

FISH PARASITES AS A POTENTIAL TOOL FOR ENVIRONMENTAL BIOMONITORING

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ABSTRACT: Fish parasites have been widely recognized as sensitive indicators of environmental conditions, often responding more rapidly to ecological disturbances than their hosts. In this study, we evaluated parasite occurrence in freshwater fish collected before and after an extended drought in São Paulo, Brazil. A total of 150 fish specimens were collected from three distinct aquatic environments: Ibirapuera Lake (urban park), Biritiba Reservoir (drinking water supply), and a Recreational Fishing Lake (managed aquaculture system), with 63 and 87 fish, respectively, before and after the drought. Parasitological analyses were performed using fresh smears of gills and intestinal contents, as well as histopathological examination with hematoxylin–eosin and Giemsa staining. Our results showed that reduced water levels associated with drought conditions were accompanied by increased parasite prevalence, although the number of parasites on the gills decreased after the drought. Protozoan parasites, particularly *Trichodina* sp., were the most prevalent in fish from Ibirapuera Lake and the Recreational Fishing Lake. In contrast, fish from Biritiba Reservoir exhibited a higher occurrence of *Entamoeba* and other amoebae in intestinal samples following the drought. These findings suggest that parasite dynamics in freshwater fish are influenced by environmental changes associated with reduced water availability. Monitoring fish parasites may be a useful, cost-effective approach to assessing environmental stress in aquatic ecosystems.

KEYWORDS: Biomonitoring; Drought; Environmental stress; Fish protozoan; Freshwater fish; *Trichodina* sp.

PARASITAS DE PEIXES COMO FERRAMENTA POTENCIAL PARA O BIOMONITORAMENTO AMBIENTAL

RESUMO: Parasitas de peixes têm sido amplamente reconhecidos como indicadores sensíveis das condições ambientais, frequentemente respondendo mais rapidamente a perturbações ecológicas do que seus hospedeiros. Neste estudo, avaliou-se a ocorrência de parasitas em peixes de água doce coletados antes e após um período prolongado de seca no estado de São Paulo, Brasil. Foram analisados 150 espécimes de peixes

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provenientes de três ambientes aquáticos distintos: o Lago do Parque Ibirapuera (ambiente urbano), a Represa de Biritiba (reservatório para abastecimento público) e um lago de pesca recreativa (sistema de aquicultura manejado); 63 e 87 peixes, respectivamente, antes e após a seca. As análises parasitológicas foram realizadas por meio de esfregaços frescos de brânquias e conteúdo intestinal, além de exame histopatológico com colorações de hematoxilina-eosina e Giemsa. Os resultados demonstraram que a redução dos níveis de água associada à seca foi acompanhada por aumento na ocorrência de parasitas, embora o número de parasitas nas brânquias tenha reduzido após a seca. Protozoários, especialmente *Trichodina* sp., foram os mais prevalentes nos peixes do Lago do Ibirapuera e do lago de pesca recreativa. Em contraste, os peixes da Represa de Biritiba apresentaram maior prevalência de *Entamoeba* e outras amebas em amostras intestinais após o período de seca. Esses achados sugerem que a dinâmica parasitária em peixes de água doce é influenciada por alterações ambientais associadas à redução da disponibilidade hídrica. O monitoramento de parasitas em peixes pode representar uma abordagem útil e de baixo custo para a avaliação do estresse ambiental em ecossistemas aquáticos.

PALAVRAS-CHAVE: Biomonitoramento; Estresse ambiental; Protozoários de peixes; Peixes de água doce; Seca; *Trichodina* sp.

