An-Najah University Journal for Research – A
Natural Sciences

Comparative Study of the Physico-chemical Characteristics of Water in the *Astacus astacus* Habitat (Sidi Mimoun Lake and Ras Elma Astaculture Station) in the Middle Atlas Morocco

Chaima Laiboud[1,2,*], Maryama Hachi[3], Hamza Essabiri[1,2], Touria Hachi[1] , Nezha Aladel[4], Abdelkhalek Zraouti[4], El Hassan Abba[1,*]
Received: 23th Oct. 2024, Accepted: 1th Feb. 2025, Published: ××××

Accepted Manuscript, In press

Abstract. In Morocco, periods of drought and the combined impact of climate change and human activities have had varying degrees of impact on the habitats of freshwater species. The study compares the physico-chemical parameters of water in two artificial sites, Sidi Mimoune Lake and Ras Elma crayfish farm station (Astaculture station) to determine the most favorable environment for raising crayfish (*Astacus astacus*). The study determined key physico-chemical parameters including temperature, T; potential Hydrogen, pH; dissolved oxygen, DO and Electrical conductivity, EC which were (T°: 13.2°C and 13.22°C; pH: 8.1 and 7.99; DO: 9.13 mg/l and 9.18 mg/l and EC: 675.47µs and 671.9µs) at Sidi Mimoune lake and Ras Elma Astaculture Station, respectively. Regarding organic nutrients (ammonium, NH+4; nitrites, NO_2-; nitrates, NO_3- and orthophosphates, $H3PO_42^-$), the average concentrations were (NH+4: 0.14 mg/l and 0.15; mg/l; NO_2-: 0.1 mg/l and 0.24 mg/l; NO_3-: 1.87 mg/l and 1.2 mg/l; $H3PO_42^-$: 0.62 mg/l and 0.65 mg/l). Concerning water hardness, the average values were (total hardness: 39.29 °F and 39.98°F; calcium hardness: 9.49°F and 8.46°F; magnesium hardness: 4.15°F and 4.39°F). The determination of the physico-chemical parameters in the two sites and the assessment of the environmental conditions favorable to crayfish farming are vital for the conservation of *Astacus. astacus* and also for maintaining biodiversity and the ecological balance of freshwater ecosystems in Morocco.

Keywords: water quality, physicochemical parameters, *Astacus astacus*. Middle Atlas, Morocco

Introduction

The freshwater crayfish *Astacus astacus*, also known as the red-clawed crayfish.is a native European freshwater species (1, 2). This species has been introduced outside of Europe, as is the case in Morocco on several occasions during the years 1931, 1932, and 1940 (3) for acclimatization purposes.

Crayfish habitats varies depending on the species and geographical region. They can be found in a variety of aquatic environments (rivers, streams, lakes, etc…). Freshwater crayfish species prefer clear and well-oxygenated waters with rocky bottoms or aquatic vegetation. These habitats provide shelter, hiding places as well as sources of food such as algae, plants, and aquatic invertebrates. According to (4, 5, 6), *A. astacus* prefers depths ranging from 1.5m to 2m and nearly stagnant or low-flow waters, not too cold, with temperatures that can rise in summer to 22°C (7). The combined effect of human activities and climate change leads to habitat degradation and, consequently the decline of populations of this noble species within its original distribution range (2, 8) as well as in Morocco (3). In order to preserve this species and promote its survival, captive breeding can play an important role by providing a controlled environment and conditions suitable for the reproduction and growth of crayfish.

To support indigenous populations of *A. Astacus*, reintroductions and breeding programs have been carried out in some European countries such as Austria, Italy, England, Estonia, Ireland, Czech Rep., Croatia, France, and Portugal (9). In order to rehabilitate this species in the Middle Atlas waters of Morocco, a study characterizing the water quality of an artificial lake (Sidi Mimoune) and at the crayfish farming station (Ras Elma Astaculture Station) was carried out for 12 months (November 2021 - November 2022). The results of this study will enable managers to make decisions regarding the quality of the habitat

1 Khénifra Higher School of Technology. Sultan Moulay Slimane University. Morocco.
2 Sciences and technologies Faculty. Beni Mellal. University of Sultan Moulay Slimane. Morocco.
3 Faculty of sciences, Ibn Tofail University. Kénitra. Morocco.
4 National Center of Hydrobiology and Pisciculture Azrou. Morocco.
* Corresponding authors' emails: e.abba@usms.ma ; chaimaalaiboud@gmail.com

and, consequently, the restocking of Lake Sidi Mimoune with *A. astacus* juveniles produced at the crayfish farming station.

This research is not only vital for the conservation of *Astacus. astacus* but also for maintaining biodiversity and the ecological balance of freshwater ecosystems in Morocco. Understanding the specific habitat requirements and the effects of environmental changes will guide effective management strategies. Additionally, this study aims to foster community engagement and awareness about the importance of preserving local aquatic species, ultimately contributing to the sustainable use of natural resources in the region.

Materials and Methods

Study area

The Sidi Mimoune Lake is located (coordinates: 32°39.6500'N, 5°31.5240'W) in the heart of the village of Sidi Mimoune in the National Park of Ifrane at an altitude of 1460 m and 30 km from Ifrane city and (Figure 1). The site under study is a fenced artificial lake used for sport fishing for rainbow trout. Excess water from the artificial lake flows directly into a watercourse called Oued Sidi Mimoune, characterized by low banks of no more than 0.5 m and a substrate with clay-limestone substrate. On a 200 m stretch of this watercourse, just downstream of the lake, the banks of the watercourse have been landscaped by piling up dry stones. The purpose of these installations and landscaping is to provide shelter for crayfish spat discharged into the lake and the watercourse for monitoring the dynamics of this species. Ras Elma station is located in the Middle Atlas geographical zone, between latitudes north 32°55' and 34°, and longitude 5°05'05"E, at an altitude of 1650 m from Azrou city (9 km) on the road (NR8) connecting Azrou to Ifrane (Figure 2).

