

# Unveiling new data on fish parasite diversity in reservoirs of the Brazilian semi-arid

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## Research Paper

**Cite this article:** de Lima VMM, Mendonça-Filho JCG, Lima MKO, Honório LCB, Falkenberg JM, Yamada FH, Yamada POF, Lustosa-Costa SY, Ramos TPA, Teixeira de Mello F, Menezes RF, Windsor FM and Lacerda ACF (2025). Unveiling new data on fish parasite diversity in reservoirs of the Brazilian semi-arid. *Journal of Helminthology*, **99**, e56, 1–11  
<https://doi.org/10.1017/S0022149X25000288>

Received: 09 January 2025  
Revised: 25 February 2025  
Accepted: 26 February 2025

### Keywords:

Ichthyoparasitology; Paraíba; Mamanguape; Caatinga; host-parasite interactions

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### Abstract

Parasite biodiversity is underestimated or unknown in many regions, yet information on parasites is critical to understanding ecosystem structure and how this will change into the future. Understanding the diversity and role of parasites is especially important in regions exposed to anthropogenic pressures, such as aquatic ecosystems, as their interactions with other stressors can either exacerbate or mediate negative impacts. Water scarcity in the Brazilian semi-arid has led to a proliferation of reservoirs for human use. These artificial waterbodies host a diversity of taxa, including a large number of fish species; however, fish parasite diversity remains undocumented. This study investigated the parasitological diversity of fishes from reservoirs in the Paraíba and Mamanguape River basins in the Caatinga domain, Brazil – one of the most populated semi-arid regions worldwide. Eight reservoirs were studied, with fish sampled across the two phases of the hydrological cycle (dry and rainy seasons) using gillnets, cast nets, and trawl nets. Endo- and ecto-parasites were identified and enumerated, and parasitological indices (prevalence, intensity, and abundance) were calculated. In total, 1,170 individuals of 21 fish species were examined. Of these individuals, 42% were parasitized with at least one of 54 parasite taxa. We recorded 32 new geographical occurrences of parasites and 23 new fish-parasite interactions, expanding our understanding of ichthyoparasite diversity in the Brazilian semi-arid. Moving forward, it is important to develop knowledge around how anthropogenic changes (e.g., biological invasions, climate, and land use change) influence host-parasite structure and dynamics and ecosystem functioning in these ecosystems.

### Introduction

Parasites live in and/or on other organisms, obtaining the necessary resources for their survival, such as shelter, protection, or food (Goater *et al.* 2014). Although parasites are often associated with diseases, zoonoses, and economic losses, they contribute significantly to biodiversity and biomass across ecosystems, as well as support essential ecosystem functions (Frainer *et al.* 2018; Hudson *et al.* 2006). Despite this, parasite biodiversity is underestimated or unknown in many regions, for different reasons, including geographical biases and lack of knowledge of the host fauna itself (Poulin 2014; Poulin *et al.* 2023). In this sense, studies surveying parasite assemblages in locations not yet studied are extremely important for the knowledge of local biodiversity, especially in regions that suffer from anthropogenic pressures, as is the case in many continental aquatic environments worldwide (Morley 2007).

The Brazilian semi-arid zone, also known as the Caatinga domain, covers 70% of the Northeastern region of the country and is characterized by a high potential for evapotranspiration. As a result, the aquatic ecosystems in this region are either intermittent or artificial waterbodies, such as reservoirs (Silva *et al.* 2017). Such artificial waterbodies are widespread in the Caatinga domain due to water scarcity and long periods of meteorological drought, alongside the ever-increasing human need for water (Dantas *et al.* 2020). These reservoirs exhibit low outflow and high residence time, leading to nutrient accumulation and increasing their vulnerability to eutrophication and pollution (Barbosa *et al.* 2012). Moreover, they have fragmented natural fluvial habitats, resulting in habitat loss and disconnection, which have driven species loss, invasions, and biotic homogenization (Yamada *et al.* 2017).

