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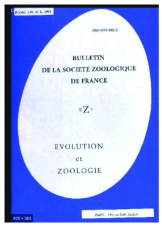

Parasitism of *Carassius gibelio* (Bloch, 1782) in the Ain Zada dam (Wilaya of Bordj-Bou Arreridj, Algeria) in relation with water pollution

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Abstract

This study aims to contribute to investigate the relationship between aquatic pollution and parasitism in *Carassius gibelio*. For this purpose, the physicochemical and bacteriological status of the water in the Ain Zada Dam was assessed during spring 2024, alongside the detection of parasites in cyprinid fish, particularly *Carassius gibelio* (Bloch, 1782), a species inhabiting this reservoir. The study included examinations of external teguments, gills, swim bladder, and digestive tracts of the fish. The parasitological inventory revealed the presence of 8,299 parasites belonging to 16 genera: *Ichthyophthirius sp.*, *Myxobolus sp.*, *Techamoeba sp.*, *Trichodina sp.*, *Chilodonella sp.*, *Gyrodactylus sp.*, *Raphidascaris sp.*, *Amphileptus sp.*, *Acanthogyrus sp.*, *Lernaea sp.*, *Khawia sp.*, *Argulus sp.*, *Ergasilus sp.*, *Margaritifera sp.*, *Ligula sp.*, *Bothriocephalus sp.*, as well as trematodes. A predominance of tegument-infecting parasites was observed, particularly for *Ichthyophthirius* sp. (prevalence: 88%) and *Lernaea* sp. (52%). Parasites were generally widespread across the freshwater fish distribution range but primarily affected juveniles, males, and specimen of medium size and medium weight. Physicochemical and bacteriological analyses identified heavy metals as the main pollutants in the dam water. Additionally, the low pH of the water had a significant direct or indirect impact on the total parasite load in cyprinids."

Keywords: Cyprinids, parasites, water pollution, Aïn Zada, Algeria

Parasitisme de *Carassius gibelio* (Bloch, 1782) dans le barrage de Ain Zada (Wilaya de Bordj-Bou Arreridj), Algérie, en relation avec la pollution

Résumé

Cette recherche a pour objectif de contribuer à étudier la relation entre la pollution aquatique et le parasitisme chez les *Carassius gibelio*. Pour ce faire, l'état physico-chimique et bactériologique de l'eau du barrage d'Aïn Zada a été examiné au printemps 2024, parallèlement à la détection des parasites des poissons cyprinidés, en particulier *Carassius gibelio* (Bloch, 1782), une espèce vivant dans ce même barrage. L'étude a inclus l'inspection des téguments externes, des branchies, de la vessie natatoire et du tube digestif des poissons. L'inventaire a révélé la présence de 8 299 parasites appartenant à 16 genres **:** *Ichthyophthirius sp.*, *Myxobolus sp.*, *Techamoeba sp.*, *Trichodina sp.*, *Chilodonella sp.*, *Gyrodactylus sp.*, *Raphidascaris sp.*, *Amphileptus sp.*, *Acanthogyrus sp.*, *Lernaea sp.*, *Khawia sp.*, *Argulus sp.*, *Ergasilus sp.*, *Margaritifera sp.*, *Ligula sp.*, *Bothriocephalus sp.*, ainsi que des trématodes. Une prédominance des parasites infectant les téguments a été constatée, notamment pour les genres *Ichthyophthirius sp.* et *Lernaea sp.*, avec une prévalence respective de 88 % et 52 %. Les parasites étaient généralement répandus dans toute l'aire de répartition des poissons d'eau douce, mais affectaient principalement les poissons jeunes, les mâles, ainsi que ceux de taille et de poids moyens. Selon les analyses physico-chimiques et bactériologiques, les métaux lourds constituent les principaux polluants de l'eau du barrage. Par ailleurs, le faible pH de l'eau exerce un impact significatif, directement ou indirectement, sur le nombre total de parasites chez les cyprinidés.

Mots-clés: Cyprinidés, parasites, pollution aquatique, Aïn Zada, Algérie

INTRODUCTION

Fish represent more than 25% of the animal protein source for humans (ASHMAWY *et al*., 2018). About 80% of fish diseases are parasitic, particularly in warm-water species (EISSA & GHARIB, 2005). Disease outbreaks in fish pose a significant challenge to aquaculture production. Many freshwater fish species are severely affected by various parasites, leading to high mortality rates, reduced aquaculture productivity, and an increased likelihood of secondary infections due to weakened immunity. This has a negative impact on the economy (MADSEN & STAUFFER, 2024). In addition, fishes and other aquatic organisms are affected by various stressors induced by human activities, which result in changes to environmental parameters. Chemical pollutants (e.g., contaminants), nutrients, flow velocity, pH, dissolved oxygen, turbidity, temperature changes, and other physico-chemical variables can be significantly altered by human activities, thus becoming pressures. Organisms respond to these pressures by exhibiting reactions outside their normal physiological range (BIRK *et al*., 2020; SUERS & NACHEV, 2022).

In northern Africa, freshwater fish populations are primarily composed of cyprinids (OULD ROUIS *et al*., 2012), which are used for ornamental purposes, dam cleaning, and as a food source. The study of aquatic parasitology in relation to aquatic pollution has gained increasing interest over the past fifty years. Nevertheless, while considerable effort has been devoted to understanding the role of pollution as a trigger for tumors, anomalies, and infectious diseases in aquatic organisms, the interactions between pollution and parasitism has not been much studied. Several studies have investigated freshwater fish parasites in northern Algeria. However, data on the environmental factors that may affect the parasitic fauna of cyprinid fishes remain poorly known.