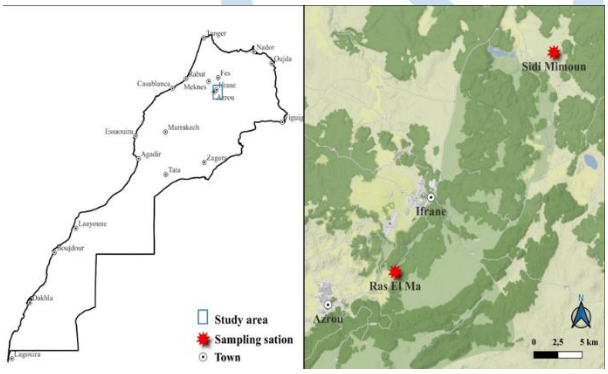

Figure 1: Geographical location of Sidi Mimoune and Ras Elma Astaculture Station.

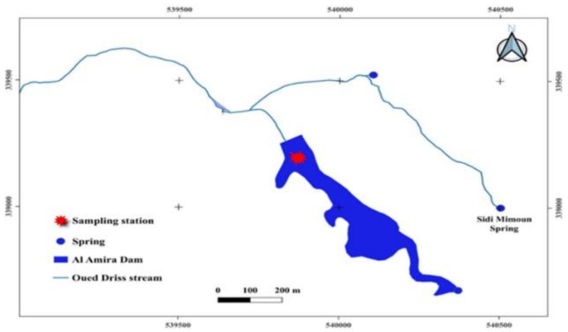

Figure 2: Geographical location of Sidi Mimoune.

Sampling and Collection Conditions

This study was conducted for 12 months, to examine the nocturnal activity of crayfish. Water samples were collected at two distinct sites. First, we collected water at multiple points in the small Sidi Mimoune Lake. However, the results obtained were very similar from one point to another. To simplify the analysis, we decided to focus on a single sampling point located downstream of Sidi Mimoune Lake. This choice also allowed us to use data regarding water quality in the section of the river that serves as a refuge for young crayfish, located 200 meters downstream of the lake. The second sampling site was the Ras Elma Astaculture station. At each of these stations, a one-liter water sample was collected from approximately 50 centimeters below the surface using a polyethylene bottle.

Immediately after conducting in-situ analyses (potential hydrogen, temperature, electrical conductivity, and dissolved oxygen) using a multiparameter instrument (HI 9829 HANNA), the bottles were stored in a cooler at 4°C and transported to the laboratory of the National Center for Hydrobiology and pisciculture in Azrou,where additional analyses (Total hardness, TH, calcium hardness, magnesium hardness, ammonium, nitrites, nitrates, and orthophosphates) were performed within 24 hours after sampling. This methodology, inspired by the work of (10), ensures the quality and reliability of the collected samples.

Nitrate Measurement

For nitrate measurement, 10 ml of the sample to be analyzed is placed in a 60 ml capsule, followed by 1 ml of sodium salicylate solution. The mixture is then evaporated in an oven set between 75 °C and 80 °C and allowed to cool. The residue is dissolved in 2 ml of concentrated sulfuric acid and allowed to rest for 10 minutes. Then, 15 ml of distilled water and 15 ml of sodium hydroxide and sodium potassium tartrate solution are added, developing a yellow color in the presence of nitrates. A control is prepared with 10 ml of distilled water. Measurements are then taken using a spectrometer at a wavelength of 415 nm, with the yellow color being proportional to the nitrate concentration.

Nitrite Measurement

For nitrite measurement, 50 ml of the sample is placed in a volumetric flask. 1 ml of diazotation reagent is added, and the mixture is homogenized. After a waiting time of 10 minutes to stabilize the reaction, readings are taken using a spectrophotometer set to 537 nm.

Ammonium Measurement

For ammonium measurement, 20 ml of the sample is placed in a 100 ml conical flask. 1 ml of sodium nitroprusside and phenol solution is added, followed by 1 ml of chlorinated solution. After mixing, the mixture is kept in the dark for at least 6 hours. A control is prepared with 20 ml of distilled water. Readings are taken using a spectrometer at a wavelength of 630 nm.

Orthophosphate Measurement

For orthophosphate, 20 ml of the sample is placed in a 25 ml volumetric flask. 1 ml of ascorbic acid is added, and the mixture is stirred and allowed to rest for 30 minutes to develop a blue color. A control is prepared in the same way with 20 ml of distilled water. Readings are taken using a spectrophotometer at a wavelength of 700 or 880 nm.

Hardness Measurement

The measurement of calcium and magnesium concentrations is performed by titration with an EDTA solution. The titration is carried out until an equivalence point is reached, where all calcium and magnesium ions are complexed by the EDTA. The use of an indicator, such as Eriochrome T black or Calcon indicator, allows for the visualization of this point through a color change.

The concentration of calcium and magnesium ions is calculated based on the volume of EDTA used:

For a 100 ml sample:

$[Ca^{2+}]=V\times 2$in °F

$[Ca^{2+}]=V\times 8$in mg/L

$[Ca^{2+}]=V\times 0.4$meq/L

Where V represents the volume of EDTA added.

The total concentration of calcium and magnesium is expressed in milliequivalents per liter:

$TH=1000V_2\times(C\times V_1)$ in meq/L

$TH=1000V_2\times(C\times V_1)\times 5$in °F

Where V_1 is the volume in ml of the EDTA solution with concentration C in meq/L and V_2 is the volume of the water sample to be analyzed.

