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Metazoan parasite fauna of detritivorous and omnivorous fishes from Amapá Lake, in western Brazilian Amazon

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Abstract: Despite being an important component of the freshwater ecosystems and an important factor controlling wild fish populations, Amazonian fish parasites have been poorly studied. Here, we analyzed the fauna of metazoan parasites from 10 detritivorous and omnivorous fish species from Amapá Lake in the western Amazon. Of 159 fish specimens examined, 73.6% were parasitized by one or more species of metazoan parasites. A total of 5,260 parasites (24 Monogenea, 14 Nematoda, 10 Digenea, 2 Acanthocephala, and 6 Crustacea) were identified. Aggregated dispersion pattern of parasites was observed. There was a predominance of endohelminth species that presented a similar pattern regarding the level of component communities (i.e., a low species number, low diversity and dominance of a single species, mainly the digeneans and nematodes in their larval stages). Five species of parasites presented correlation with the body size of the hosts. In the fish community, the presence of endoparasites in the larval and adult stages suggests that these are intermediate, paratenic and definitive hosts, reflecting their detritivorous or omnivorous feeding habits. The trophic level and diet had an influence on the structuring of endohelminth communities and infracommunities. Lastly, 38% of the metazoan parasite species were new records for examined hosts.
Keywords: Diet; freshwater fish; infection; parasites.

Fauna parasitária de metazoários em peixes detritívoros e onívoros do Lago Amapá, na Amazônia Ocidental brasileira

Resumo: Apesar de ser um importante componente dos ecossistemas de água doce e um importante fator controlador das populações naturais de peixes, os parasitos de peixes amazônicos ainda são pouco estudados. Foi analisada a fauna de parasitos metazoários em 10 espécies de peixes detritívoros e onívoros do Lago Amapá na Amazônia ocidental. Dos 159 espécimes de peixes examinados, 73,6% estavam parasitados por uma ou mais espécies de parasitos metazoários. Um total de 5.260 parasitos (24 Monogenea, 14 Nematoda, 10 Digenea, 2 Acanthocephala e 6 Crustacea) foram identificados. Houve um padrão de dispersão agregado de parasitos. Houve predominância de espécies de endohelmintos que apresentaram padrão semelhante quanto ao nível de comunidades componentes, ou seja, baixo número de espécies, baixa diversidade e dominância de uma única espécie, principalmente os digenéticos e nematoides em estágio larval. Cinco espécies de parasitos apresentaram correlação com o tamanho corporal dos hospedeiros. Na comunidade de peixes, a presença de endoparasitos em fase larval e adulta sugere que esses são hospedeiros intermediários, paratênicos e definitivos, refletindo seus hábitos alimentares detritívoros ou onívoros. O nível trófico e dieta influenciaram na estruturação das comunidades e infracomunidades de endohelmintos. Por fim, 38% das espécies de parasitos metazoários foram novos registros para os hospedeiros examinados.
Palavras-chave: Dieta; infecção; parasitos; peixes de água doce.

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Introduction

Amapá Lake is located on the right bank of the Acre River and is 10 km from the city of Rio Branco, in the state of Acre (Brazil), in the southwestern Amazon region (10°02'043.5"S and 67°51'18.2"W), where horseshoe-shaped lakes are common. This lake was formed more than 40 years ago by an abandoned meandering of the Acre River. The lake is, therefore, isolated from the Acre River during the entire dry season, being connected with this river only during the flood season. It is an open and slightly deep body of water, about six km long with rich fauna and flora, and its margins are completely surrounded by dense tropical forest (Rodríguez-Zorro et al. 2015). From July to December, the lake remains hydrologically isolated from the main river channel. However, a connection is established when the river level exceeds 380 cm, thus surpassing the levee and flowing into the lake. This high-water period generally begins in January and lasts five to six months (Silva et al. 2013, Rodríguez-Zorro et al. 2015). More than sixty zooplankton species such as Rotifera, Cladocera and Cyclopoida have been found in this lake (Keppeler 2003, Keppeler & Hardy 2004, Keppeler et al. 2018). The lake, in addition to receiving the load of material in suspension from the forming river, at the time of the decennial floods, it undergoes silting and eutrophication processes resulting from human action. Among these actions are the predatory fishing, deforestation, the opening of an unpaved road, as well as the disordered occupation of its margins (Rodríguez-Zorro et al. 2015, Keppeler et al. 2018). More than a hundred families live in the area surrounding Amapá Lake.