Ain Zada Dam Lake is situated within the Bordj Bou Arreridj province in the upper basin of the Bou Sellam River, approximately between 35°45'57" and 36°20'50" N and between 004°58'30" and 005°32'55" E (Figure 1) (BOULGUERAGUER *et al*., 2014; MEBARKIA *et al*., 2017; BENSEFIA *et al*., 2024). The area encompassed by the Ain Zada Lake basin is roughly estimated to be around 2080 km^2. It is situated along the Bou Sellam River, which joins the Malah River, the Kharoua Stream, and the Ain Taghrout Stream to the south (BENSEFIA *et al*., 2024). Initially, the dam was constructed for irrigation purposes in the agricultural lands of the eastern upper plains (in Ain Taghrout and Ain Zada). Later, it became a major source of drinking water for residents of nearby cities, including Setif and Bordj Bou Arreridj (BOULAHBAL, 2007; BENSEFIA *et al*., 2024).

The present study focuses on:

1. The evaluation of the diversity of cyprinid parasites in Ain Zada Dam.
2. The assessment of the relation of the parasitic fauna and water pollution in the same dam.

Figure 1: (A) Map of Ain Zada dam location according to google maps © (B) Visualization of the Ain Zada dam, Wilaya of Bordj Bou Arreridj, on Alsat-2A satellite image (ASA, 2015).
Figure 1: (A) Carte de localisation du barrage d'Ain Zada selon Google maps © (B) Visualisation du barrage d'Ain Zada, Wilaya de Bordj Bou Arreridj, sur image satellite Alsat-2A (ASA, 2015).

MATERIALS AND METHODS

During the spring of 2024, fishes and water samples were collected from Ain Zada Dam. A total of 50 live specimens of *Carassius gibelio* were collected using a gillnet and a fishing boat. On the same day and at the same location, water samples were collected in sterilized bottles. The fish samples were examined immediately after capture to prevent the deterioration of parasites. For each specimen, measurements of length (using an ichthyometer), weight (using an electronic scale (EMB 6000-1, ± 0.1 g)), and deter-mination of sex (based on gonads macroscopic examination) and age (using fish scales) were conducted prior to parasite analysis.

The same methods for the collection of fish specimens and for the examination protocol the research of ectoparasites (on the integument and gills) as in 2014 (GHERBI *et al*., 2016) was applied. The detection of ectoparasites was performed carefully with the naked eye for protozoan and platyhelminths, which the size is up to 1 mm, followed by the methods described by MEDDOUR *et al*. (2010, 2011). After dissecting each fish, mesoparasites were examined in the digestive tract and swimbladder using the same methodologies.

Morphological identification of parasites was primarily conducted using the keys of PAPERNA & STEINITZ (1982), with additional references to YAMAGUTI (1963), MELHORN (2008), DJEBBARI *et al*. (2009), and ASHMAWY *et al*. (2018).

Physicochemical, heavy metal, and bacteriological analyses of the water samples were performed in a state-approved quality-testing laboratory. For the results exploitation, three parasitic indices were used according to (ROUAG-ZIANE *et al*., 2007). For data analysis, three parasitic indices were calculated according to ROUAG-ZIANE *et al*. (2007):

1. Prevalence (P%): the proportion of hosts infested by a given parasite species, expressed as a percentage:

$$P\% = N/H \times 100$$

N = Number of infested hosts
H = Total number of hosts examined

2. Mean Intensity (MI): the average number of parasites per infested host:

$$MI = (\sum I)/N$$

I = Number of parasites per infested host (intensity)
N = Number of infested hosts

Interpretation of Mean Intensity:
MI < 10 → Very low intensity
10 ≤ MI < 50 → Low intensity
50 ≤ MI < 100 → Moderate intensity
MI ≥ 100 → High intensity

Epidemiological implications:
High prevalence + low MI → Widespread but low parasite burden in the population.
Low prevalence + high MI o Parasite aggregation (few hosts carry heavy infestations).

3. Abundance (AB): the average number of parasites per host examined (including non-parasitized hosts):

$$AB = n/H$$

n = Total number of parasites found
H = Total number of hosts examined
The obtained data were analysed using Microsoft Excel 2013 on Windows 10.

RESULTS

Out of 50 specimens of *Carassius gibelio* examined, 98% were infested. A total of 8299 parasites were collected belonging to sixteen genera (Table 1).