We selected these parameters because they are crucial for ensuring the well-being of crayfish and other species (11, 12, 13) in their aquatic environment. Each parameter plays a specific role in their health and development (3, 14).

Descriptive statistics (means, standard deviations) were obtained and plotted using Excel.

Results and Discussion

The data presented in this study are from two areas (Sidi Mimoune and the Ras Elma Astaculture Station). To study the changes of physicochemical parameters, these samples were collected monthly over the course of a year. Table 1 shows the values of different physicochemical parameters (Min, Max and Average) obtained over 12 months at different stations.

Temperature

Water temperature is an ecological factor that has significant ecological repercussions (13, 15). It can influence viscosity, density, gas solubility in water, dissociation of dissolved salts, as well as chemical and biochemical reactions, and the development and growth of organisms living in water, particularly microorganisms (16). Understanding water temperature is crucial because it is an important ecological factor (17).

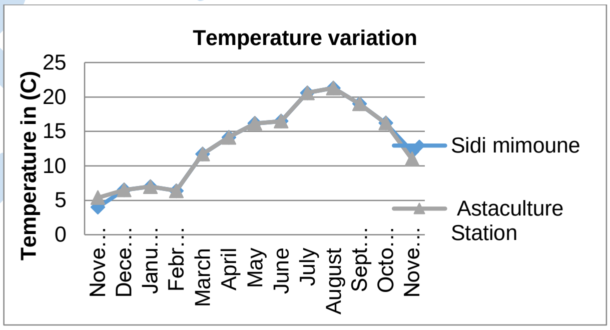

Figure 3: Spatiotemporal variation in temperature Values at Sidi Mimoune Lake and Ras Elma Astaculture Station

The results obtained during this experiment in the studied areas (Sidi Mimoune and the Ras Elma Astaculture Station) (Figure 3) show that the water temperature falls within the standards for astaculture waters (18). The maximum temperature measured at Sidi Mimoune is 21.3 °C, which was also observed at the Ras Elma Astaculture Station in August. In contrast, the minimum temperature is 4 °C at Sidi Mimoune and 5.4 °C at the Ras Elma Astaculture Station. Consequently, these temperatures pose no risk to astaculture.

Potential Hydrogen

The water pH measures the concentration of H+ protons in the water. It reflects the stability of the equilibrium established between different forms of carbonic acid and is linked to the buffer system developed by carbonates and bicarbonates (19). The average pH recorded during this study is 8.03 at Sidi Mimoune and 7.98 at the Ras Elma Astaculture Station (Figure

4). These values indicate that the water in the studied stations is slightly alkaline, falling within the standards for cold waters. According to (20), pH stability is crucial in astaculture; the ideal pH range for optimal functioning of aquatic organisms is 6, 5 to 9. Indeed, water pH can play a significant role in the well-being and health of crayfish. However, it is worth noting that different crayfish species can tolerate and prefer different pH values. In general, most freshwater crayfish prefer a pH range between 6.2 and 8.5 (21, 22, 23).

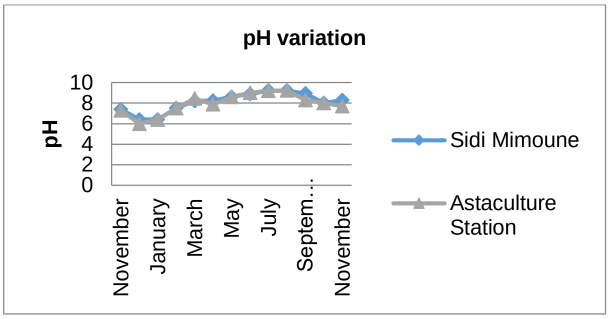

Figure 4: Spatiotemporal variation of pH Values at Sidi Mimoune Lake and Ras Elma Astaculture Station

Dissolved Oxygen

The concentration of dissolved oxygen in water is a crucial factor for living organisms as it contributes to the majority of chemical and biological processes. The recorded minimum is 8.8 mg/l, and the maximum is 10.68 mg/l at Sidi Mimoune, ranging from 8.6 mg/l to 10.65 mg/l at the Ras Elma Astaculture Station (Figure 5). These values fall within the standards for astaculture water. *Astacus astacus* has a relatively high oxygen demand, requiring levels between 5.2 mg/l and 12 mg/l for proper development (3). An optimal dissolved oxygen content of 7 mg/L is reported (16). According to (24), stress can be induced with exposures of several days to levels below 5 mg/L.

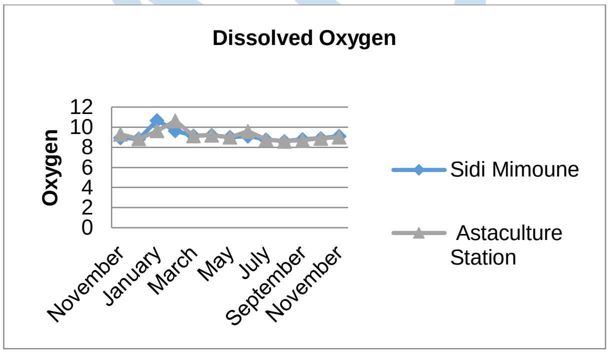

Figure 5: Spatiotemporal variation of Dissolved Oxygen Values at Sidi Mimoune Lake and Ras Elma Astaculture Station

Electrical Conductivity (µs/cm)

Electrical conductivity serves as one of the means to validate the physicochemical analysis of water. Indeed, contrasting environmental measurements can reveal the existence of polluted areas, mixing zones, or infiltration areas (25).The conductivity measured in both zones (Sidi Mimoune and Ras Elma Astaculture Station) for Sidi Mimoune ranged from 512 to 783µs/cm, and for the Ras Elma Astaculture Station, it ranged from 600 to 783 µs/cm (Figure 6). It is observed that electrical conductivity is higher during the dry season compared to the rainy season. This could be attributed to a dilution phenomenon due to the increase in water volume (26). These values are characterized by low natural mineralization, falling within the standards and posing no risk to crayfish life as they do not exceed the Moroccan standard for surface water (2700 µS/cm).