This lake presents an ichthyofauna comprised of 53 species of 18 families and five orders, with predominance of small and medium-size fishes that have socioenvironmental importance, especially for local fishing (Pereira et al. 2011, Silva et al. 2013). Among these diverse species of fish are some Siluriformes and Characiformes. However, no study about the parasitic fauna in fish species from Amapá Lake is known. The parasites of *Pimelodus blochii* Valenciennes, 1840 (Negreiros et al. 2018), *Calophysus macropterus* Lichtenstein, 1819 (Negreiros et al. 2019) from the Acre River, as well as diverse fish species from rivers Juruá, Crôa, Paranã, Gama and Santa Rosa, in the state of Acre have been reported (Virgilio et al. 2022).

Parasites represent important components of global biodiversity in the ecosystems which have been neglected numerically and functionally for long time; despite them providing important information on the influence of environmental variation on species richness and diversity of parasites in the population distribution of hosts (Negreiros et al. 2019, Paterson et al. 2021, Virgílio et al. 2021). Parasites can be also important agents of selection on wild host populations, affecting host fitness through effects on host growth, reproduction and survival (Tavares-Dias et al. 2017, Virgílio et al. 2021). Due to the predominantly negative attention parasites receive, it is unsurprising that free-living species, as host fish, have received greater biodiversity conservation attention than the parasite species they harbor. However, understanding which factors drive differences in parasite diversity in wild fish populations has long been of great interest in fish parasitology (Paterson et al. 2021).

Amazonian wild fish populations can generally harbor ectoparasites and endoparasites of diverse taxa, which display a variety of strategies in direct or indirect their life cycle. Freshwater fish of this Neotropical region can be parasitized by several taxa of metazoans in larval and adult stages (Karling et al. 2013, Tavares-Dias et al. 2014, Baia et al.
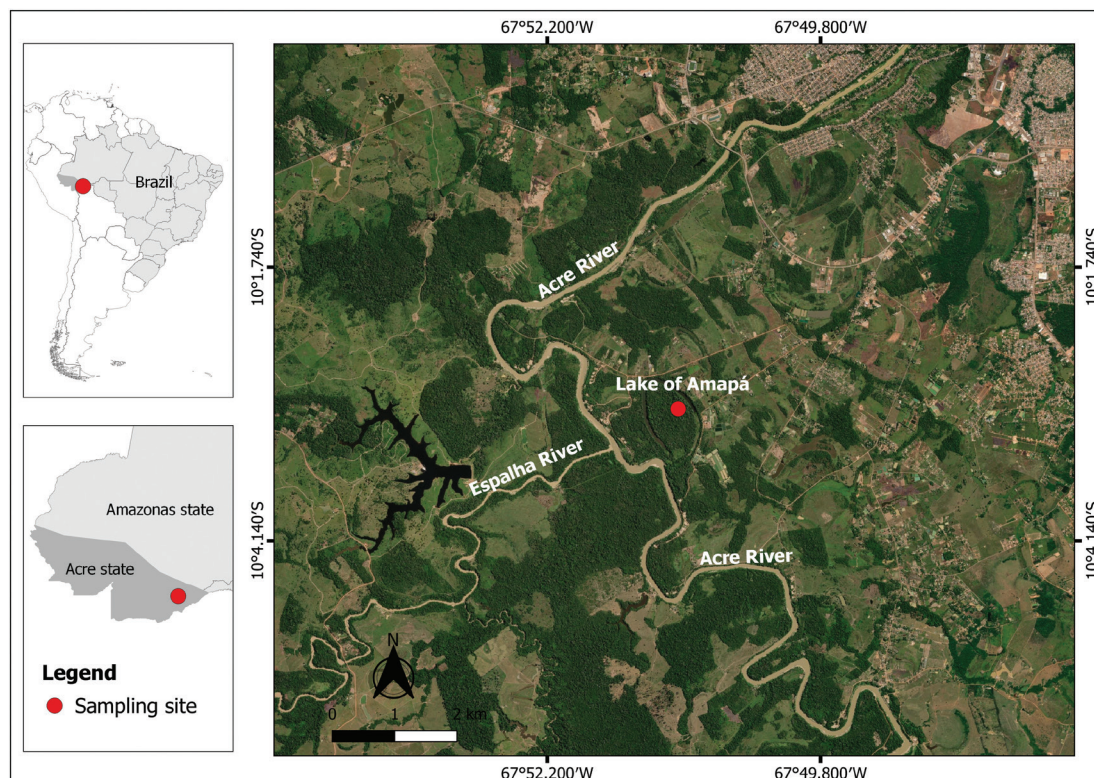

Figure 1. Collection site of the fish in Amapá Lake, in western Amazon (Brazil).