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Changes on abiotic and biotic factors might lead to variation in parasite distribution, for example, due to the different life cycle complexities (Anderson *et al.* 2010). Hence, the most diverse host communities in theory will support a higher diversity of parasites and more stable trophic links (Hudson *et al.* 2006). As drivers of biodiversity, native parasites can shape the dynamics of the community, and the introduction of host species can lead to different scenarios (Chalkowski *et al.* 2018), including enemy release (Schatz and Park 2023) and release from the enemy effect (Lacerda *et al.* 2013a), or may lead to spillover and/or spillback of parasites, disrupting trophic interactions (Britton *et al.* 2013; Kelly *et al.* 2009; Llaberia-Robledillo *et al.* 2022). Parasites might represent an early indicator to assess impacts on the community dynamics affected by anthropogenic events (Falkenberg *et al.* 2019; Lacerda *et al.* 2018; Sures *et al.* 2023), and monitoring these dynamics in vulnerable systems, such as Caatinga domain reservoirs, can provide fundamental and faster answers regarding to those impacts (Marcogliese *et al.* 2005; Palm 2011).

Fishes are the most parasitized vertebrates (Poulin & Morand 2004), and among the known diversity of Brazil's freshwater ichthyofauna, approximately 11% have been reported as hosts (Eiras *et al.* 2011). There are approximately 400 fish species in the Caatinga domain, distributed across 137 genera, 34 families, and 7 orders (Lima *et al.* 2017). The Paraíba River Basin, which is predominantly situated in the Caatinga domain, is home to a diversity of 47 freshwater fish species, distributed across 38 genera, 20 families, and 6 orders (Ramos *et al.* 2018), and the Mamanguape River Basin is home to 32 freshwater fish species distributed across 26 genera, 16 families, and 6 orders (Oliveira-Silva *et al.* 2018). Both basins are located in the Paraíba geographical state, one of the semi-arid areas most densely populated in the world and a region with significant socio-economic concerns as a consequence of water deficits caused by recurrent meteorological and hydrological droughts (Dantas *et al.* 2020).

Despite the high diversity of potential hosts, a significant portion of the parasite fauna in Brazil remains undocumented (Luque and Poulin 2007). The main aim of this study was therefore to expand data on fish parasite diversity, providing the first inventory

for fish parasite interactions in eight reservoirs in the Caatinga domain and widen our understanding of ichthyoparasites in these ecologically vulnerable and socio-economically crucial ecosystems. In addition, current and future changes plan to deal with water scarcity in the region, such as a water diversion project and its consequences for the aquatic biota (Sousa *et al.* 2025), emphasizing the timeliness of the present inventory.