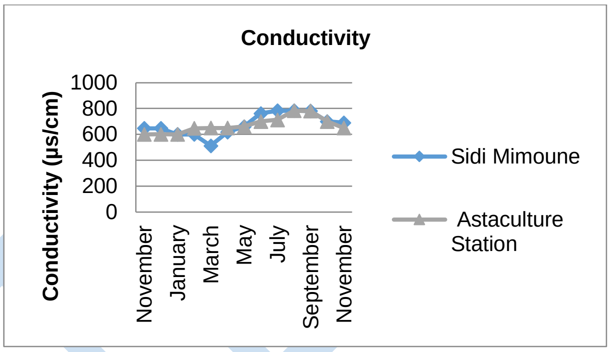

Figure 6: Spatiotemporal variation of Conductivity Values at Sidi Mimoune Lake and and Ras Elma Astaculture Station

Nitrates

Nitrates represent the final stage of nitrogen oxidation and constitute the highest oxidation state of nitrogen present in water. Their concentrations in natural waters typically range from 1 to 10 mg/l (27). Nitrates, which provide nitrogen to plants, can pose significant problems when present in excess. Indeed, excessive nitrate levels can have various negative impacts on aquatic species, including delayed maturation and deterioration of water quality. In natural environments, nitrates are major contributors to the eutrophication of aquatic ecosystems. For Sidi Mimoune the maximum nitrate levels were recorded in February and April (3.9 mg/l and 7.8 mg/l, respectively). For the Ras Elma Astaculture Station, the maximum nitrate content was recorded in April at 3.9 mg/l (Figure 7).

This may be attributed, in part, to the leaching of fertilizers used in agriculture, and on the other hand, it may result from the decomposition of organic matter through bacterial oxidation of nitrites (28). Throughout the experiment, all these values remain below 13 mg/l for astaculture water (29). This indicates that the water under study is not subject to a risk of nitrate pollution.

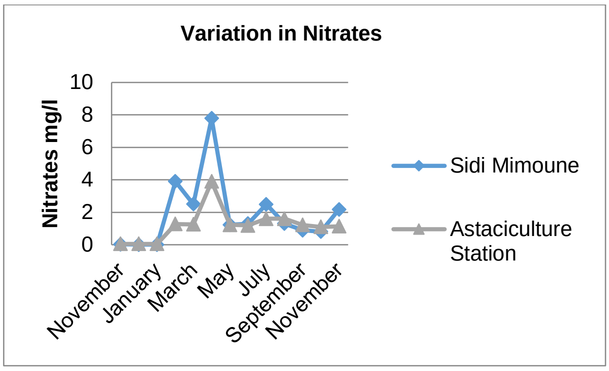

Figure 7: Spatiotemporal Variation of Nitrate Values at Sidi Mimoune Lake and Ras Elma Astaculture Station

Nitrites

Nitrite levels (Figure. 8) are relatively stable at both sites. The lowest value was recorded at Sidi Mimoune, at 0.001 mg/l, and the highest value was recorded at the Ras Elma Astaculture Station, at 1.6 mg/l. The increase in nitrite content in January at the Ras Elma Astaculture Station may be linked to the bacterial oxidation of ammonia (30), or the decomposition of organic matter from crayfish in the breeding basins at the Ras Elma Astaculture Station. However, the nitrite values obtained during the experiment remain below the standard of 0.5 mg/l according to the Moroccan standard (Surface water quality standards Decree nº 2-97-787 r.No. 2028-03 dated November 5, 2003.). This indicates that the water under study is not subject to a risk of nitrite pollution.

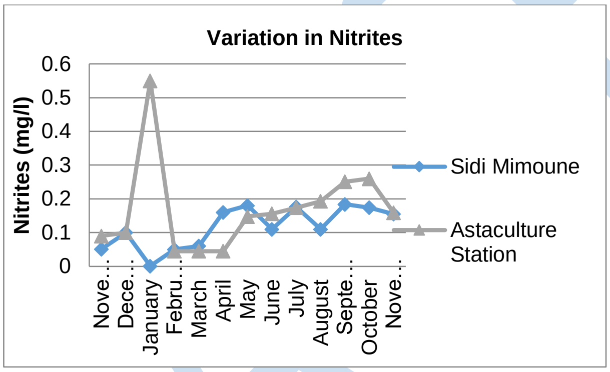

Figure 8: Spatiotemporal Variation of Nitrite Values at Sidi Mimoune Lake and Ras Elma Astaculture Station

Ammoniacal nitrogen

Ammoniacal nitrogen is one of the components of the complex nitrogen cycle in its primitive state. It is a gas soluble in water and exists in small proportions, less than 0.1 mg/l of ammoniacal nitrogen in natural waters (27). It serves as a good indicator of river pollution from urban effluents. In surface waters, it originates from nitrogenous organic matter and gas exchange between water and the atmosphere (31). Ammonium is the product of the final reduction of nitrogenous organic substances and inorganic matter in waters and soils. It also comes from the excretion of living organisms and the reduction and biodegradation of waste, not to mention contributions from domestic, industrial, and agricultural sources. Ammonium ions result from the degradation of animal proteins (nitrogen cycle), domestic effluents (urea), and urban runoff(32, 33). Figure 9 shows various results obtained in different stations.