2018, Negreiros et al. 2018, Negreiros et al. 2019, Neves et al. 2021, Virgilio et al. 2021). These parasites, particularly endohelminths, have life cycles that involve transmission through a trophic web of intermediate, paratenic and definitive hosts (Karling et al. 2013; Baia et al., 2018, Neves et al. 2021, Virgilio et al. 2021, Virgilio et al. 2022). Hence, endohelminths can provide information regarding trophic interactions because their complex life cycle requires multiple hosts. The aim of study was to investigate the fauna of metazoan parasites in 10 detritivorous and omnivorous fish species from the Amapá Lake, in the State of Acre (Brazil). These fish species that occur in greater abundance in Amapá Lake.

Material and Methods

From December 2019 to December 2021, 10 fish species (Table 1) were collected in Lake Amapá (Figure 1), in the municipality of Rio Branco, in the State of Acre (Brazil). The fish were packed on ice and transported to the Multidisciplinary Laboratory of the Acre Federal Institute (IFAC), in Rio Branco (Brazil). Each fish was weighed (g) and measured in total length (cm), and analyzed for parasites. The gills, eyes, viscera and gastrointestinal tract of each fish were examined for the presence of metazoan parasites. The parasites were collected, fixed, preserved and prepared for identification according to the methods suggested by Eiras et al. (2006). To identify the parasites, previous recommendations were used (Moravec 1998, Thatcher 2006, Kohn et al. 2007, Cohen et al. 2013, Rigby 2014).

Prevalence, mean intensity, and mean abundance were used to describe parasite infection parameters (Bush et al. 1997). The dispersion index (ID) and Poulin discrepancy index (D) were calculated using the Quantitative Parasitology 3.0 software to detect the distribution pattern of each parasite infracommunity with a prevalence >10% (Rózsa et al. 2000). The significance of the ID for each parasite infracommunity was tested using the d-statistical test (Ludwig & 1988). Spearman's correlation coefficient (rs) was used to determine possible correlations between the abundance of parasites and the length and weight of host fish (Zar 2010).

This study was approved by the Ethics Committee for the Use of Animals at Embrapa Amapá (Protocol Nº 014/2018 – CEUA/CPAFAP).

Results

A total of 159 specimens of four species of detritivorous and six omnivorous fish were examined (Table 1).

The host fish were parasitized by 56 taxa of metazoan parasites: 24 species of Monogenea, 14 species of Nematoda, 2 Acanthocephala, 10 Digenea and 6 Crustacea. Of the 159 fish examined, 73.6% (N = 117) were parasitized by one or more species of metazoan parasites. A total of 5,260 parasites were recovered mostly of the gills and intestine of the host fish. Prevalence, mean intensity and mean abundance of the parasites varied between the host species examined (Table 2).

The parasites of *Potamorhina latior* Spix & Agassiz, 1829 and *Hypophthalmus marginatus* Valenciennes, 1840 showed an aggregated dispersion pattern, and in some infracommunities this pattern was highly aggregated (Table 3).

A positive correlation of Proterodiplostomidae gen. sp. abundance with the body length of *Curimata inornata* Vari, 1989, and a negative correlation with the body length and weight of *P. latior* was found. A positive correlation of monogenean abundance with the body weight, as well as of the *Miracetyma* sp. abundance with the length of *H. marginatus* was observed. There is also a positive correlation of abundance of *Notozothecium lamotherargumedoi* Cohen & Kohn, 2008 with the length of *Rhaphiodon vulpinus* Spix & Agassiz, 1829 (Table 4).

Table 1. Body parameters of fish from Amapá Lake, in western Amazon (Brazil).

Fish species	Family	N	Weight (g)	Length (cm)	Trophic level*	Main feeding items*
Curimata inornata Vari, 1989	Curimatidae	8	74.3 ± 13.9	18.2 ± 1.2	Detritivorous	Zoobenthos, algae and detritus
Curimatella meyeri Steindachner, 1882	Curimatidae	13	124.5 ± 37.7	18.2 ± 1.3	Detritivorous	Detritus and aquatic plants
Potamorhina latior Spix & Agassiz, 1829	Curimatidae	31	82.5 ± 22.4	18.6 ± 2.5	Detritivorous	Detritus and aquatic plant
Psectrogaster rutiloides Kner, 1858	Curimatidae	8	76.3 ± 18.1	16.2 ± 1.1	Detritivorous	Detritus, aquatic plants and periphyton
Rhaphiodon vulpinus Spix & Agassiz, 1829	Cynodontidae	13	191.1 ± 96.5	34.9 ± 4.0	Omnivorous	Nekton and fish
Hypophthalmus marginatus Valenciennes, 1840	Pimelodidae	34	269.3 ± 69.3	33.2 ± 4.9	Omnivorous	Zooplankton and invertebrates
Nemadoras humeralis Kner, 1855	Doradidae	19	43.3 ± 15.4	14.3 ± 0.6	Omnivorous	Detritus, aquatic plants, invertebrates, crustacean and fish
Auchenipterus nuchalis Spix & Agassiz, 1829	Auchenipteridae	15	78.0 ± 14.7	19.8 ± 1.2	Omnivorous	Zoobenthos, nekton, insects, invertebrates, crustacean and fish
Pimelodus blochii Valenciennes, 1840	Pimelodidae	14	63.2 ± 40.1	19.6 ± 3.1	Omnivorous	Zoobenthos, nekton, detritus, aquatic plants, insects, invertebrates, crustacean and fish
Sorubim lima Bloch & Schneider, 1801	Pimelodidae	4	73.8 ± 24.7	27.0 ± 2.8	Omnivorous	Zoobenthos, nekton, detritus, aquatic plants, insects, invertebrates, crustacean and fish