LOS PARÁSITOS DE LOS PECES COMO FUENTE POTENCIAL DE BIOMONITORIZACIÓN AMBIENTAL

RESUMEN: Los parásitos de peces han sido ampliamente reconocidos como indicadores sensibles de las condiciones ambientales, ya que con frecuencia responden más rápidamente a las perturbaciones ecológicas que sus hospedadores. En este estudio, se evaluó la frecuencia de parásitos en peces de agua dulce recolectados antes y después de un período prolongado de sequía en el estado de São Paulo, Brasil. Se analizaron 150 especímenes de peces provenientes de tres ambientes acuáticos distintos: el Lago del Parque Ibirapuera (ambiente urbano), la Represa de Biritiba (reservorio para abastecimiento público) y un lago de pesca recreativa (sistema de acuicultura manejado), con 63 y 87 peces, respectivamente, antes y después de la sequía. Los análisis parasitológicos se realizaron mediante frotis frescos de branquias y de contenido intestinal, además de un examen histopatológico con tinciones de hematoxilina-eosina y de Giemsa. Los resultados demostraron que la reducción de los niveles de agua asociada a la sequía estuvo acompañada de un aumento de la prevalencia de parásitos, aunque el número de parásitos en las branquias disminuyó tras la sequía. Los protozoos, especialmente *Trichodina* sp., fueron los más prevalentes en los peces del Lago del Ibirapuera y del lago de pesca recreativa. En contraste, los peces de la Represa de Biritiba presentaron una mayor frecuencia de *Entamoeba* e otras amebas de vida libre en muestras intestinales después del período de sequía. Estos hallazgos sugieren que la dinámica parasitaria en peces de agua dulce está influida por cambios ambientales asociados a la reducción de la disponibilidad hídrica. El monitoreo de parásitos en peces puede ser un enfoque útil y de bajo costo para evaluar el estrés ambiental en ecosistemas acuáticos.

PALABRAS CLAVE: Biomonitoreo; Protozoos en peces; Peces de agua dulce; Sequía; Estrés ambiental; *Trichodina* sp.

1. INTRODUCTION

Parasites have been increasingly recognized as useful indicators of environmental pollution, acting as accumulation indicators, effect indicators, and integrators of host–environment interactions (Sures *et al.*, 2017). Parasitological analyses can provide valuable insights into alterations in food web structure and ecological function driven by disturbances such as changes in host distribution, water level fluctuations, eutrophication, thermal stratification, acidification, ultraviolet radiation, and extreme climatic events. These factors are expected to intensify under current climate change scenarios (Marcogliese, 2016; Sures *et al.*, 2023).

Host–parasite interactions are highly dynamic and depend on multiple factors, including the nature and intensity of environmental stressors, parasite life cycles, and exposure duration (Marcogliese, 2008; Morris *et al.*, 2022). Environmental degradation can modify parasite occurrence, abundance, and diversity, although the direction and magnitude of these changes depend on their biological and ecological characteristics, particularly their life-cycle strategies, modes of transmission, and dependence on intermediate and definitive hosts; thus, while parasites with direct life cycles may respond more directly to environmental changes and to the physiological and immune status of their hosts, those with complex life cycles may be particularly affected by changes in biodiversity, trophic interactions, and host availability required for transmission, making parasite community structure a potential indicator of environmental integrity (Vidal-Martínez; Wunderlich, 2017; Sures *et al.*, 2017).

Ectoparasites are among the most studied groups in environmental monitoring, particularly trichodinids and monogeneans (Byers, 2020; Rajarajan *et al.*, 2025). These organisms are characterized by direct transmission and rapid reproduction, allowing their populations to respond quickly to environmental stress (Suliman; Al-Harbi, 2016). Disturbances often increase host susceptibility, especially in sensitive organs such as the gills (Suliman; Al-Harbi, 2016). As highly vascularized and externally exposed structures, gills are particularly vulnerable to environmental changes and pathogen invasion.

Previous studies have demonstrated correlations between *Trichodina* spp. infections in *Merlangius merlangus* and levels of organic pollution, including nitrite, nitrate, and phosphate concentrations (Ogut; Palm, 2005). These findings support using parasites as biological indicators of environmental quality.

The parasite–host–environment relationship forms the foundation of epidemiological studies. Climate change can directly influence pathogen survival, transmission dynamics, and disease prevalence. However, identifying these relationships in natural systems remains challenging. In this context, biological indicators that reflect environmental changes are essential. Parasites have been proposed as effective indicators of climate-driven ecological shifts, as they respond rapidly to environmental disturbances and can reflect changes in ecosystem structure and biodiversity (Lacerda *et al.*, 2018; Palm, 2011).

In the present study, we investigated parasite occurrence in freshwater fish collected before and after an extreme drought in São Paulo, Brazil. We hypothesized that environmental stress caused by reduced water availability would influence parasite prevalence. Our findings show a significant increase in parasitic infections—particularly protozoans—after the drought, supporting the use of fish parasites as indicators of climate-related environmental change.