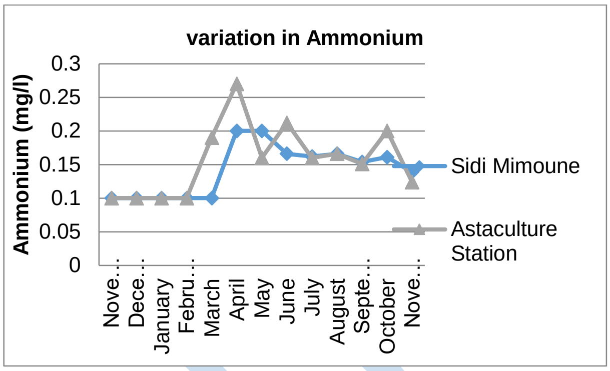

Figure 9: Spatiotemporal variation of Ammonium Values at Sidi Mimoune Lake and Ras Elma Astaculture Station

The ammonium levels recorded during this study for the Sidi Mimoune station vary between 0.1 mg/l and 0.166 mg/l, and for the Ras Elma Astaculture Station, the concentration ranged from 0.1 mg/l to 0.27 mg/l. This increase can be explained by the contact between waste or urine with these water points or may be due to leaching. The concentrations obtained do not present any risk for the biology of the crayfish since the concentration of dissolved oxygen is high, which allows the water to pass into the nitrate form.

Orthophosphates

(Figure 10) represents the variation in orthophosphates in the water bodies of the two study areas over the course of a year (Sidi Mimoun, Ras Elma Astaculture Station). According to the results obtained, orthophosphate levels vary almost identically in both stations, with concentrations ranging between 0.31 mg/l and 0.817 mg/l in Sidi Mimoun and between 0.43 mg/l and 0.9 mg/l in the Ras Elma Astaculture Station. An increase is observed during the dry season. This availability of orthophosphates may be related to detergent discharges into these waters.

The concentrations generally recorded remain below the Moroccan standard set at 1 mg/L. These values classify these waters in the middle-quality class (27).

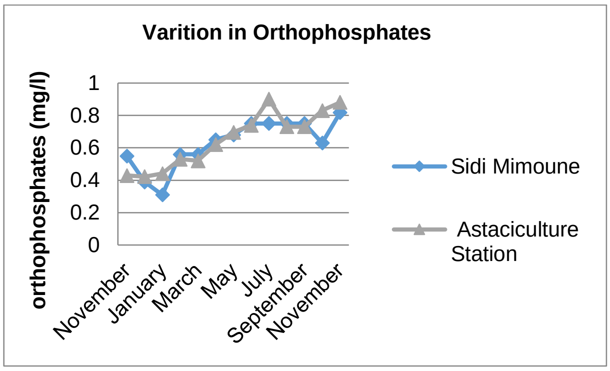

Figure 10: Spatiotemporal variation of Orthophosphate Values at Sidi Mimoune Lake and Ras Elma Astaculture Station

Hardness

Figures 11 and 12 represent the various concentrations obtained for calcium and magnesium in all the stations studied. These concentrations vary between 15.6 °F recorded in Sidi Mimoune in February and 4.5 °F recorded in Ras Elma in September for calcium. As for magnesium, the highest concentration was recorded at the same station, Ras Elma, at 8.02 °F, and the lowest value was also recorded in Sidi Mimoune, at 1.313 °F in February. These high concentrations indicate the intervention of gypsum in enriching the water with calcium and magnesium according to the study (34).

The water bodies of the Ras Elma Astaculture Station are characterized by high total hardness (Figure 13), with a value of 48°F. These high values could be explained by the nature of the sedimentary rocks crossed by the water, rich in limestone and runoff. The lowest values are recorded in Sidi Mimoune, at 29.18°F, which could be explained by the consumption of calcium and magnesium by living organisms in the water. These findings indicate that water bodies are generally hard water. These elements are essential for the development of crayfish, especially for the construction of their shells (35).

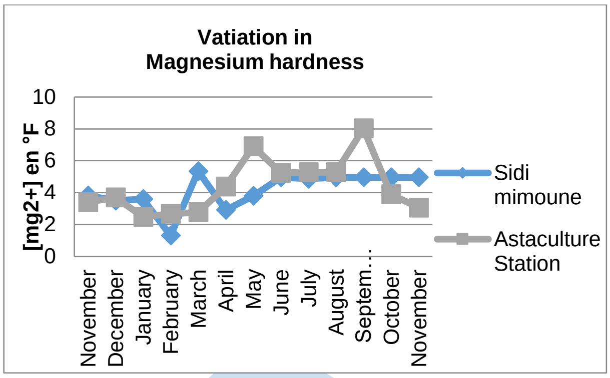

Figure 12: Variation of Magnesium Hardness Values at Sidi Mimoune Lake and Ras Elma Astaculture Station

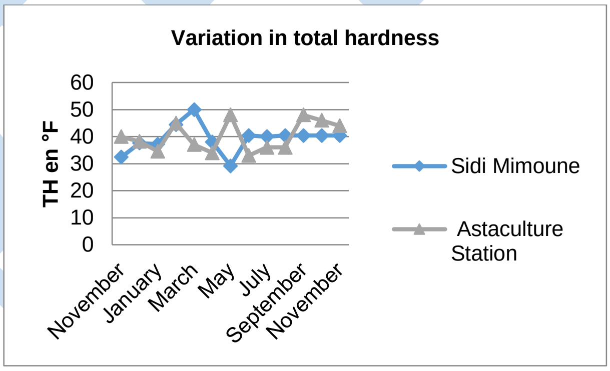

Figure 13: Variation of Total Hardness Values at Sidi Mimoune Lake and Ras Elma Astaculture Stati