*Based on Froese and Pauly (2023).

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Table 2. Metazoan parasites in fish species from Amapá Lake, in western Amazon (Brazil).

Host species	Parasite species	P (%)	MI	MA	TNP	Infection site
Psectrogaster rutiloides	–	0	0	–	–	–
Curimata inornata	Proterodiplostomidae gen. sp. (metacercariae)	37.5	42.0	15.8	126	Intestine
	Ergasilus jaraquensis Thatcher & Robertson, 1982 #	12.5	1.0	0.1	1	Gills
Curimatella meyeri	Dactylogyridae gen. sp.1	23.1	2.0	0.5	6	Gills
	Dactylogyridae gen. sp.2	7.1	1.0	0.08	1	Gills
Potamorhina latior	Dactylogyridae gen. sp.1	3.2	2.0	0.1	2	Gills
	Dactylogyridae gen. sp.2	22.6	2.4	0.5	17	Gills
	Dactylogyridae gen. sp.3	9.7	2.7	0.3	8	Gills
	Dactylogyridae gen. sp.4	6.6	1.0	0.06	2	Gills
	Anacanthorus spathulatus Kritsky, Boeger & Van Every, 1992#	9.7	9.7	0.9	29	Gills
	Anacanthorus thatcheri Boeger & Kritsky 1988 #	3.2	1.0	0.03	1	Gills
	Anacanthorus sp.#	3.2	1.0	0.03	1	Gills
	Rhinoxenus sp.#	3.2	1.0	0.03	1	Gills
	Proterodiplostomidae gen. sp. and Diplostomidae gen. sp. (metacercariae)	67.7	56.2	38.1	1181	Intestine
	Anisakidae gen. sp. (larvae)	6.5	3.0	0.2	6	Liver
	Miracetyma etimaruya Malta, 1993	14.3	3.0	0.3	9	Gills
Rhaphiodon vulpinus	*Notozothecium lamotherargumedoi* Cohen & Kohn, 2008	100	42.5	43.5	553	Gills
	Digenea gen. sp. (metacercariae)	7.7	7.0	0.5	7	Intestine
	Eustrongylides sp. (larvae)#	7.7	3.0	0.2	3	Intestine
	Contracaecum sp.L3 (larvae)	7.7	3.0	0.2	3	Liver
	Terranova sp. L3 (larvae)#	30.8	13.0	4.0	52	Intestine
	Spirocamallanus sp.#	7.7	1.0	0.1	1	Intestine
	Pseudoproleptus sp. (larvae)#	7.7	28.0	2.2	28	Intestine
	Anisakidae gen. sp. (larvae)	7.7	19.0	1.5	19	Intestine
	Ergasilus tipurus Varella, Morey & Malta, 2019	46.2	5.5	2.2	33	Gills
	Miracetyma kawa Malta, 1994	7.7	4.0	3.0	4	Gills
Hypophthalmus marginatus	Dactylogyridae gen. sp.1	2.9	8.0	0.2	8	Gills
	Dactylogyridae gen. sp.2	5.9	3.0	0.2	6	Gills
	Ameloblastella edentensis Mendoza-Franco, Mendoza-Palmero & Scholz, 2016 #	79.4	57.2	43.8	1484	Gills
	Ameloblastella martinae Mendoza-Palmero, Rossin, Irigoitia & Scholz, 2020 #	5.9	4.0	0.2	8	Gills
	Ameloblastella peruensis Mendoza-Franco, Mendoza-Palmero & Scholz, 2016#	8.7	4.5	0.3	9	Gills
	Digenea gen. sp. (metacercariae)	14.7	5.4	0.8	27	Intestine
	Contracaecum sp.L3 (larvae)#	20.6	33.2	7.8	266	Intestine
	Anisakidae gen.sp. (larvae)	14.7	12.4	1.9	62	Liver
	Terranova sp. L3 (larvae)#	5.9	11.5	0.7	23	Abdominal cavity
	Neochinorhynchus sp. (larvae)	32.4	11.7	3.9	129	Intestine
	Miracetyma sp.#	73.5	23.8	28.0	595	Gills
Nemadoras humeralis	*Cosmetocleithrum* sp.1#	10.5	11.5	1.2	23	Gills
	Cosmetocleithrum sp.2#	10.5	2.0	0.1	2	Gills
	Dactylogyridae gen. sp.	10.5	2.0	0.1	2	Gills
	Rhipidocotyle sp. and Proterodiplostomidae gen. sp.#	31.6	9.2	2.9	55	Intestine
	Anisakidae gen. sp. (larvae)#	63.9	2.2	1.4	27	Intestine
	Isopoda gen. sp.	5.3	1.0	0.05	1	Gills
Pimelodus blochii	*Ameloblastella amazonica* Negreiros, Tavares-Dias & Pereira, 2019	7.1	31.0	2.2	31	Gills
	Ameloblastella satoi Monteiro, Kritsky & Brasil-Sato, 2010#	7.1	3.0	0.2	3	Gills