Table 1: Taxonomic list of parasites found in *Carassius gibelio*.
Tableau 1: Liste systématique des parasites recensés chez les Carassius gibelio *examinés.*

Phylum	class	Order	Family	Genera
Protozoa	Phyllopharyngea	Chlamydodontidea	Chlamydodontidae	*Chilodonella* sp
	Ciliata	Holotrichia	Ophryonglenidae	*Ichthyophthirius* sp
	Lobosea	Amoebida	Amoebidae	*Techamoeba* sp
	Oligohymenophorea	Mobilida	Trichodinidae	*Trichodina* sp
	Litostomatea	Pleurostomatida	Amphileptidae	*Amphileptus* sp
	Myxosporea	Bivalvulidae	Myxosporidae	*Myxobolus* sp
Platyhelmintha	Monogenca	Monopisthocotylea	Gyrodactylidae	*Gyrodactylus* sp
		Dactylogyridea	Dactylogyridae	*Dactylogyrus* sp
	Cestoda	Caryophyllidea	Lytocestidae	*Khawia* sp
		Diphyllobothriidea	Diphyllobothriidae	*Ligula* sp
		Pseudophyllidea	Bothriocephalidae	*Bothriocephalus* sp
	Trematoda	NI	NI	NI
Nemathelmintha	Chromadorea	Ascaridida	Anisakidae	*Raphidascaris* sp
Acanthocephala	Eoacanthocephala	Gyracanthocephala	Quadrigyridae	*Acanthogyrus* sp
Arthropoda	Maxillopoda	Poecilostomatoida	Ergasilidae	*Ergasilus* sp
	Copepoda	Cyclopoida	Lernaeidae	*Lernaea* sp
Mollusca	Bivalvia	Eulamellibranchia	Unionidae	*Margaritifera* sp

NI: Not Identified

While identification was successfully performed at the generic level, species-level determination remained uncertain for all genera examined. Among these, the most abundant species were *Ichtyophtirius* sp (97.32%) followed by *Chilodonella* sp, *Margaritifera* sp, *Lernaea* sp, *Techamoeba* sp, *Myxobolus* sp, *Gyrodactylus* sp, *Ligula* sp, *Khawia* sp, *Bothriocephalus* sp, *Raphidascarıs* sp, *Acanthogyrus* sp, Trichodina sp, *Amphileptus* sp, *Ergasilus* sp, *Dactylogyrus* sp representing all together (2.68%) (Figure 2).

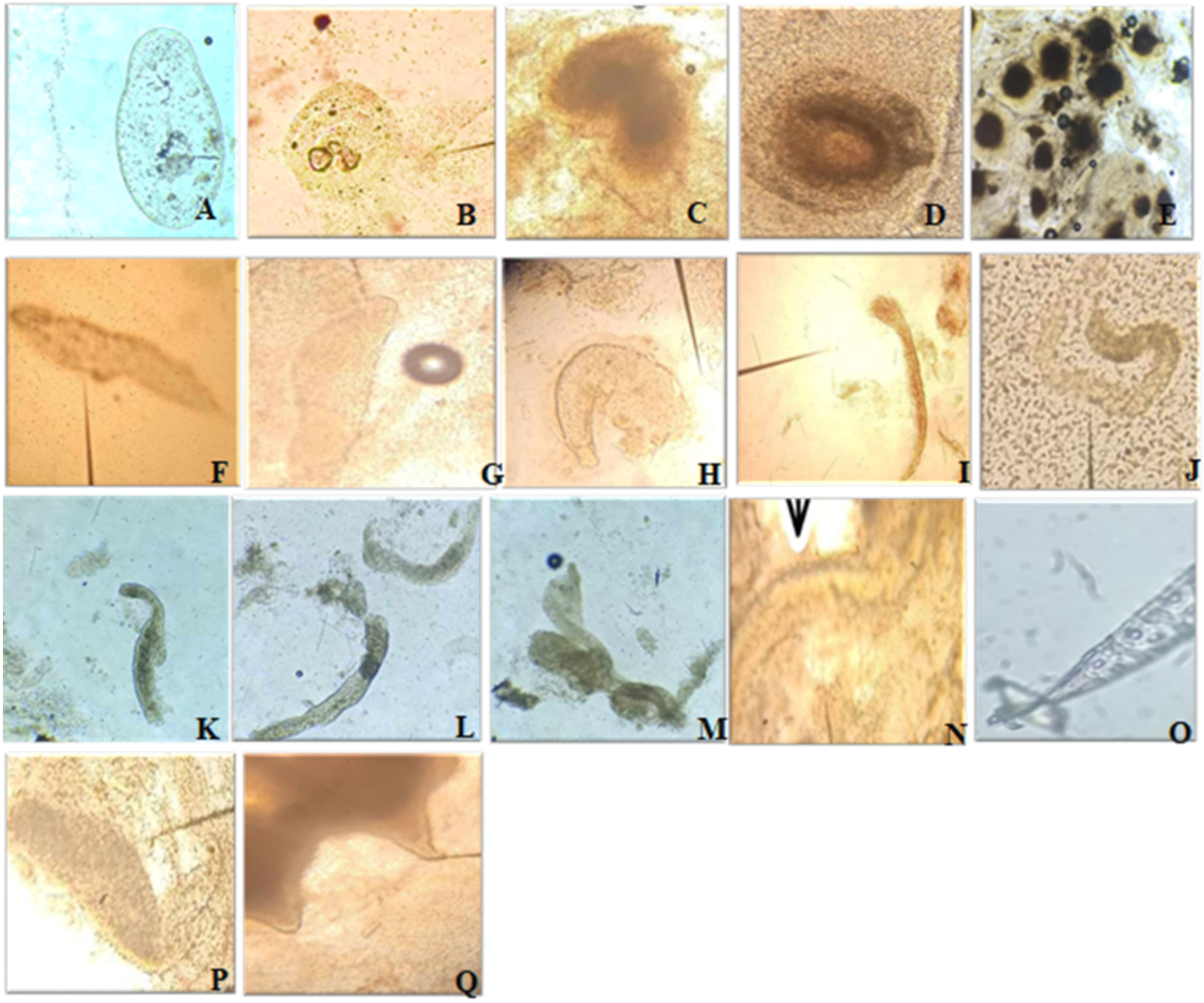

Figure 2: Photos representing (A) *Chilodonella* sp (B) *Techamoeba* sp (C) *Trichodina sp* (D) *Ichthyophthirius* sp (E) *Myxobolus* sp (F) *Amphileptus* sp (G) *Gyrodactylus* sp (H) *Dactylogyrus* sp (I) *Khawia* sp (J) *Ligula* sp (K) *Bothriocephalus* sp (L) Trematoda (M) *Raphidascaris* sp (N) *Acanthogyrus* sp (O) *Lernaea* sp (P) *Ergasilus* sp (Q) *Margaritifera* sp under the microscope magnification 40.