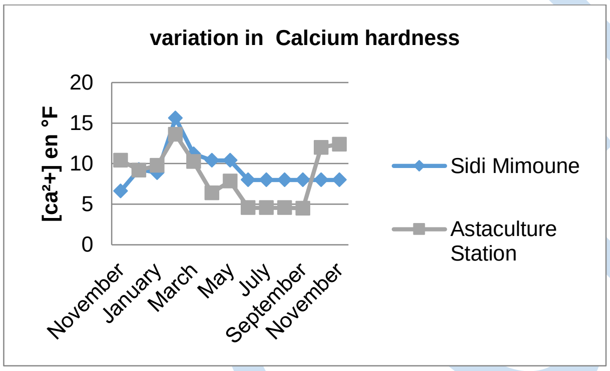

Figure 11: Variation of Calcium Hardness Values at Sidi Mimoune Lake and Ras Elma Astaculture Station

Water quality

Table (1) presents the average results of the physico-chemical parameters measured in Lake Sidi Mimoune and Ras Elma Astaculture Station, along with the corresponding Moroccan Water Quality Standards to assess the quality of these waters. By comparing the results with the Moroccan Standards Decree nº 2-97-787 r, we notice that the parameter values in both sites are well within the acceptable limits. The water of Lake Sidi Mimoune and Ras Elma Astaculture Station is therefore of excellent quality. Corresponding to Class 1 according to Moroccan Standards Decree nº 2-97-787 r. This reflects a healthy aquatic environment that is conducive to the life of aquatic organisms in these two sites.

Throughout the year, water quality can vary considerably due to factors such as runoff, erosion, precipitation, and changes in stream flow, which have a significant impact. During low-flow periods, concentrations of certain substances in water may be much higher than during the rest of the year. Conversely, during floods, some substances are diluted in a larger volume of water, while others, reaching the water source through runoff, are found in higher concentrations. Therefore, the concentration of naturally occurring insoluble substances due to erosion increases with flow, including elements of geological origin (iron, aluminum, etc.) and associated substances (such as phosphates). Furthermore, concentrations of various pollutants regularly discharged into water bodies decrease as runoff increases. Hence, a thorough understanding of the hydrological regime of the water source is crucial for the accurate interpretation of water quality data.

Discussion

Water quality is characterized by the various substances it contains, their quantities, and their effects on the ecosystem. The concentration of these different elements determines water quality and indicates its suitability for specific uses (36).

Indeed, water quality is a determining factor for the survival of crayfish. In our study, the temperatures measured at the two sites ranged from a maximum of 21.3 °C to a minimum of 4 °C at Sidi Mimoune, and from a maximum of 21.3 °C to a minimum of 5.4 °C at the Ras Elma Astaculture Station. Regarding dissolved oxygen, the recorded values varied from 8.8 mg/l to 10.68 mg/l at Sidi Mimoune and from 8.6 mg/l to 10.65 mg/l at the Ras Elma Astaculture Station. For average pH, the measured values were 8.1 at Sidi Mimoune and 7.99 at the Ras Elma Astaculture Station, which are slightly alkaline and fall within the ideal range for most crayfish, which prefer a pH between 6.2 and 8.5 (21, 22, 23).

As for dissolved oxygen, the recorded values varied from 8.8 mg/l to 10.68 mg/l at Sidi Mimoune and from 8.6 mg/l to 10.65 mg/l at the Ras Elma Astaculture Station. These levels comply with the requirements of *Astacus astacus*, which needs oxygen concentrations between 5.2 mg/l and 12 mg/l for optimal development (3). This indicates that both sites provide an adequate environment for the life of crayfish. Electrical conductivity ranged from 512 to 783 µS/cm at Sidi Mimoune and from 600 to 783 µS/cm at the Ras Elma Astaculture Station, remaining well below the Moroccan standard for surface waters (2700 µS/cm).

Regarding nutrients, nitrate and nitrite levels remained below pollution thresholds, with maximum nitrate concentrations of 7.8 mg/l at Sidi Mimoune and 3.9 mg/l at the Ras Elma Astaculture Station. Nitrite levels, while slightly higher at the Ras Elma Astaculture station with an average concentration of 0.24 mg/l compared to 0.1 mg/l at Ras Elma Astaculture Station, also remain below the standard of 0.5 mg/l, indicating an absence of nitrite pollution risk.

Ammonium and orthophosphate concentrations are also within acceptable limits, with values not exceeding 1 mg/l for orthophosphates, classifying these waters as intermediate quality (27). Indeed, calcium and magnesium concentrations, essential for crayfish development, are adequate at both sites, with values indicating generally hard water, favorable for the construction of their shells (35).

The results show that both sites, Sidi Mimoune and the Ras Elma Astaculture Station, present physico-chemical conditions favorable to the life of red-legged crayfish. The measured parameters comply with water quality standards according to Moroccan decree no. 2-97-787 r., indicating that there is no risk to the rehabilitation and survival of red-legged crayfish *(Astacus astacus*) in these aquatic environments.

Conclusion

The reproduction and development of aquatic species depend on the quality of the water in which they live. In general, water quality is assessed based on quantitative and qualitative standards. This study evaluated the physical-chemical quality of water in two sites, Sidi Mimoune and the Ras Elma Astaculture Station. The analysis of results, including temperature, dissolved oxygen, pH, nitrites, nitrates, calcium hardness, magnesium hardness, orthophosphates, and ammonium, revealed that the waters in the monitored sites fall within the normal range for astaculture waters during both campaigns, according Moroccan standard (to the Joint Ministerial Decree, Surface water quality standards Decree nº 2-97-787 r. No. 2028-03 of November 5, 2003). The water bodies at Sidi Mimoune and the Ras Elma Astaculture Station provide suitable habitats for crayfish survival. The study also highlighted the importance of using analyses in planning and monitoring water quality in a region for the rehabilitation of endangered species.