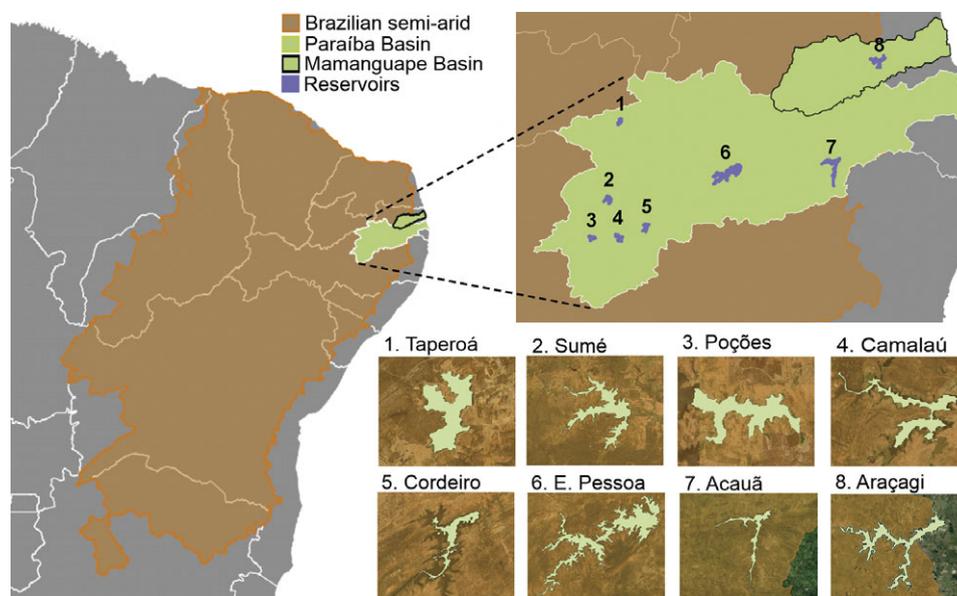
## Material and methods

### Study area

The Paraíba River Basin (37° 20' to 36° 10' W and 7° 20' to 8° 20' S), on the Borborema Plateau, represents 32% of the Paraíba state area and drains total or partially 85 municipalities (Xavier *et al.* 2012). A total of eight reservoirs were selected: Poções Reservoir (Municipality of Monteiro), Camalaú Reservoir (Municipality of Camalaú), Epitácio Pessoa Reservoir (Municipality of Boqueirão), Acauã Reservoir (Municipality of Itatuba), Cordeiro Reservoir (Municipality of Congo), Sumé Reservoir (Municipality of Sumé), Taperoá Reservoir (Municipality of Taperoá), and Araçagi Reservoir in the Mamanguape River Basin (Municipality of Araçagi) (Figure 1).

### Sample collection

Sampling was carried out as part of the Long-Term Ecological Project (*Projeto Ecológico de Longa Duração Rio Paraíba Integrado*; PELD-RIPA). Due to the hydrological seasonality of the reservoirs (Barbosa *et al.* 2012), samples were collected during two distinct periods: one corresponding to the rainy season (May to June 2022) and another to the dry season (December 2021 to January 2022). At each reservoir, sampling was performed using three types of fish-collecting gear: gillnets, trawl nets, and cast nets. Two sets of gillnets were placed, with measures of 40 meters in length and 1.5 meters in height, and consisting of four 10-meter sections with different mesh sizes (60 mm, 80 mm, 100 mm, and 120 mm). The gillnets were installed in the littoral zone of the reservoirs in the late afternoon and retrieved after 12 hours. Additionally, two trawl nets measuring



**Figure 1.** Reservoirs of the Paraíba and Mamanguape River basins used in this study, and where they are geographically inserted.

10 m in length and 1.5 m in height were used, along with 6 casts of cast nets (16 palms with a mesh size of 2.5 cm). This sampling effort was conducted separately for each reservoir during both the rainy and dry seasons. Samplings were conducted with authorization from the Brazilian Biodiversity Authorization and Information System (SISBIO) (License number: 83108-4) and were registered at the National Genetic Heritage Management System (SISGEN) (Access Number: AB202CE).

Fish were euthanized with eugenol solution and fixed in 10% formalin, which was injected mainly into the abdominal cavity to ensure the preservation of organs and any parasites (Lucena *et al.* 2013; Malabarba and Reis 1987). In the laboratory, fish were identified (Ramos *et al.* 2018) and necropsied, with all potential infection sites examined – external tegument, nostrils, fins, mesentery, eyes, gills, heart, intestine, stomach, liver, kidneys, gallbladder, swim bladder, and gonads. Selected structures were observed under a stereomicroscope, and the parasites found were stored in microtubes with 70% ethanol (Eiras *et al.* 2006).

Before parasite identification, a series of processing methods was used to aid visualization: Nematoda specimens were clarified in lactic acid or Amman's lactophenol; Copepoda and Monogenea were mounted in slides with Grey & Wess's medium; and Digenea, Cestoda, and Acanthocephala were stained with Acetic Carmine (Eiras *et al.* 2006). To identify parasites, literature sources including Boxshall and Montú (1997), Cohen *et al.* (2013), Gibson *et al.* (2002), Moravec (1998), and Yamaguti (1963) were used. The specimens were identified to the lowest taxonomic level possible and grouped by the lower identification, sometimes with the use of morphospecies. All individuals identified at least to the family level were deposited at the Coleção de Invertebrados Paulo Young (CIPY), Universidade Federal da Paraíba, João Pessoa, except for those who only had damaged specimens (deposit numbers: UFPB.NEMA-170 to 175; UFPB.CRUST-7262 to 7266; UFPB.PLAT-97 to 124).