Figure 2: Photos représentant (A) Chilodonella *sp (B)* Techamoeba *sp (C)* Trichodina *sp (D)* Ichthyophthirius *sp (E)* Myxobolus *sp (F)* Amphileptus *sp (G)* Gyrodactylus *sp (H)* Dactylogyrus *sp (I)* Khawia *sp (J)* Ligula *sp (K)* Bothriocephalus *sp (L)* Trematoda *(M)* Raphidascaris *sp (N)* Acanthogyrus *sp (O)* Lernaea *sp (P)* Ergasilus *sp (Q)* Margaritifera *sp sous le microscope grossissement 40.*

The occurrence and prevalence of the revealed observed parasites from the examined fish showed that the Protozoan parasites predominated followed by Helminths, Crustaceans and Molluscs (Figure 3).

The result of the parasitic research in relation to their localization has demonstrated that parasites of the external integuments are the most present (Figure 4).

The different parasites classes affect almost all fish's ages, males and females, all weight classes, and all sizes specimen. The results of Middle Intensity, and abundance revealed that 2 years old, males, 24 cm size and 300 to 350 g class weight are the most affected (Figures 5-8). Males present a much higher abundance of parasites and mean intensity than females (figure 6). The prevalence is also higher in males, though it is high in both sexes.

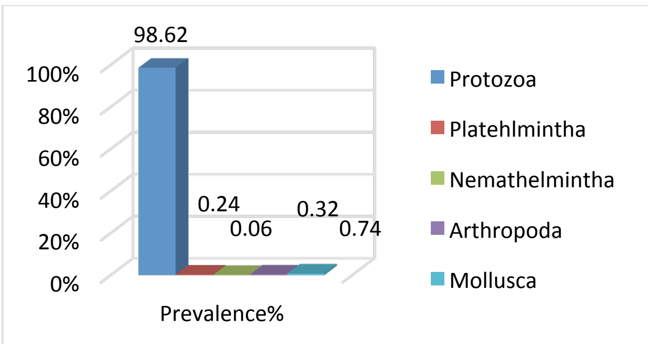

Figure 3: Diagram of the distribution of the infestation rate according to the location of their classification.

Figure 3 : Diagramme de la distribution du taux d'infestation selon la localisation de leur classification.

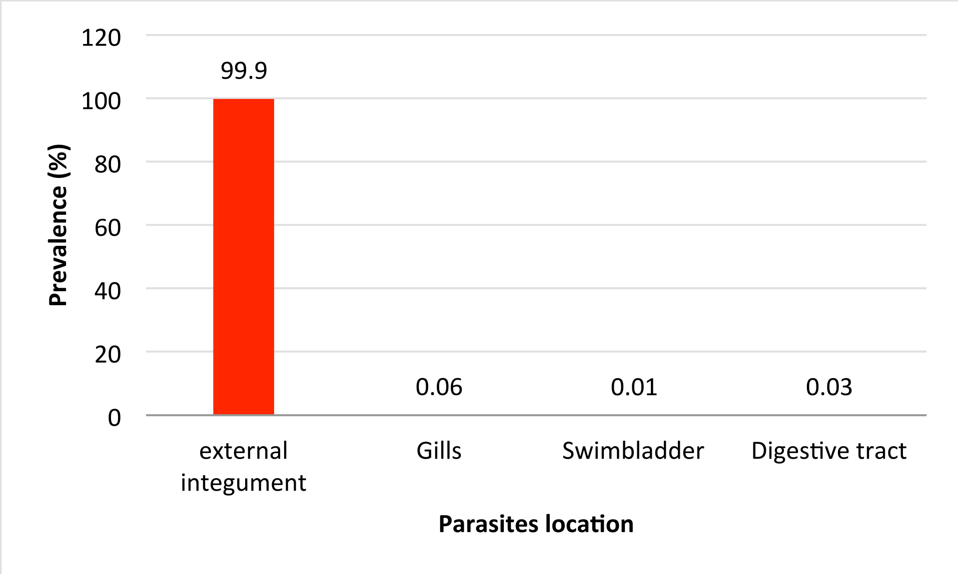

Figure 4: Diagram of the distribution of the infestation rate according to the location of the parasite.
Figure 4 : Diagramme de la distribution du taux d'infestation en fonction de la localisation du parasite.