Ethics approval and consent to participate

Not applicable

Consent for publication

Not applicable

Availability of data and materials

The data, cases and materials that support the findings are available in the study manuscript. Historical information and case studies included in this study were acquired from various publications and scholarly sources. The manuscript is supported with the relevant citations to the referenced materials.

Author's contribution

Laiboud chaima and Abba El Hassan. Conceptualization; data curation; formal analysis; investigation; methodology; writing original draft; writing, review and editing. Hachi touria: data curation; investigation; methodology. Hachi Maryama writing original draft; writing—review and editing. Essabiri Hamza writing—review and editing. N Aladel ,H El idrissi , A. Zeraouti. engineers from the astaculture and fish-farming station: support during various field trips.

Funding

No funding for this work

Conflicts of interest

No conflict of interest between different authors

Acknowledgements

The authors would like to thank the managers of the National center of Hydrobiology and Pisciculture at Azrou and the Director of the Higher School of Technology -Khénifra for allowing us to carry out the various analyses.

References

1) Souty-Grosset,C., Holdich, D.M., Noël P.Y. , and al. (Eds.), Atlas of Crayfish in Europe, Muséum national d'Historie naturelle, Paris, France (2006).

2) Edsman, L., Füreder, L., Gherardi, F., Souty-Grosset C (2010). Astacus astacus. IUCN 2013. IUCN Red List of Threatened Species. Version 2013.2 (Available at: http://www.iucnredlist.org).

3) Benyahia,M., 2003. Etude de la variabilité morphométrique, du cycle biologique, des glandes cementaires et de leur secretion chez Astacus astacus (LINNE 1758) au Maroc.

4) Aiken D.E., 1968. Orconectes virilis survival in a région severe winter conditions. Can. J. Zool. 46, (2) : 207 - 211.

5) Clement J.L. et Durecu A. 1978. Current data on astaciculture and location 6) Cukerzis J. 1984. The biology of the crayfish Astacus astacus L. I.N.R.A publications. Versailles. 313p.

7) Kouba A., Kanta J., Buřič M, Policar O., and Kozák P., (2010).The Effect of Water Temperature on the Number of Moults and Growth of Juvenile Noble Crayfish, Astacus astacus (Linnaeus). International Association of Astacology Freshwater Crayfish 17:37–41, 2010.

8) Gherardi F. 2011. Public perception of invasive alien species in Mediterranean Europe. In: Rotherham ID, Lambert R (eds) Invasive and introduced plants and animals: human perceptions, attitudes and approaches to management, Earthscan, London, UK (in press).

9) Kouba A., Kozák P., Füreder L., Reynolds J. and Souty-Grosset C. 2011.Current conservation strategies for European crayfish .

10) Serge Hébert and al Qualité de l'eau du Saint-Laurent de 2000 à 2014 : paramètres classiques, pesticides et contaminants émergents. Le Naturaliste canadien 140(2):26 DOI:10.7202/1036500ar;

11) Abba E.H., Hachi T., Bahouar L., Benkadour R., Idrissi I., Chibani A., Zarrouk A., (2023). Assessment of the impact of the water quality on ichthyological biodiversity in Morocco: Case of Oum Er Rabia River, Materials Today: Proceedings, 72, 3927-3933.

12) Abba E.H, M'barki M., El Yaacoubi A., Cherroud S., Ainane T., Khaffou M., (2021), Comparative study of zootechnical parameters between two species of salmonids,O1ncorhynchus aguabonita and Oncorhynchus mykiss. Egypt, 25, 741-751.

13) Abba, H., Nassali H, Benabid M, El Ibaoui H, Chillasse L, Physicochemical approach to the waters of lake dayet Aoua (Morocco) 2012. Journal of Applied Biosciences 58: 4262– 4270.

14) Arrignon J. L'écrevisse et son élevage. Collection Aquaculture-pisciculture, Édition tec&doc. Paris ; 2004. 281p.

15) Zerkani, S., Abba, E. H., Hachi, T., & Zine, N.-E. 2023. Assessment of heavy metal and organic pollution of a salmonid ecosystem: Case of the Oued Guigou River, Middle Atlas (Morocco). Lakes & Reservoirs: Research & Management, 28, e12430. https://doi.org/10.1111/lre.12430.

16) World Health Organization, WHO. Guidelines for Drinking Water Quality, vols. 1 and 2. World Health Organization, Geneva, Switzerland. 1987.

17) Benaabidate L. 2000. Hydrological characterization of the Sebou watershed: hydrogeology, water quality and geochemistry of thermal waters. Thesis Doc. Es-sc, F.S.T. Fes, 250 p.

18) Synusie-Eau, 2003. Crayfish and water quality in Franche-Comté. 17 p.

19) Himmi N., Fekhaoui M., Foutlane A., Bourchic H., El Maroufy M., Benazzout T., Hasnaoui M. (2003). Relazione plankton-parametri fisici chimici in un bacino dimaturazione (laguna mista beni slimane – Morocco. Rivesta di idrobiologia. Universitadegli studi di Perugia, departemento di biologia animale ed ecologia laboratoire di idrobiologia "G.B. Grassi", 110– 111p.

20) Boyd C.E. Water Quality, An Introduction, Second Edition. Springer International Publishing Switzerland ; 2015. 357p. DOI : 10.1007/978-3-319-17446-4.

21) Andre M., 1960. Les écrevisses françaises.Ed. P. Lechevalier, Paris, 293 p.

22) Roqueplo C., Amato G., Arrignon J., Attard J., Chaisemartin C., Chartier L., Clement J.L., Durecu A., Daguerre De Hureaux N., Farges G., Laurent P.J., Vey A., Vigneux D., Vigneux E., 1984. Austropotamobius pallipes Study by the French Association of Limnology, Science, Technique and Development.