### Data analysis

For the data analysis, only the non-encysted parasites were considered. Parasitological indices (prevalence, mean intensity, and mean abundance) were calculated for the host-parasite interaction data following Bush *et al.* (1997) using the software Quantitative Parasitology (QPweb, version 1.0.15). All subsequent data analysis was completed using R (version 4.4.2) (R Core Team, 2024), and the 'vegan' (Oksanen *et al.* 2024), 'dplyr' (Wickham *et al.* 2023), 'iNEXT' (Hsieh *et al.* 2024), 'ggplot2' (Wickham 2016), and 'bipartite' (Dormann *et al.* 2008) packages. Rarefaction was completed to understand whether the sampling effort was sufficient for each host species to represent the parasite diversity. For the rarefaction curve, the 'q = 0' method was used to rarefy and extrapolate based on parasite richness per host (Chao *et al.* 2014). The overall host-parasite network for the region was visualised as a directed bipartite network, with nodes ordered by their similarity of interactions between hosts and parasites using correspondence analysis (CCA - Dormann *et al.* 2008).

Data are available at the DATA-PB repository (Lacerda & de Lima, 2025), and a version-controlled repository is also available for the code and analysis (<https://github.com/civlima/fish-parasite-diversity>).

### Results

A total of 1,170 fish were sampled and necropsied, belonging to 21 species: *Astyanax bimaculatus* (Linnaeus 1758) (n=282),

*Characidium bimaculatum* Fowler 1941 (n=3), *Cichla monoculus* Spix & Agassiz 1831 (n=22), *Cichlasoma orientale* Kullander 1983 (n=107), *Geophagus brasiliensis* (Quoy & Gaimard 1824) (n=137), *Hemigrammus marginatus* Ellis 1911 (n=63), *Hoplias malabaricus* (Bloch 1794) (n=70), *Hypostomus puarum* (Starks 1913) (n=27), *Leporinus piau* Fowler 1941 (n=29), *Moenkhausia costae* (Steindachner 1907) (n=3), *Oreochromis niloticus* (Linnaeus 1758) (n=239), *Plagioscion squamosissimus* (Heckel 1840) (n=8), *Poecilia vivipara* Bloch & Schneider 1801 (n=24), *Prochilodus brevis* Steindachner 1875 (n=72), *Psalidodon fasciatus* (Cuvier 1819) (n=1), *Psectrogaster rhomboides* Eigenmann & Eigenmann 1889 (n=7), *Saxatilia brasiliensis* (Bloch 1792) (syn. *Crenicichla brasiliensis*) (n=49), *Serrapinnus piaba* (Lütken 1875) (n=4), *Steindachnerina notonota* (Miranda Ribeiro 1937) (n=19), *Synbranchus marmoratus* Bloch 1795 (n=1), and *Triportheus signatus* (Garman 1890) (n=1).

Among the fishes collected, 42% of the individuals (n=491) were parasitized by at least one unencysted parasite, three species were parasitized only by cysts (*C. bimaculatum*, *P. rhomboides*, and *S. piaba*), and three species were not parasitized (*P. fasciatus*, *S. marmoratus*, and *T. signatus*). The rarefaction curve showed that *A. bimaculatus* is the host species most well-represented in parasite diversity, also highlighting *O. niloticus* as a host species with a high parasite diversity and greater abundance compared with *A. bimaculatus*. *Cichla monoculus*, *P. brevis*, and *H. malabaricus* supported high abundances of parasites, although parasite diversity was low (Figure 2).

A total of 3,567 non-cyst parasite specimens were identified, belonging to 52 taxa across seven parasitological groups. The groups recorded here were Monogenea (23 taxa), Digenea (10), Cestoda (1), Nematoda (12), Acanthocephala (1), Copepoda (4), and Argulidae (1) associated with 15 parasitized fish species (Figure 3; Table 1).

The most abundant taxa were *Cichlidogyrus* sp. 2 (Monogenea), parasitizing *O. niloticus*, and *Proteocephalus microscopicus* (Cestoda), parasitizing *C. monoculus* (Figure 4), which also presented the highest intensity value among the community. Other high values of mean intensities found were in the host *H. malabaricus*, for the digeneans *Sphincterodiplostomum* spp. and *Dendrorchis* sp. 1. High prevalences were present on *Procamallanus* (*Spirocamallanus*) *inopinatus* (Nematoda) in the host *L. piau*, *Austrodiplostomum compactum* (Digenea) in *P. squamosissimus*, and *Miracetyma piraya* (Copepoda) in *P. brevis* (Table 1).