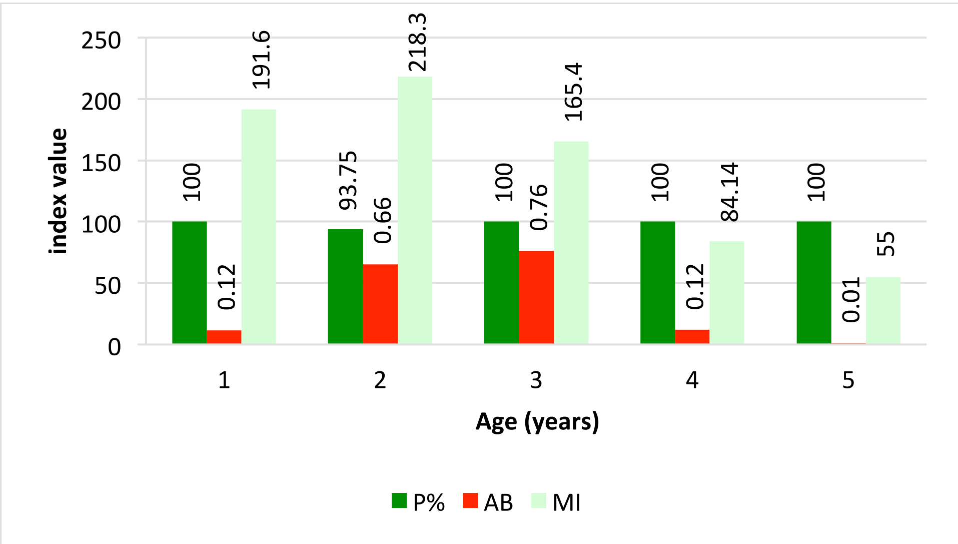

Figure 5: Distribution of the infestation rate in terms of prevalence (P), abundance (AB) and mean intensity (MI) according to fish's age (years). *Figure 5 : Distribution du taux d'infestation en fonction de l'âge des poissons (années).*

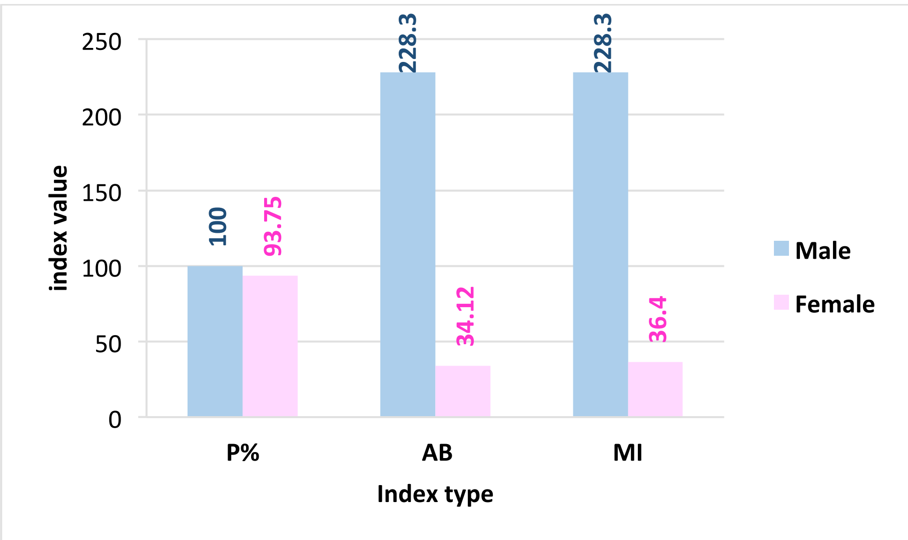

Figure 6: Diagram of the distribution of the infestation rate according to fish's sex.
Figure 6 : Diagramme de la distribution du taux d'infestation selon le sexe des poissons.

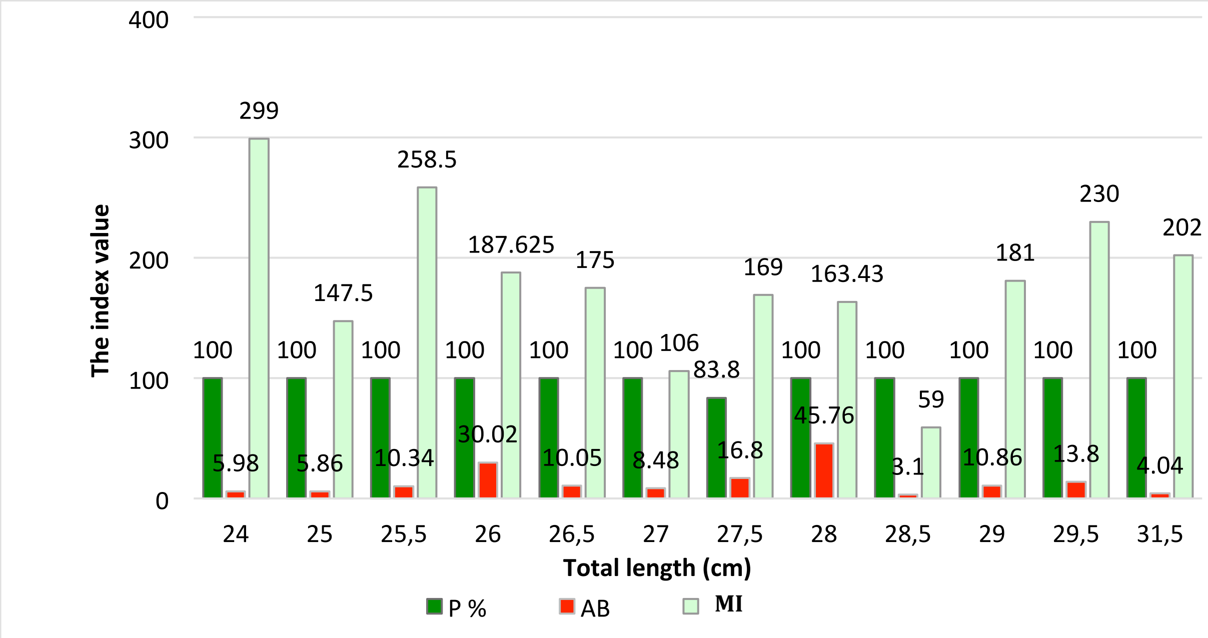

Figure 7: Diagram of the distribution of the infestation rate according to fish's length (cm).