...Continuation

Host species	Parasite species	P (%)	MI	MA	TNP	Infection site
	Demidospermus striatus Mendoza-Palmero & Scholz, 2011	7.1	4.0	0.3	4	Gills
	Demidospermus leptosynophalus Kritsky & Gutiérrez, 1996	7.1	2.0	0.1	2	Gills
	Demidospermus peruvianus Mendoza-Palmero & Scholz, 2011	7.1	56.0	4.0	56	Gills
	Digenea gen. sp. (metacercariae)	7.1	1.0	0.07	1	Intestine
	Prosthenhystera obesa Diesing, 1850	7.1	1.0	0.07	1	Intestine
	Dadaytrema oxycephalum Diesing, 1850	21.4	14.0	2.9	42	Intestine
	Anisakidae gen. sp. (larvae)	28.6	8.7	2.5	35	Intestine
	Philometroide acreanensis Cavalcante, Moravec & Santos, 2017	7.1	2.0	0.1	2	Intestine
	Spirocamallanus pimelodus Pinto, Fabio, Noronha & Rolas, 1976	14.3	9.5	1.4	19	Intestine
	Ergasilus sp.	35.7	5.4	1.9	27	Gills
Sorubim lima	Digenea gen. sp. (metacercariae)	75.0	11.0	8.2	33	Intestine
	Anisakidae gen. sp. (larvae)	100	21.0	21.0	84	Intestine
Auchenipterus nuchalis	Diplostomidae gen. sp. (metacercariae)	6.7	46.0	3.1	46	Intestine
	Neochinorhynchus sp. (larvae) #	73.3	4.1	3.0	45	Intestine
	Spirocamallanus sp. (larvae) #	40	1.3	0.5	8	Intestine

P: Prevalence, MI: Mean intensity, MA: Mean abundance, TNP: Total number of parasites. #: First report for this host.

Table 3. Dispersion index (DI), *d*-statistic (*d*), and discrepancy index (D) for the infracommunity of metazoan parasites in fish species from Amapá Lake, in western Amazon (Brazil).

Host species	Parasite species	DI	*d*	D	Type of dispersion
Potamorhina latior	Monogeneans	1.848	2.345	0.668	Aggregated
Potamorhina latior	Proterodiplostomidae gen. sp. and Diplostomidae gen. sp.	3.639	6.591	0.494	Aggregated
Hypophthalmus marginatus	Monogeneans	3.052	6.007	0.429	Aggregated
Hypophthalmus marginatus	Digenea gen. sp.	2.04	3.418	0.838	Aggregated
Hypophthalmus marginatus	*Contracaecum* sp. L3	2.854	5.539	0.707	Aggregated
Hypophthalmus marginatus	Anisakidae gen. sp.	2.04	3.418	0.838	Aggregated
Hypophthalmus marginatus	*Miracetyma* sp.	2.737	5.535	0.497	Aggregated

Table 4. Spearman correlation coefficient (*rs*) of the abundance of metazoan parasites with the length and weight of fish species from Amapá Lake, in western Amazon (Brazil).