There were 38 previously unrecorded parasite taxa for the Paraíba and Mamanguape River Basins. Additionally, 23 unknown host-parasite interactions were documented for the first time through this study, including the invasive host species *C. monoculus*, with the new record of interaction with the copepod *Lamproglana monodi* and the nematoda *Procamallanus* (*Spirocamallanus*) *neocaballeroi* (Figure 5).

### Discussion

Expanding our understanding of host-parasite interactions is critical to fully understand the impacts of anthropogenic activities on biodiversity. Here, we developed the knowledge of ichthyoparasites in an understudied region of Brazil, identifying previously unobserved parasite taxa and interactions for both native and invasive fishes. The data produced here contributes significantly to the inventory of fish-parasite interactions, with only a few existing studies on fish parasites, mainly at a community level, in Brazilian semi-arid freshwater systems. Regarding the Brazilian semi-arid

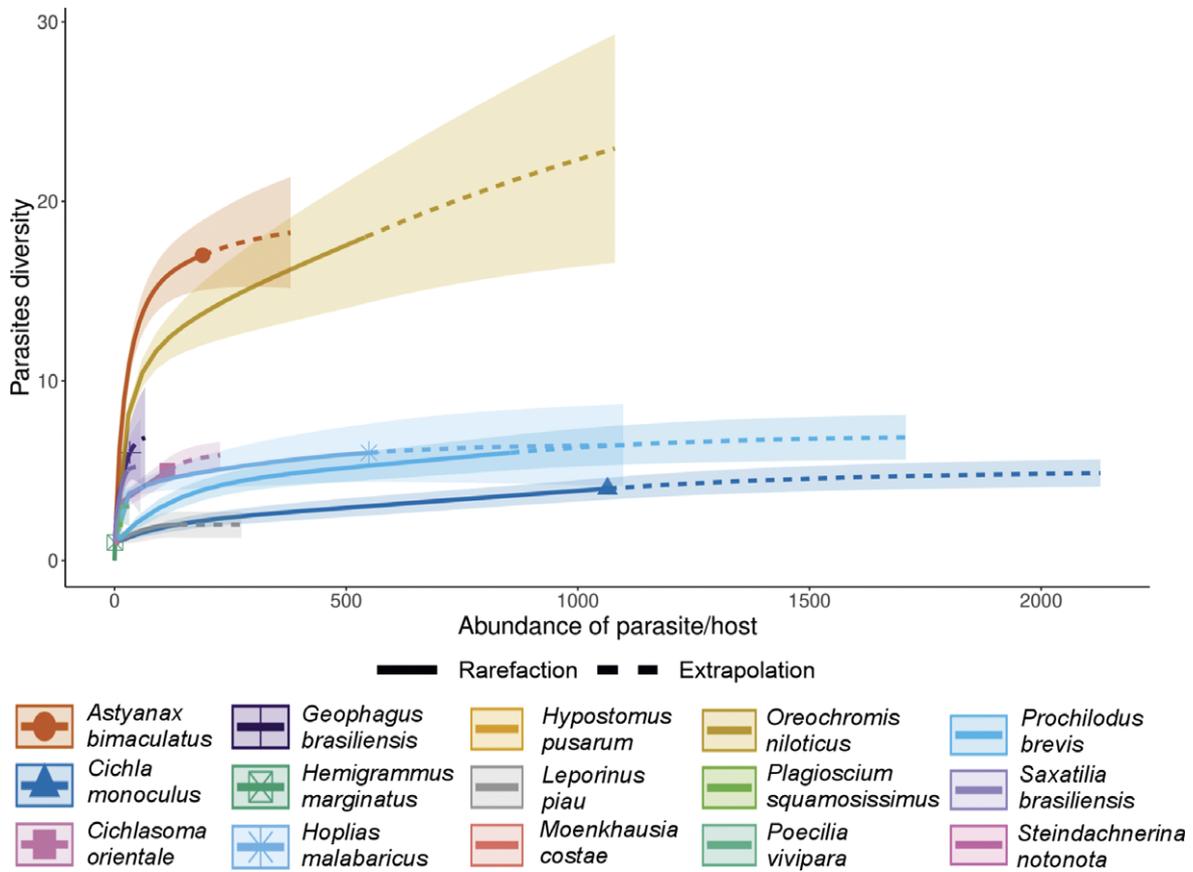


Figure 2. Rarefaction curve of parasite diversity based on species richness across host species on Paraiba and Mamanguape basins reservoirs.