2. MATERIALS AND METHODS

2.1 Study area

Freshwater fish were collected from three distinct aquatic environments: Biritiba Reservoir, Ibirapuera Lake, and a Recreational Fishing Lake. The Biritiba Reservoir is located near the municipality of Biritiba-Mirim (23°36'10.14" S; 46°05'26.24" W), with a perimeter of approximately 102,440 m and a surface area of 1,494 ha. It is part of the Alto Tietê water supply system, managed by Sabesp, and plays an important role in water storage and treatment for the São Paulo metropolitan region. Ibirapuera Park, located in the central area of the São Paulo Metropolitan Region, covers approximately 1,584,000 m². The park contains three interconnected lakes supplied by the Sapateiro Stream, which is part of the Pinheiros River basin. This stream is subject to organic pollution due to untreated wastewater discharge, resulting in elevated nutrient levels. The Recreational Fishing Lake consisted of two artificial tanks (32 m each), stocked at high density (approximately 1,500 kg of fish per tank). Management supplied water from an artesian well, and management practices partially controlled environmental conditions.

2.2 Fish collection and transport

Fish were collected during two distinct sampling periods: the pre-drought period ($n = 63$) and the post-drought period ($n = 87$). These periods correspond to the most severe drought recorded in São Paulo state in approximately 80 years. Specimens were captured using standard fishing equipment. A total of 150 fish were collected across the three study sites. After capture, fish were transported alive to the research laboratory at Paulista University (UNIP) in aerated containers containing water from their original environment. In the laboratory, fish were maintained in controlled aquaria at $24 \pm 1^\circ\text{C}$. All procedures followed institutional ethical guidelines and were approved by the Animal Ethics Committee (protocol no. 2202014).

2.3 Biometric analysis and parasitological examination

Prior to necropsy, fish were anesthetized by immersion in a 150 mg/L solution of tricaine methanesulfonate (MS-222; Sigma-Aldrich, St. Louis, Missouri, USA) until loss of opercular movement (Neiffer; Stamper, 2009). Biometric data, including body mass and total length, were recorded for each specimen. The external surface of each fish was examined under a stereomicroscope to detect lesions, scale loss, or visible parasites. Gill samples were obtained by gentle scraping and examined under light microscopy. Intestinal contents were collected and stained with 10% Lugol's iodine solution to detect protozoan parasites. When parasites were observed, samples were mounted on glass slides, fixed with methanol, and stained using Giemsa and Ziehl-Neelsen techniques. Identification was performed based on morphological characteristics according to established taxonomic criteria (Lom; Dyková, 1992; Woo; Buchann, 2026).

2.4 Necropsy and histopathology

Necropsies were performed using standard procedures, including ventral incisions to expose internal organs. The body surface, fins, oral cavity, eyes, and opercular regions were examined for parasitic lesions. Tissues including gills, skin, liver, spleen, and intestine were collected and fixed in Davidson's solution for 8 hours, then preserved in 70% ethanol (Miki *et al.*, 2018). Histological processing included paraffin embedding, sectioning, and staining with hematoxylin and eosin (H&E) and Giemsa. For quantitative analysis, parasites in gill tissues were counted in 10 microscopic fields ($100\times$

magnification) from randomly selected specimens collected before and after the drought. Mean parasite counts were calculated for each group.

2.5 Statistical analysis

The Mann–Whitney U test was used because comparisons involved independent groups and the quantitative data did not meet the assumptions for parametric testing. Each fish was considered the experimental/sampling unit, and measurements obtained from the same individual were not treated as independent replicates. Statistical significance was set at $p < 0.05$. Analyses were performed using SPSS software (version 15.0).

3. RESULTS

3.1 Fish species and biometric data

A total of 150 fish specimens were collected, comprising the following species: *Oreochromis niloticus* ($n = 81$), *Hypostomus affinis* ($n = 4$), *Astyanax bimaculatus* ($n = 40$), *Crenicichla lenticulate* ($n = 9$), and *Geophagus brasiliensis* ($n = 15$). Table 1 presents species distribution across sampling sites and their respective biometric parameters. Statistical analysis revealed no significant differences in biometric measurements between fish collected before and after the drought ($P > 0.05$).

Table 1. Average biometrics collected fish in Ibirapuera Lake, Biritiba Dam and Recreational Fishing considering weight and average length of examined species.