Host species	Parasite species	Weight		Length	
		rs	p	*rs*	p
Curimata inornata	Proterodiplostomidae gen. sp.	0.151	0.721	**0.731**	**0.039**
Curimatella meyeri	Dactylogyridae gen. sp. 1 and 2	0.098	0.751	0.124	0.686
Hypophthalmus marginatus	Monogeneans	**0.631**	**0.0001**	0.258	0.14
Hypophthalmus marginatus	Nematodes	0.054	0.762	0.249	0.156
Hypophthalmus marginatus	*Miracetyma* sp.	**0.639**	**0.0001**	−0.11	0.534
Potamorhina latior	Monogeneans	0.531	0.777	0.099	0.596
Potamorhina latior	Proterodiplostomidae gen. sp. and Diplostomidae gen. sp. (metacercariae)	**−0.349**	**0.045**	**−0.373**	**0.039**
Potamorhina latior	*Miracetyma etimaruya*	0.038	0.841	−0.037	0.844
Rhaphiodon vulpinus	*Notozothecium lamotherargumedoi*	0.391	0.186	**0.597**	**0.031**
Rhaphiodon vulpinus	*Terranova* sp. L3	0.051	0.887	0.037	0.903
Rhaphiodon vulpinus	*Ergasilus tipurus*	0.014	0.965	−0.419	0.154
Nemadoras humeralis	*Diplostomum* sp.	−0.17	0.486	0.022	0.93
Nemadoras humeralis	Anisakidae gen. sp	−0.435	0.063	−0.128	0.612

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Discussion

Host fish species of Amapá Lake occupying same trophic niche, but consuming different food items and presenting divergent feeding behavior, were exposed to different parasite species and had different parasite diversity, resulting in differences in the infection patterns. In parasites infracommunity level, these host fish showed a variation in the prevalence, intensity and abundance. Differences in exposure to parasites may have led to these divergences among sympatric host fish, which have differenced immunity. In addition, in *P. latior* and *H. marginatus,* an aggregated pattern of the parasites was found, and the level of aggregation varied between parasite species. In freshwater fish species, aggregated distribution of parasites is a common pattern and potentially influenced by factors related to parasites and host fish (Tavares-Dias et al. 2014, Neves et al. 2021). This distribution pattern of parasites indicates that either some fish are more attractive to the parasites or the infection is patchy, or both. Therefore, aggregated parasitic loads appear to be largely controlled by differences in opportunity for infection to occur that result from spending different amounts of time in vicinity of a hotspot of infection.

We found that the metazoan parasite communities of the 10 species of detritivorous and omnivorous fish here examined consisted of monogeneans, nematodes, acanthocephalans, digeneans and crustaceans, but with a dominance by monogeneans. However, some of the helminths were in the larval stages, including nematodes (24%), digeneans (18%) and acanthocephalans species (4.0%); hence, the predominance was of endoparasites in larval stage. This suggests that the host fish play an important role in the transmission dynamics of these endoparasites (Pavanelli et al. 2004, Neves et al. 2021). In the food web, the trophic level of populations host fish may be a good indicator regarding these hosts' exposure to parasites. In addition, the endohelminths presented a similar pattern regarding the level of component communities (i.e., a low species number, low diversity and dominance of a single species, mainly the digeneans and nematodes in larval stage). The endohelminth communities of an assemblage of omnivorous and piscivorous fish of Matapi River, a tributary of Amazon River system in northern Brazil, also presented a similar pattern regarding the component community level, i.e. a low number of species, low diversity and dominance of a single species, mainly nematode species (Neves et al. 2021). In an assemblage of detritivorous, carnivorous, omnivorous and piscivorous fish of a tributary from the Amazon River system in northern Brazil, the predominance was also of nematode species in larval stage (Baia et al. 2018). However, in an assemblage of detritivorous, omnivorous and piscivorous fish Juruá River system, a tributary of the Amazon River in northern Brazil, the predominance was of nematode and cestode species (Virgilio et al. 2021). Therefore, these characteristics seem to be adaptations to the food web and to the high densities of organisms distributed over wide spatial scales that are common in Amazonian ecosystems (Neves et al. 2021). The knowledge on the benthic and zooplankton species in these Amazonian ecosystems could provide information that are fundamental to explaining these compositions of the endohelminth fauna in these assemblages of host fish. Amapá Lake has more than sixty zooplankton species (Keppeler 2003, Keppeler & Hardy 2004, Keppeler et al. 2018), in addition to invertebrates as crustaceans and mollusks. Almost all digeneans uses mollusks as first intermediate host in their life cycle. Nematodes also have

complex life cycle involving several intermediate hosts, and their first intermediate hosts are nearly always invertebrates of the zooplankton fauna, particularly copepod species. Thus, surveys about the fauna of invertebrates may explain the compositions of the endohelminths in assemblages of host fish, because these parasites are transmitted to fish by predation of invertebrates, which are the primary intermediate hosts (Pavanelli et al. 2004, Karling et al., 2013; Mbokane et al. 2015, Baia et al. 2018, Neves et al. 2021). Thus, the presence of intermediate hosts in the aquatic environment may explain the abundance and diversity of the endoparasites of a certain region. The feeding habit of the host fish populations is one of the most relevant factors explaining the composition of the endoparasite species in this study, which hosts have different feeding habit.