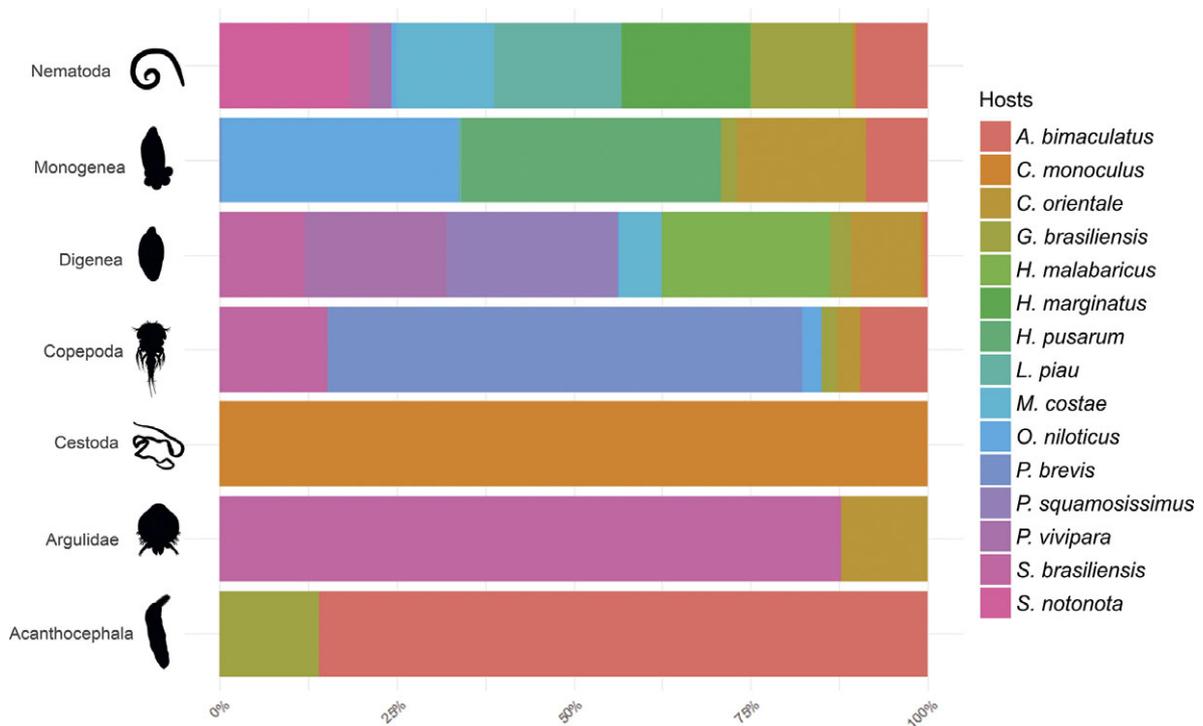


Figure 3. Relative abundance of the major parasite groups identified across all host species.