Figure 7 : Diagramme de la distribution du taux d'infestation en fonction de la longueur des poissons (cm).

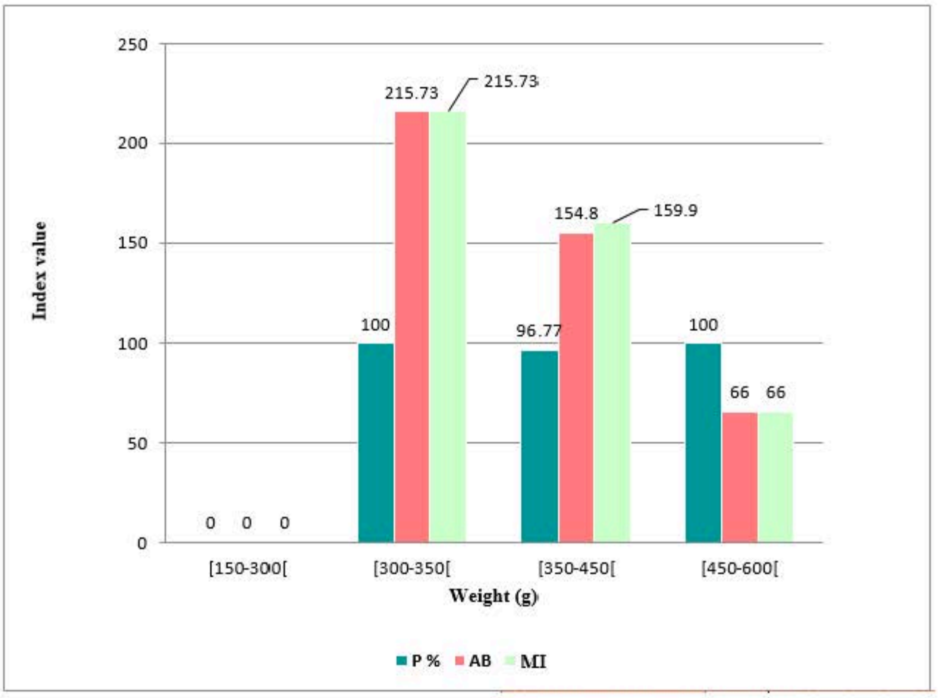

Figure 8: Distribution of the infestation rate according to fish's weight range.

Figure 8 : Distribution du taux d'infestation en fonction de la gamme de poids des poissons.

The results of epidemiological indexes according to parasite genera revealed that the highest prevalence in *Ichthyophthirius* sp with an infection rate reaching 88%, followed by *Lernaea* sp 52%, *Chilodonella* sp 24%, *Margaritifera* sp and *Techamoeba* have the same infection rate 14%, *Gyrodactylus* sp 10%, *Khawia* sp 8%, *Ligula* sp, *Bothriocephalus* sp, *Raphidascaris* sp and trematodes have an infection rate reaching 6%, *Ergasilus* sp, *Trichodina* sp, *Amphileptus* sp, *Myxobolus* sp, *Dactylogyrus* sp have a low prevalence (2%).

The average intensity varies from one genus to another, the highest is 183.57 for *Ichthyophthirius* sp and the lowest is 1 for *Dactylogyrus* sp, *Khawia* sp, *Bothriocephalus* sp, *Raphidascaris* sp (Table 2).

The results of water analyses are presented in Table 3 and Table 4, which compare the chemical and bacteriological analysis of water from the Ain Zada Dam between 2014 and 2024. The data show a decrease in the pH and conductivity of the water. Nitrate, calcium, and chloride levels are lower compared to the levels found in 2014. Additionally, magnesium is absent, and nitrite and aluminium have appeared in 2024, substances that were not present ten years before. Regarding heavy metals, we were able to measure iron and zinc, both of which have decreased compared to 2014.

Regarding to bacteriological infection, only coliforms persist from 2014 to 2024.

Table 2: Variation of epidemiological indexes by parasite genera/class in examined fish.
Tableau 2 : Variation des indices épidémiologiques par genre/classe de parasites chez les poissons examinés.