23) Arrignon, J. 1996. French whitewater, brackish pond and marine fish farming, 123, 34 p.

24) Westman K. 1985. Effect of habitat modification on freshwater crayfish.In Alabaster J.S. (ed), Habitat modification and freshwater fischeries, Butterworths, London, p 245-255.

25) Ghazali, D. and Zaid, A. Study of the physico-chemical and bacteriological quality of water from the Ain Salama-Jerri spring (Meknes region, Morocco). Larhyss Journal, ISSN 1112-3680, n° 12, pp. 25-36. 2013.

26) Ngabirano, H., Byamugisha D., Ntambi E. 2016.Effects of Seasonal Variations in Physical Parameters on Quality of Gravity Flow Water in Kyanamira Sub-County, Kabale District, Uganda.DOI: 10.4236/jwarp.2016.813099.

27) Elhammoumi T., Elatmani A. , Lakhlifi M. , Hamdaoui. F., Elborjy A., Sibari M., Benchikh M., Achhar A. , Elbourkadi1 A., Ztit G. Belghyti D., EL KHARRIM K. 2017. Assessment of the waters physicochemical quality of the middle Sebouriver at Kariat Bamohamed (Fez-Morocco). Journal of Water Sciences & Environment Technologies ISSN: 2508-9250, JOWSET, 2017(02), N°02, 193-199.

28) Abboudi A., Tabyaoui H., EL Hamichi F., Benaabidate L., Lahrach A. 2014. Study of the physico-chemical quality and metal contamination of surface waters in the Guigou watershed, Morocco . European Scientific Journal, August 2014, Edition vol. 10 n° 23, ISSN 1857 –7881 (Print) e – IISSN 1857-7431,84 – 94.

29) Roqueplo C., Daguerre de Hurreaux N., 1983.Studies of natural crayfish (Austropotamobius pallipes Lereboullet) populations in southwest France. First approach to a repopulation methodology. Study n°14 by CEMAGREF 177Moroccan standard (Surface water quality standards Decree nº 2-97-787 r.No. 2028-03 dated November 5, 2003.

30) Bengoumi M, Traoure A, Bouchriti N, Bengoumi D et El Haraiki A 2004 Qualité de l'eau en aviculture. Revue trimestrielle d'information scientifique et technique 3 (1) : 5-29.

31) Chapman D., Kimstach V. Selection of water quality variables.Water assessments : a guide to the use of biota, sediments and water in environment monitoring, Chapman edition, 2nd ed. E & FN Spon, London, (1996) 59-126.

32) Udert K.M., Larsen T., Biébow A.M,. Gujer W. 2003. Urea hydrolysis and precipitation Dynamics in a urine-collecting system. Water Res., 37: 2571- 2582.

33) Bonté S.L., Pons M., Potier O., Rocklin P.2008. Relation between Conductivity and Ion Contentt in Urban Wastewater. Journal of Water Science, 21(4): 429- 438.

34) Achour F., 2008. Characterization of organic matter in household waste. Search for stability indicators. Thesis. L'Institut National des Sciences Appliquées de LyonDissociation Energies of the M-O2 Bond: A Key Step in Water Splitting Reactions. ACS Omega. 2022;7(24):20800-8.

35) Lyons R., Kelly -Quinn M., 2003. An investigation into the disappearance of Austropotamobius pallipes (Lereboullet) populations in the headwaters of the Nore River, Ireland, and correlationto water quality.Bull. Fr. Pêche Piscic. 370/371, p 139-150.

36) Luvhimbi N., Tshitangano T.G., Mabunda J.T. et al. 2022. Water quality assessment and evaluation of human health risk of drinking water from source to point of use at Thulamela municipality, Limpopo Province. Sci Rep 12, 6059 (2022). https://doi.org/10.1038/s41598-022-10092-4.

.

Table 1: Characteristics and quality of water from Sidi Mimoune Lake and the Ras Elma Astaculture Station according to Moroccan Quality Standards

Stations / Parameters		Sidi Mimoune Lake				Astaculture station				MQS	Water Quality
	Unit	Min	Mean	Max	standard deviation	Min	Mean	Max	standard deviation		
T°	°C	4	13.2	21,3	5,782	5,4	13.22	21,3	5,634	<20	Class 1
pH	-	6,4	8.1	9,22	0,947	6	7.99	9,2	0,997	6,5-8,5	Class 1
Dissolved O2	mg/l	8,8	9.13	10,68	0,531	8,6	9.18	10,65	0,546	>7	Class 1
E-Conductivity	µs/cm	512	675.47	783	84,479	600	671.9	783	61,16	<750	Class 1
Nitrates	mg/l	0	1.87	7,8	2,116	0,05	1.2	3,9	0,982	≤10	Class 1
Nitrites	mg/l	0,001	0.1	0,184	0,06	0,045	0.24	1,6	0,397	≤1	Class 1
Ammonium	mg/l	0,1	0.14	0,166	0,038	0,1	0.15	0,27	0,052	≤0,1	Class 1
Orthophosphates	mg/l	0,31	0.62	0,817	0,15	0,43	0.65	0,9	0,169	≤0,2	Class 3
Ca Hardness	°F	6,64	9,49	15, 6	2,24	4,5	8. 46	13,6	3,15	7,5-20	Class 1
Mg Hardness	°F	1,313	4,15	4,96	1,1	2,48	4,39	8,025	1,629	3,0-15,0	Class 1
Total Hardness	°F	29,18	39.29	50	5,05	33	39.98	48	5,503	----------	Class 1

MQS: Moroccan Quality Standards Decree nº 2-97-787 r