In host fish, in addition to adaptations to environmental factors, specific adaptations to parasitic mode of life may lead to restriction of infections. These parasite-host interactions are generally characterized by highly complex processes. In host-parasite networks, the host fish body provides a microhabitat for parasite species of different taxa and with different life history and strategies attachment (Tavares-Dias et al. 2015, Neves et al. 2021, Oliveira et al. 2022). In this study, host-endoparasite interaction showed that the host fish provided a microhabitat, typically the intestine, for more than two third species of endohelminths which have different developmental strategies; mostly *R. vulpinus*, *H. marginatus* and *Pimelodus blochii* Valenciennes, 1840. In addition, there was a moderate diversity of endohelminths associated with each host species, as microhabitats are limited environments and because even susceptible host species are unable to harbor all of the parasites in a network. Although some host fish have the same feeding habits, they differ in body size and immune system, factors that restrict interactions between many parasite species (Bellay et al. 2013, Neves et al. 2021). Due to the complex relationship between parasites and the environment, initially the parasite attempts to establish itself in the host fish while the latter resist the infection via its defense mechanisms. Consequently, host susceptibility and resistance will determine whether the infection becomes established or not (Tavares-Dias et al. 2017). Variations in infection patterns also may be related to several biotic and abiotic factors (Tavares-Dias et al. 2014, Karling et al. 2013, Mbokane et al. 2015, Baia et al. 2018, Negreiros et al. 2018, Negreiros et al. 2019, Neves et al. 2021). However, *Psectrogaster rutiloides* Kner, 1858 from Amapá Lake was the single host uninfected among the examined host species, because only eight fish were examined.

Amapá Lake, in addition to receiving the load of material in suspension from the forming river, at the time of the decennial floods, it also undergoes silting and eutrophication processes resulting from anthropogenic action (Rodríguez-Zorro et al. 2015, Keppeler et al. 2018). Hence, monogenean species which are ectoparasites with simple and direct life cycle and that are present mainly in eutrophized and lentic environments (Dogiel 1961, Pavanelli et al. 2004, Cunha et al. 2021), were collected in 66.7% of the examined host fish. Metacercariae of digeneans were found in *C. inornata*, *P. latior*, *R. vulpinus*, *A. nuchalis*, *H. marginatus*, *Nemadoras humeralis* Kner, 1855, *P. blochii* and *Sorubim lima* Bloch & Schneider, 1801, which are intermediate hosts for these endoparasites with complex life cycle. Larvae of acanthocephalans were recovered only of *H. marginatus*. Nematode larvae, mostly anisakid species, were found in *P. latior*, *R. vulpinus*, *H. marginatus*, *N. humeralis*, *P. blochii* and *S. lima,*

which are secondary intermediate hosts for these endoparasites. Lentic ecosystems provide specific conditions, such as a higher water temperature and lower water currents, which facilitates concentration of the first and secondary intermediate hosts, thus increasing the probability of the cercariae of digeneans (Mbokane et al. 2015) and larvae of nematodes to locate its hosts. In addition, these conditions make the secondary intermediate hosts more vulnerable to predation by fish-eating birds, which are definitive hosts for some endohelminths species. Endohelminths in larval stages have been also reported for assemblage of omnivorous and piscivorous fish of Matapi River (Neves et al. 2021), as well as for assemblage of detritivorous, carnivorous, omnivorous and piscivorous fish from Igarapé Fortaleza River (Baia et al. 2018), due to presence of infective stages in these Amazonian environments.

Pimelodus blochii from Amapá Lake presented a community of endoparasites lower than reported for this same host of rivers Acre and Iaco in western Amazon (Negreiros et al. 2018). *Curimatella meyeri* Steindachner, 1882 was infected only by monogeneans while this same host from Juruá River was parasitized by *Cosmoxynema vianai* Travassos, 1949 and unidentified Cladorchiidae (Virgilio et al. 2021). These divergences in parasitofauna are influenced by the distinct environments of host fish. However, the community of endoparasites in *R. vulpinus* was similar to this same host of floodplain from upper Paraná River (Karling et al. 2013), as well as the monogenean fauna of hosts of lakes from the State of Amazonas (Morey & Malta, 2018). Third-stage larvae of *Contracaecum* sp., *Terranova* sp. and Anisakidae gen. sp. were found in *H. marginatus* of this study. However, for this same host from Tocantins River, larvae of third-stage of *Hysterothylacium* sp. and *Anisakis* sp. has been reported (Cárdenas et al. 2021).