Genera/class	**H**	**N**	**n**	**P%**	**AB**	**MI**
Ichtyophtirius sp	50	44	8077	88	161.54	183.57
Chilodonella sp	50	12	81	24	1.62	6.75
Techamoeba sp	50	7	14	14	0.28	2
Trichodina sp	50	1	2	2	0.04	2
Amphileptus sp	50	1	2	2	0.04	2
Myxobolus sp	50	1	9	2	0.18	9
Gyrodactylus sp	50	5	6	10	0.12	1.2
Dactylogyrus sp	50	1	1	2	0.02	1
Khawia sp	50	3	3	6	0.06	1
Ligula sp	50	3	4	6	0.06	1.3
Bothriocephalus sp	50	3	3	6	0.06	1
Raphidascarıs sp	50	3	3	6	0.06	1
Acanthogyrus sp	50	1	2	2	0.04	2
Ergasilus sp	50	1	1	2	0.02	1
Lernaea sp	50	26	26	52	0.52	1
Margaritifera sp	50	7	62	14	1.24	8.86
Trematoda	50	3	3	6	0.06	1

Table 3: Results of physicochemical analyses of Ain Zada dam water (2014/2024)
Tableau 3: Les résultats des analyses physicochimique de l'eau du barrage d'Ain Zada (2014/2024).

Parameter	The norm	2014	2024
pH	From 6.5 to 8.5	8.02	7.32
Conductivity mS/cm at 20°C	2800 max	635	2.21
Calcium (mg/L)	75 to 200	160	112.22
Magnesium (mg/L)	150	97	00
Chloride (mg/L)	From 200 to 500	178	162.64
Nitrate (mg/L)	50 max	29	9.4
Nitrite (mg/L)	0.1 max	00	0.09
Dissolved O_2 (mg/L)	From 6.5 to 8	5	6.5
Aluminium (mg/L)	0.2 max	00	Trace
Iron (mg/L)	0.3 max	0.5	0.1
Zinc (mg/L)	3 max	0.09	1.10

Table 4: Results of bacteriological analyses of Ain Zada dam water (2014/2024).
Tableau 4 : Résultats des analyses bactériologiques de l'eau du barrage d'Ain Zada (2014/2024).

Bacteriological test	Norm	2014	2024
Total Coliforms	00	Presence	Presence
Fecal Streptococci	00	Presence	Absence

DISCUSSION AND CONCLUSION

Compared to the 2014 study (GHERBI *et al.*, 2016) that identified 13 parasite genera, our findings revealed higher diversity across protozoans to molluscs. This increase likely reflects degraded water quality and climate warming facilitating parasite establishment. Methodological constraints (e.g., microscopy of external tissues) may have missed smaller parasites, larval stages, or cryptic species, meaning our results represent a partial assessment of the total parasitic burden.

Protozoans dominated (97.32 %), particularly *Ichthyophthirius* sp., due to their simple life cycles and direct waterborne transmission (KABATA, 1985;

POULIN, 2007). External parasites prevailed, attributable to gill/skin exposure and environmental stressors (SCHALCH *et al*., 2016; MARCOGLIESE, 2001). Mesoparasites (e.g., cestodes) were more rare, linked to intermediate host availability (POULIN, 2007). While cestodes may sequester heavy metals (TIMEA *et al*., 2012), genera like *Bothriocephalus* sp. pose health risks even after cooking (BARUS *et al*., 2001; FRASER *et al*., 2023).

The extreme *Ichthyophthirius* sp. prevalence (88%) contrasts with lower rates in Tunisian (<20%) and Moroccan (<40%) Cyprinids (BEN HASSINE *et al*., 2018; DAHBI *et al*.; 2020), suggesting Ain Zada's ecological imbalance. Unlike Asian *C. gibelio* populations where *Dactylogyrus* sp. dominates (70–90% prevalence; ZHAO *et al*., 2019), its near-absence here (2%) implies eutrophication or thermal stress favoring protozoans over helminths (LAFFERTY & KURIS, 2005). *Lernaea sp*. prevalence (52%) aligned with Turkish reports (ÖZTÜRK & ALTUNEL, 2021), but low cestode/nematode burdens (≤8%) contrasted with Asian systems (WANG *et al*., 2021), possibly due to intermediate host limitations.

Juveniles (2-year-olds) show higher parasitism due to active foraging, habitat exploration, and immature immunity (ELLIS, 2001; BUCHMANN & LINDENSTRØM, 2002; POULIN, 2007; MORAVEC, 2009).

The much higher abundance and mean intensity observed in males than females (Figure 6) was observed previously, in other species, and understood to come from behavioural and physiological factors. Male fish may exhibit more aggressive territorial and feeding behaviours that expose them to infection. In addition hormonal differences, in particular the higher level of testosterone, can suppress immune function, making males more susceptible parasitic infestation (FOLSTAD & KARTER, 1992).

Peak parasite loads occur in intermediate-sized fish (24 cm, 300–350 g), aligning with the intermediate-size hypothesis (POULIN & GEORGE-NASCIMENTO 2007). This size (~65% of max length; KOTTELAT & FREYHOF 2007) optimizes parasite resource access vs. host resistance. The congruence with global trends (POULIN & GEORGE-NASCIMENTO, 2007) suggests that the parasitism context in Ain Zada is not exceptional, but further research could explore whether lake-specific factors (e.g., eutrophication, temperature) modulate these effects.

The high Prevalence Parasites of *Ichthyophthirius* sp. (88%) and *Lernea* sp can be attributed to its direct life cycle, transmission without an intermediate host, which facilitates rapid spread in dense fish populations and environmental factors such as poor water quality, temperature fluctuations, and high stocking densities (MATTHEWS, 2005). For *Lernaea* sp. these crustacean parasites, are common in aquaculture and natural water bodies, particularly in warmer conditions. Their high prevalence is linked to host stress and the extended duration of parasitic attachment (PIASECKI *et al*., 2004).