Local	Sample	Fish number	Average weight g ($\pm$ SD) Before	Average length cm ($\pm$ SD) Before
Ibirapuera Lake	<i>Oreochromis niloticus</i>	46	619.1 ($\pm$ 291.4)	36.3 ($\pm$ 0.8)
	<i>Hypostomus affinis</i>	4	934.7 ($\pm$ 387.4)	60 ($\pm$ 1.6)
Biritiba Dam	<i>Astianax bimaculatus</i>	40	30.7 ($\pm$ 8.8)	13.2 ($\pm$ 0.3)
	<i>Crenicichla lenticulata</i>	10	245.2 ($\pm$ 103.7)	37.8 ($\pm$ 0.38)
Recreational Fishing	<i>Oreochromis niloticus</i>	35	100.8 ($\pm$ 42.6)	15.6 ($\pm$ 0.45)
	<i>Geophagus brasiliensis</i>	15	20.5 ($\pm$ 4.4)	11.9 ($\pm$ 0.8)

3.2 Parasite occurrence in relation to environmental changes

During the study period, São Paulo state experienced one of the most severe droughts recorded in recent decades. Comparative analysis of fish collected before and after this event revealed notable changes in parasite occurrence across all sampling sites. In natural reservoirs—particularly Ibirapuera Lake and Biritiba Reservoir—parasite dynamics appeared to be strongly influenced by reduced water levels and environmental stress. In contrast, the Recreational Fishing Lake, where water levels were artificially managed, showed less pronounced environmental fluctuations, although water volume still decreased (Figure 1; Table 2). Quantitative analysis of gill parasitism showed mean parasite counts of 4.08 ± 2.05 before the drought and 2.33 ± 1.35 after the drought. Despite this apparent decrease, the difference was not statistically significant ($p > 0.05$).

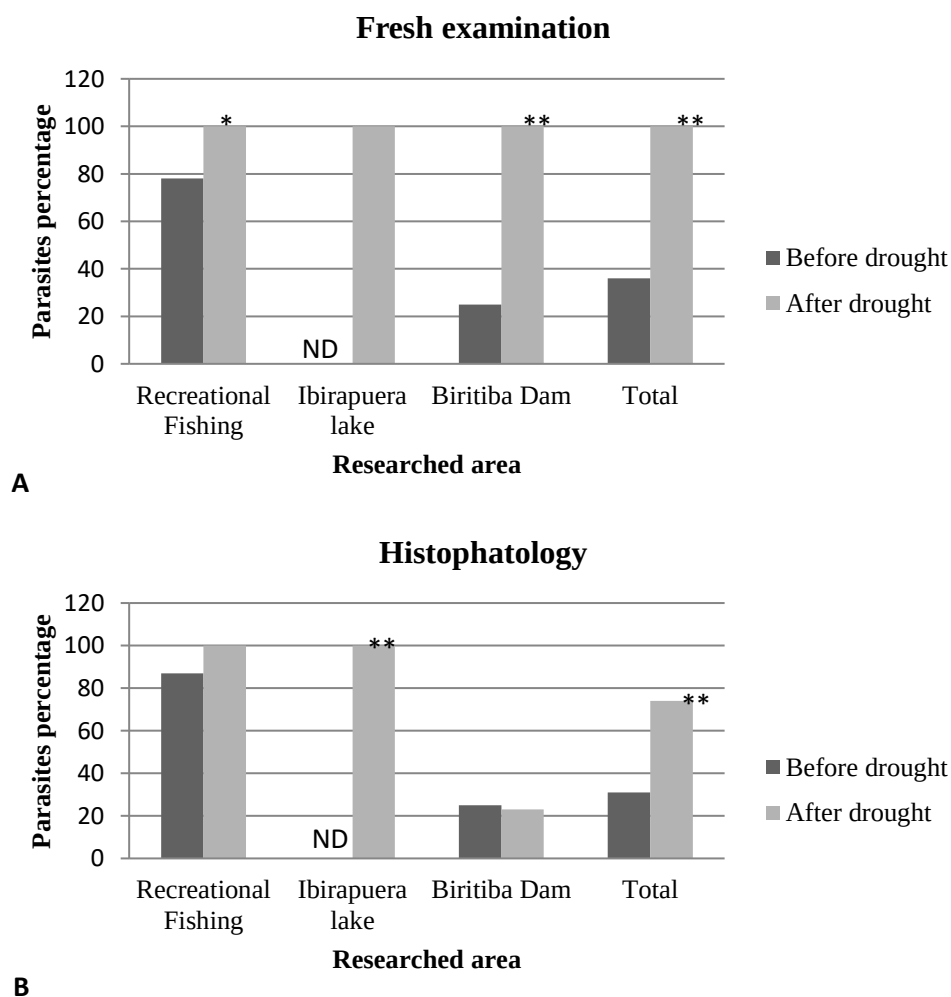


Figure 1. Parasites percentage observed in fresh examination (A) and by histopathology (B) of fish before and after the dry period in all studied areas. ND – Not identified. ** Statistically significant difference $P < 0.1$, Mann-Whitney test.