A wide diversity of parasite crustacean species infests wild fish populations, and these can attack the gills, oral cavity, nostrils and/or skin of the hosts. Microhabitat in the gills, and the physical attributes of crustacean ectoparasites, have been proposed as causal factors for the distribution of host fish populations. It has been suggested that attachment site specificity is result of the need to avoid interspecific competition for space and food (Oliveira et al. 2022). Crustaceans are ectoparasites that can exhibit host specificity and interspecific variations, as well as affinity of microhabitat in the host fish (Tavares-Dias et al. 2015, Williams & Bunkley-Williams 2019, Oliveira et al., 2022). *Ergasilus jaraquensis* Thatcher & Robertson, 1982 occurred in *C. inornata*, *Miracetyma etimaruya* Malta, 1993 occurred in *P. latior*, *Miracetyma kawa* Malta, 1994 infested *R. vulpinus*, *Miracetyma* sp. was found in *H. marginatus*, *Ergasilus* sp. infested *P. blochii* and Isopoda unidentified infested *Nemadoras humeralis* Kner, 1855. These parasites were found attached in the gills of host fish, and in low infestation levels, except *Miracetyma* sp., which had a high prevalence and moderate intensity and abundance.

The body size of host fish can be another factor influencing the structure of infracommunities of parasites; however, this factor explains only part of the variation in parasite abundance, because other factors than host body size are more important determinants of this variation (Tavares-Dias et al. 2014, Mbokane et al. 2015, Baia et al. 2018, Negreiros et al. 2019, Neves et al. 2021). In *C. inornata*, the abundance of metacercariae of digeneans increased with host body size; contrarily, in *P. latior* decreased with increase in weight and length of the hosts. In *R. vulpinus*, the abundance of monogeneans increased with host length,

while in *H. marginatus* the abundance of monogeneans increased with host weight. These results suggest a variation in the feeding behavior of these fish in different age (Neves et al. 2021). Considering the complexity of these involved factors, further investigations need to be carried out in the future for a better understanding the influence of these factors in determining variation on parasite abundance.

In conclusion, data of the present study revealed interactions and importance on the parasite-hosts of an Amazonian lake. The metazoan parasites fauna was composed of different species and showed a dominance of monogeneans followed by nematodes > digeneans > crustaceans > acanthocephalans. The present study also revealed that 38% of the metazoan parasite species were new records for the different hosts examined. Endoparasites were found in the larval and adult stages, suggesting that these fish are intermediate, paratenic and definitive hosts, providing the basis for the development of these organisms and intermediating the way to their definitive hosts. Parasite-host interaction network reflected the detritivorous and omnivorous feeding habits of the sampled fish species, some of which are prey for other fish that are top of web. The size of the host fish had influence on the structuring of parasites infracommunities, but the trophic level and diet also had an influence. This epidemiological survey is the first attempt to understand patterns and processes of parasitic infections in wild fish populations in a lake of abandoned meandering in Amazon. Considering the complexity of the Amapá Lake, other investigations need to be conducted in the future for a better understanding of other factors that may determine the patterns and processes in the acquisition of parasite species. Lastly, this study established diversity and infection data for the metazoan parasite fauna of some fish species in the Amapá Lake, an ecosystem that is subject to increase in environmental changes due to agriculture activities, deforestation and urbanization. Therefore, these data could be used for comparisons in future studies regarding environmental anthropogenic impacts in this lake.

Associate Editor

Juan Schmitter-Soto

Author Contributions

Luciano Pereira Negreiros: substantial contribution to the idea and design of the study, and contribution to the analysis and interpretation of data, the writing of the paper, and critical review (adding intellectual content).

João Victor Couto: contribution to the identification of parasites
Marcos Tavares-Dias: contribution to the analysis and interpretation of data, the writing of the paper, and critical review (adding intellectual content).

Conflicts of Interest

The authors declare no conflict of interest related to the publication of this manuscript.

Ethics

Ethics approval to obtain access to genetic heritage was authorized by the Brazilian Ministry of the Environment (SISBio No 71522–1). This study was developed in accordance with the principles adopted by the Brazilian College of Animal Experimentation (COBEA) and was conducted under authorization from the Ethics Committee for Animal Use of Embrapa Amapá (Protocol Nº 014/2018).

Data Availability

Records of specimens of 10 fish species with the respective measurements (weight and length) and taxonomic identification, location, collecting date and abundance of parasites. https://data.scielo. org/file.xhtml?fileId=5611&version=DRAFT

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