However the moderate prevalence parasites of *Chilodonella* sp. (24%) and of *Margaritifera* sp. and *Techamoeba* sp. (14%) suggests sporadic outbreaks likely influenced by water temperature and host immunity and may reflect specific ecological niches and host interactions (KARNA & MILLIMAN, 1978).

Finally the low prevalence parasites of *Gyrodactylus* sp. (10%) and *Dactylogyrus* sp. (2%): can be interpret as coming from host-specificity and the preferential infestation of gills or skin (LI *et al*., 2020). Their prevalence can vary depending on host density and water quality. Similarly, the low parasitic prevalence of *Khawia* sp. (8%) and *Ligula* sp. (6%) may be due to the cycle of these cestodes which require intermediate hosts (e.g. copepods or small fish), and their presence often reflects environmental conditions supporting these hosts (BAKKE *et al*., 2007; MORAVEC, 2009). For *Myxobolus* sp. (2%), this low prevalence may be associated with chronic diseases in fish and require specific conditions for sporulation and transmission (LOM & DYKOVÁ, 2006).

The average intensity, which was higher than the abundance for all genera, suggests a phenomenon of parasite aggregation. This occurs when a large proportion of the parasite population is concentrated in a small number of hosts, leaving others relatively parasite-free. This can lead to physiological stress, reduced growth, impaired reproduction, and even mortality (ANDERSON & MAY'S, 1978; MATTHEWS, 2005).

The observed decline in pH at Ain Zada Lake, driven by geological inputs, urban/industrial pollution, and anthropogenic discharges (MULLANEY *et al*., 2009), has significant implications for host-parasite dynamics. Acidification increases heavy metal solubility (e.g., Pb, Hg), which impairs fish immune function and elevates parasite susceptibility (NOLAN, 2024; BOULEGRAGGER *et al*., 2022; SEMAI *et al*., 2023), while simultaneously affecting free-living parasite stages - reducing cercariae survival but favoring salinity-tolerant species (MARCOGLIESE & PIETROCK, 2011; SURES, 2004). These pH-mediated effects are compounded by chronic stress from sublethal pollution exposure (MORLEY, 2010), as demonstrated in Boussellam Valley where pH fluctuations (7.09-8.89) correlate with elevated salinity/TDS and industrial contaminants (SEMAI *et al*., 2023). Although the precise mechanisms in Ain Zada require further study, this aligns with global patterns where acidification exacerbates parasitism through both direct (parasite viability) and indirect (host immunity) pathways, highlighting the need for integrated water quality management to mitigate these ecological impacts. The studies by EL-SEIFY *et al*. (2011) and MOUSTAFA *et al*. (2014) highlight the significant impact of heavy metals, such as iron, on freshwater fish parasitism, demonstrating that even trace amounts can weaken immune defenses and increase susceptibility to protozoans, monogeneans, and crustaceans. However, in Ain Zada Dam, the measured levels of iron (0.1 mg/L) and aluminium (trace) in 2024 were below the permissible thresholds (0.3 mg/L and 0.2 mg/L, respectively; Table 2). This suggests that, at current concentrations, these metals alone may not be the primary driver of parasitic infestations in the dam.

Nevertheless, subthreshold metal exposure could still contribute to chronic stress in fish, particularly when combined with other factors such as fluctuating pH (7.32 in 2024, down from 8.02 in 2014) or elevated conductivity (2.21 mS/cm). For instance, synergistic effects of multiple pollutants – even at low individual levels – might compromise host resilience (MARCOGLIESE & PIETROCK, 2011). Moreover, the presence of parasites like acanthocephalans, which bioaccumulate metals (SHIH *et al*., 2010), could indicate historical or episodic pollution events not fully captured by sporadic sampling thus, while the 2024 data show compliance with metal norms, the high parasite prevalence in Ain Zada fish may reflect: the cumulative stress from interacting water quality parameters (e.g., pH, dissolved oxygen), the legacy pollution or uneven metal distribution (e.g., localized near industrial inflows) and the parasite life cycles tied to ecological shifts beyond metal toxicity alone.

Further targeted studies comparing parasite loads across microhabitats with varying metal histories would clarify these relationships.

UDEZE *et al.* (2012) report that coliforms, particularly *Escherichia coli*, contribute to co-infection with the *Salmonella* genus, adversely affecting the digestive tracts of fish and promoting the proliferation of mesoparasites. On the other hand, this weakened state of fish makes them more susceptible to infestation and proliferation of parasites on the external integument, particularly around the fins and gills (MOUSTAFA *et al*., 2014). In conclusion, the study highlights the intricate interplay between environmental factors, host biology, and parasite diversity in the Ain Zada Dam. Changes in parasitic richness since 2014 underscore the impact of ecological stressors such as water quality degradation, global warming, and heavy metal pollution. These factors not only increase fish susceptibility to parasitic infections but also influence the distribution and prevalence of various parasite genera.

The predominance of external parasites reflects environmental and physiological vulnerabilities, while host-specific and life-cycle-dependent parasites further emphasize the complex dynamics within the ecosystem. Interestingly, the dual role of parasites — as both stressors and potential mitigators of environmental toxins — presents an intricate balance between ecological challenges and benefits. This underscores the need for comprehensive monitoring of aquatic ecosystems to manage both environmental and health risks effectively and the need for targeted control measures, such as water quality improvement, regulation of stocking densities, and intermediate host management.

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