Table 2. Parasite prevalence found by fresh examination or histopathological analysis before and after the drought in the Recreational Fishing Lake, Ibirapuera Lake and Biritiba Dam.

Local	Parasite by fresh examination*		Parasites by histopathology**	
	Phase one (before drought) Positive number/total (%)	Phase two (after drought) Positive number/total (%)	Phase one (before drought) Positive number/total (%)	Phase two (after drought) Positive number/total (%)
Ibirapuera Lake	0/20 (0.0)	30/30 (100) ^a	0/20 (0.0)	30/30 (100) ^a
Biritiba Dam	5/20 (25.0)	30/30 (100) ^a	0/20 (0.0)	7/30 (23.4) ^a
Recreational fishing lake	18/23 (78.2)	27/27 (100) ^a	20/23 (87.0)	27/27 (100)
Total	23/63 (36.5)	87/87 (100) ^a	20/63 (31.8)	64/87 (73.5) ^a

*Fresh examination included gill smear and direct examination of the intestinal contents.

**Histopathology included a search for parasites in the gills and intestines.

a. Statistically significant difference $P < 0.1$, Mann-Whitney test.

3.3 Site-specific parasitological findings

3.3.1 Ibirapuera Lake

Prior to the drought, no parasites were detected in fish sampled from Ibirapuera Lake. However, following the drought, all examined fish (30/30) were infected with *Trichodina* sp. in their gills. Additionally, monogeneans were detected in a subset of specimens (7/30), and *Epistylis* sp. was observed in one fish presenting a skin lesion (Table 3). Despite the marked increase in parasite occurrence, park authorities reported no significant increase in fish mortality.

Table 3. Parasites found in fishes of the Recreational Fishing Lake, Ibirapuera Lake and Biritiba Dam before and after drought.

	Parasites	Positive number before drought/total (%)	Positive number after drought/total (%)	Sample
Ibirapuera Lake	<i>Trichodina</i> sp.	-	30/30 (100)	Gill
	Monogenea	-	7/30 (23.3)	Gill
	<i>Epistylis</i> sp.	-	1/30 (3.3)	Skin lesion
Biritiba Dam	<i>Amoebae</i> sp.	-	20/30 (66.7)	Intestinal contents
	<i>Entamoeba</i> sp.	-	20/30 (66.7)	
	<i>Balantidium</i> sp.	-	4/30 (13.3)	

Recreational Fishing Lake	<i>Piscinoodinium</i>	-	2/30 (6.6)	Intestinal
	sp.	5/20 (25)	2/30 (6.6)	contents
	Trematodes eggs	-	7/30 (23.3)	Intestinal
	Monogenea			contents
				Gill
				Intestinal
				contents
				Gill
	<i>Trichodina</i> sp.	18/23 (78.2)	27/27 (100)	Gill
	<i>Myxobolus</i> sp.	3/23 (13)	-	Gill
	<i>Henneguya</i> sp.	9/23 (39.1)	4/27 (14.8)	Gill
	<i>Ichthyophthirius</i>	2/23 (8.7)	-	Gill
	<i>multifiliis</i>	-	2/27 (7.4)	Gill
	Monogenea			

3.3.2 Biritiba Reservoir

Before the drought, trematode eggs were detected in 5 out of 20 fish examined. After the drought, all sampled fish showed parasitic infections. Post-drought findings included intestinal protozoans such as unidentified amoebae (20/30), *Entamoeba* sp. (20/30), and *Balantidium* sp. (4/30). In addition, gill parasites such as *Piscinoodinium* sp. (2/30) and monogeneans (7/30) were observed (Tables 2 and 3). Unlike the pattern observed in Ibirapuera Lake, parasitic infections in Biritiba Reservoir were predominantly located in the intestinal tract rather than the gills.

