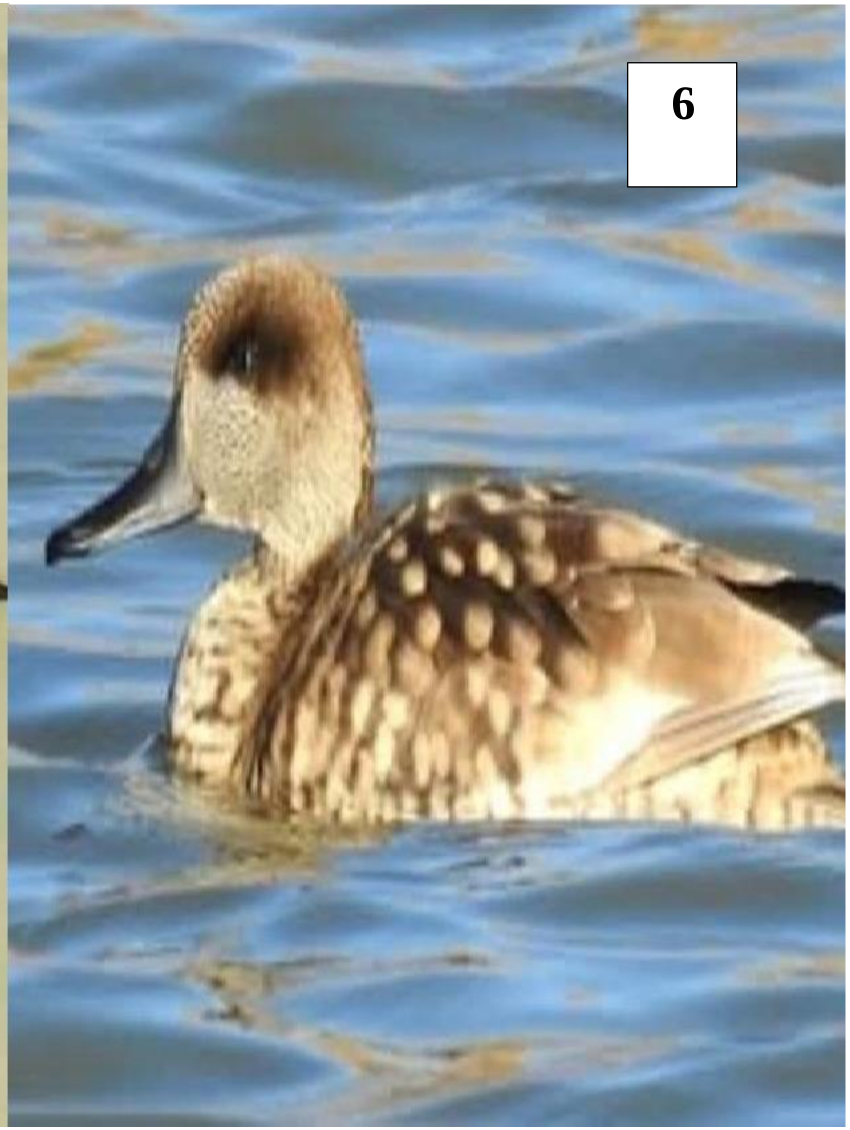

5


6