3.3.3 Recreational Fishing Lake

Parasite occurrence was high during both sampling periods in the Recreational Fishing Lake. However, parasite composition and intensity shifted noticeably after the drought, particularly in gill infections. Before the drought, the following parasites were identified: *Trichodina* sp. (18/23), *Myxobolus* sp. (3/23), *Henneguya shaharini* (9/23), and *Ichthyophthirius multifiliis* (2/23). After the drought, *Trichodina* sp. was detected in all examined fish (27/27), while *Henneguya shaharini* (4/27) and monogeneans (2/27) were also recorded. Gill colonization by *Trichodina* sp. increased markedly, suggesting a strong association with environmental stress conditions (Table 3).

3.3.4 Histopathological findings

The most significant pathological alterations were observed in the gills. These included: fusion of secondary lamellae, epithelial hyperplasia, degenerative changes associated with parasitic attachment, mucous cell hyperplasia, and inflammatory

infiltrates (Figure 2). In internal organs, lesions included focal necrosis, hyperchromatic cells, hepatic steatosis, and increased melanomacrophage centers. These findings indicate tissue responses consistent with chronic environmental stress and parasitic infection.

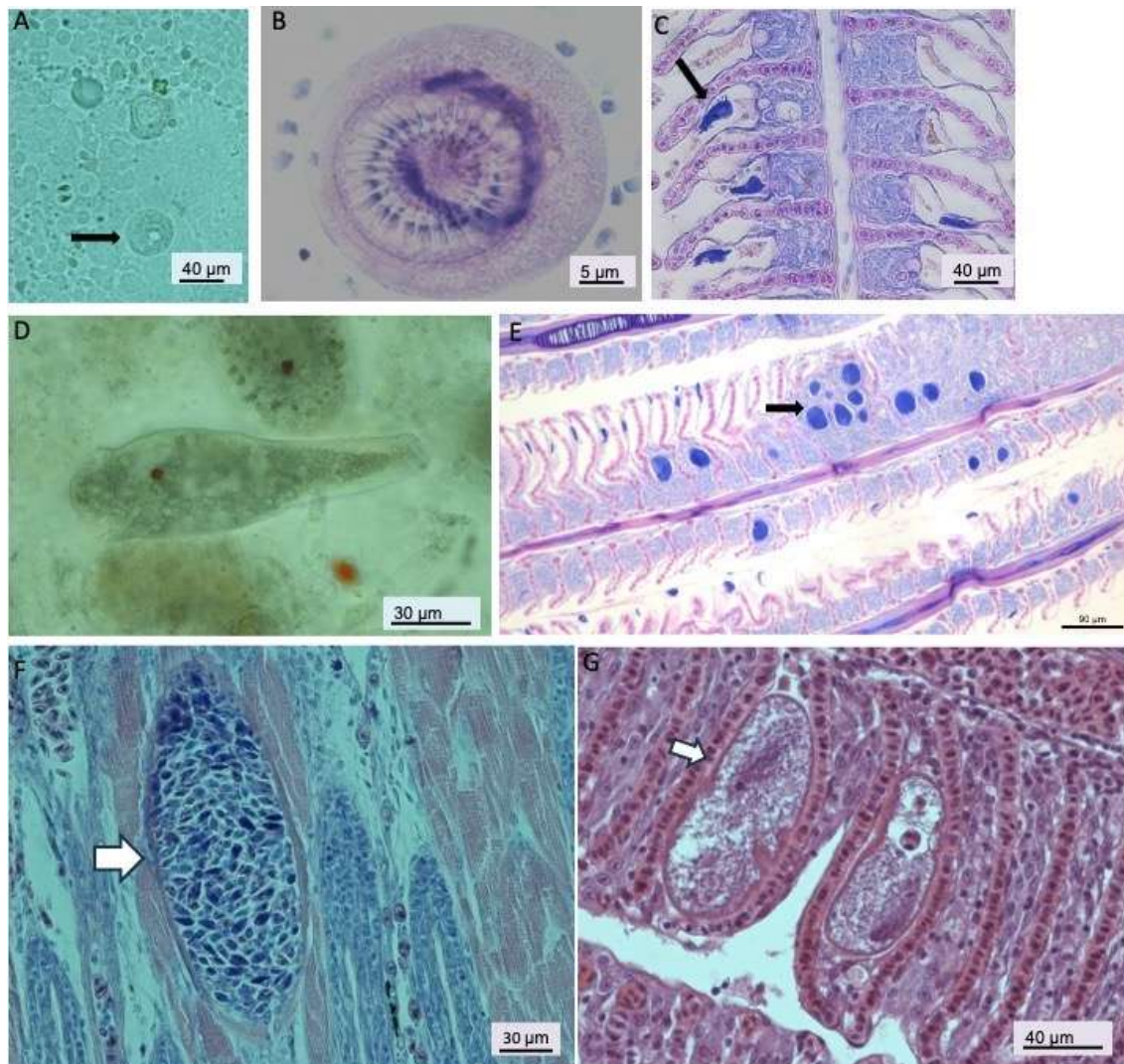


Figure 2. A- *Trichodina* sp. on the gill of *Oreochromis niloticus* from Ibirapuera Lake by fresh examination (scale bar=40 µm). B- Detail of *Trichodina* sp. (Giemsa stain, Scale bar=5 µm). C- Cross-section of gill showing *Trichodina* sp. between the secondary lamellae (Giemsa stain, scale bar=40 µm). D- *Epistylis* sp. on the fin of *Oreochromis niloticus* from Ibirapuera Lake by fresh examination (scale bar=30 µm). E- Cross-section of gill showing *Henneguya* sp. cyst (scale bar = 90 µm). F- Large cyst of *Myxobolus* sp. in the muscle associated with the branchial arch of *Geophagus brasiliensis* (Giemsa stain, Scale bar=150 µm). G- Monogenean parasites in gill lamellae (H&E, scale bar=40 µm).

3.5 Morphological characterization of parasites

3.5.1 Ciliates

Trichodina sp. presented variable morphology, including saucer-shaped and cylindrical forms, typically located between secondary gill lamellae. Fresh specimens exhibited characteristic ciliary motility (Fig. 2A, 2B, 2C).

Ichthyophthirius multifiliis measured 0.1-1.0 mm and displayed a distinctive horseshoe-shaped macronucleus.

Piscinoodinium sp. trophonts appeared as oval, non-motile structures measuring approximately 9–12 × 40–90 µm.

Balantidium sp. exhibited an oval shape, ranging from 40 to 140 × 25 to 115 µm, with a surface covered by longitudinal cilia.

Epistylis elongated on stalks; forms colonies, zooids with 40–80 µm x 20–30 µm (Fig. 2D).

3.5.2 Myxosporidia

Two genera were identified: *Henneguya* sp. (Fig. 2E) and *Myxobolus* sp (Fig. 2F).

Cysts of *Henneguya shaharini* were located within secondary gill lamellae, with free spores observed in fresh preparations.

Myxobolus sp. cysts were detected in muscle tissue associated with the gill arch.

3.5.3 Amoebae

Entamoeba sp. cysts were identified in intestinal samples, characterized by a small, round nucleus with a central nucleolus and peripheral chromatin granules.

Other amoeboid organisms were observed but could not be identified because the methods used had limited morphological resolution.

3.5.4 Monogeneans

Monogeneans of the family Gyrodactylidae were observed on gill surfaces, characterized by elongated bodies (~1 mm) and the presence of attachment structures (haptors) (Fig. 2G). Hook structures were confirmed in histological sections.

4. DISCUSSION

The relationship between ecosystem health and parasitic communities has been widely recognized in recent years (Marcogliese, 2005; Timi; Poulin, 2020). Parasites are integral components of aquatic ecosystems and play important roles in regulating host populations and shaping community structure. In addition, they can provide valuable information regarding environmental stress, food web dynamics, and biodiversity (Marcogliese, 2003; Biswas; Pramanik; Kumar, 2023).

In the present study, we observed marked changes in parasite occurrence and composition in freshwater fish following a severe drought event. These findings support the hypothesis that environmental disturbances—particularly those associated with reduced water availability—can influence host–parasite interactions. However, interpret these results with caution, as multiple interacting factors influence parasite dynamics.

Our results demonstrated a substantial increase in protozoan infections, especially *Trichodina* sp., in fish collected after the drought. This pattern was particularly evident in environments subject to natural hydrological variation, such as Ibirapuera Lake. The occurrence of ectoparasites in *O. niloticus* can be strongly influenced by environmental conditions. The abundance of *Trichodina* spp. may vary according to seasonal and limnological conditions, indicating that environmental factors can influence parasite dynamics. Because of their direct life cycle, trichodinids can respond rapidly to conditions that favor transmission and host susceptibility, supporting their potential usefulness as indicators of environmental change (Zago *et al.*, 2014).

Trichodinids are typically considered ectocommensals that feed on epithelial surfaces, particularly the skin and gills (Reyes-Mero *et al.*, 2024). Their mode of attachment can cause epithelial damage and may facilitate secondary infections (Lom; Dyková, 1992). The increased occurrence observed in this study may therefore reflect both environmental degradation and increased host susceptibility under stress conditions.

Eutrophication and organic pollution can enhance bacterial growth, which in turn supports higher densities of trichodinids (Lafferty, 2008; Sures *et al.*, 2023). Although our study did not directly measure water quality parameters, the observed increase in parasite occurrence following the drought suggests that reduced water volume may have concentrated nutrients and organic matter, thereby favoring parasite proliferation.

The response observed in the Recreational Fishing Lake further supports this interpretation. Despite artificial control of water levels and management practices,

Trichodina sp. occurrence increased after the drought. This suggests that even managed systems are not fully buffered against broader climatic influences.

In contrast, the Biritiba Reservoir exhibited a different parasitological pattern, characterized by increased intensity of intestinal protozoans, including free-living amoebae such as *Entamoeba* sp. These organisms are commonly found in aquatic environments and may act as opportunistic pathogens or commensals (Walochnik, 2014; Delumeau *et al.*, 2025). Their presence exclusively after the drought may indicate changes in water quality or microbial community composition.

Free-living amoebae interact with a variety of microorganisms, including bacteria and other pathogens, and can contribute to their persistence in the environment by protecting them from adverse conditions (Thomas *et al.*, 2010). From a public health perspective, their presence is noteworthy, as some species can harbor and transmit pathogenic microorganisms (Walochnik, 2014; Delumeau *et al.*, 2025). However, further studies are needed to assess their epidemiological significance in this context.

Species-specific responses were also observed. *Oreochromis niloticus*, a species widely used in aquaculture because of its tolerance to environmental variation, showed increased parasite loads after the drought. Although this species is generally considered resilient, our findings suggest that even tolerant hosts may become more susceptible under extreme environmental conditions.

Similarly, *Astyanax* spp., which are opportunistic feeders with broad ecological niches, showed potential as indicators of environmental change. Their typically low baseline parasitism, combined with increased infection rates following environmental stress, may make them particularly useful for monitoring ecosystem disturbances.

The response of myxosporean parasites was less evident, with a reduction in occurrence observed after the drought. However, this finding should not be interpreted as a direct effect of the extreme drought, since myxosporean occurrence is strongly dependent on parasite and host taxa, life-cycle requirements, and local environmental conditions. For many myxozoans, environmental changes may also indirectly affect transmission by altering the availability and abundance of invertebrate hosts needed to complete their life cycles. Therefore, the observed reduction may reflect changes in transmission dynamics rather than a direct response to drought, and this association should be interpreted with caution (Marcogliese; Gendron; Cone, 2009).

The absence of certain parasites may also indicate environmental change. The decline of myxosporeans observed in this study may reflect unfavorable conditions for their development or transmission, reinforcing the complexity of parasite–environment interactions.

Methodologically, our findings indicate that direct examination techniques, such as fresh gill and intestinal smears, were more effective for detecting parasites than histological analysis alone. Several organisms, particularly amoebae, were observed in fresh samples that were not associated with identifiable histopathological lesions. This highlights the importance of combining diagnostic approaches in parasitological studies.

5. CONCLUSION

In conclusion, our findings indicate that changes in parasite occurrence, particularly the increase in protozoan infections, were associated with the period following an extreme drought event. However, we cannot establish a direct causal relationship with drought, as parasite responses are taxon-specific and influenced by host characteristics, life-cycle requirements, and local environmental conditions. Parasitological examination of fresh gill and intestinal content preparations may provide a useful initial screening approach for detecting changes in selected parasite groups; nevertheless, given its taxonomic limitations, it should be complemented by appropriate morphological and/or molecular identification methods and interpreted alongside environmental and host-related variables. Further studies integrating parasitological, environmental, and microbiological data, particularly through long-term monitoring, are needed to clarify the effects of extreme environmental events on parasite dynamics and to assess the potential contribution of parasite communities to environmental monitoring of aquatic ecosystems.

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