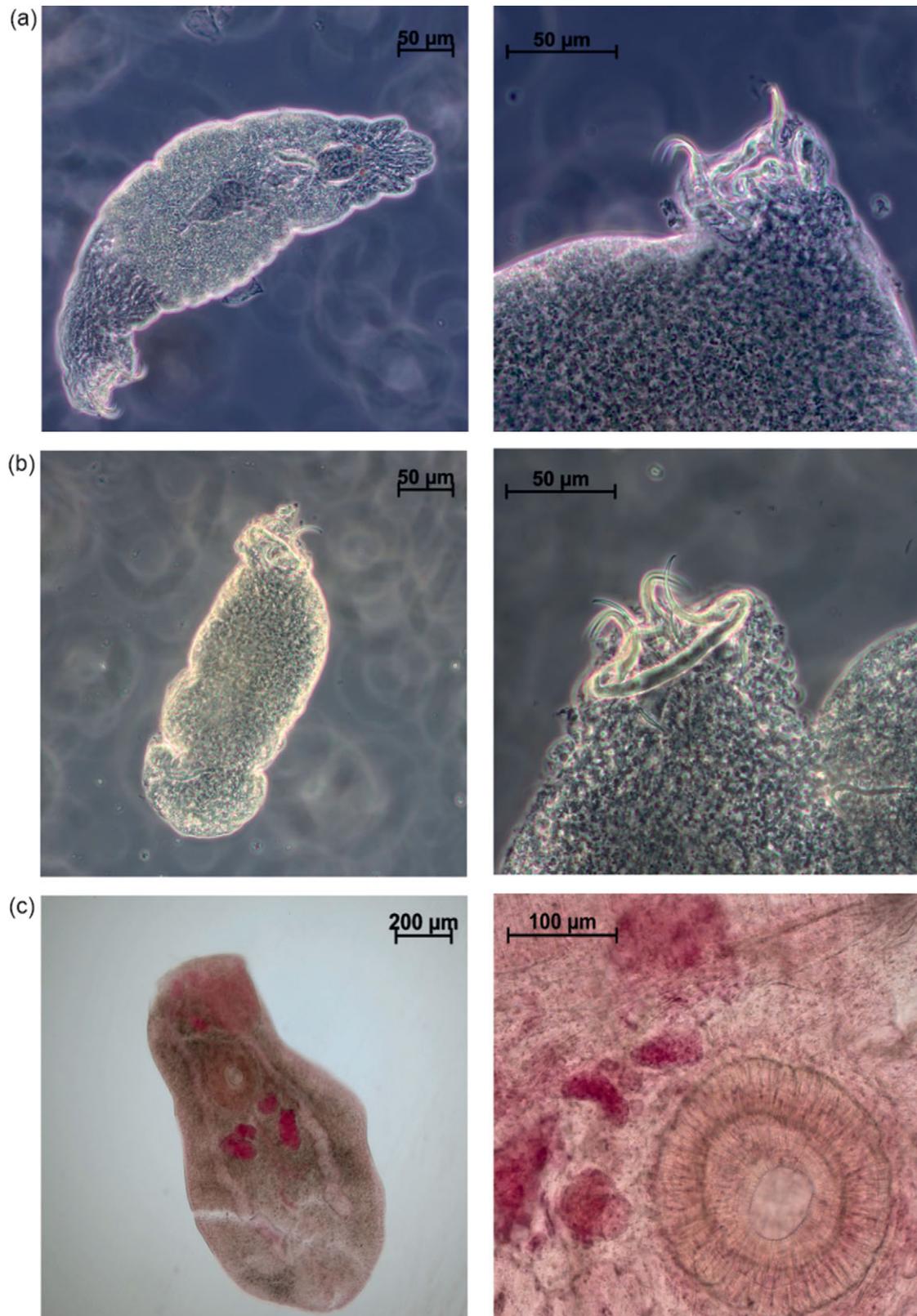
**Table 1.** Parasite indices for each host-parasite interaction. P (%) = prevalence; MI = mean intensity; MA = mean abundance; IS = infection site; CI = confidence interval. \*Only one host infected, standard deviation cannot be calculated. EY = eyes; FI = fins; GI = gills; GO = gonads; HE = heart; IC = intestinal caeca; IN = intestine; KI = kidney; LI = liver; ME = mesentery; SB = swim bladder; (M) = Metacercaria; (L) = Larva.

Parasite	Host	P (%) (CI)	MI (CI)	MA (CI)	IS
<b>Monogenea</b>					
<i>Characithecium bifurcuprolatum</i>	<i>A. bimaculatus</i>	2.10(0.00–0.04)	1.67(1.00–2.67)	0.03(0.01–0.08)	GI
<i>Characithecium costaricensis</i>	<i>A. bimaculatus</i>	1.10(0.00–0.03)	1.00*	0.01(0.00–0.02)	GI
<i>Characithecium</i> sp.	<i>A. bimaculatus</i>	0.01(0.00–0.04)	1.00*	0.01(0.00–0.03)	GI
<i>Cichlidogyrus halli</i>	<i>O. niloticus</i>	13.00(0.09–0.17)	5.68(4.10–7.94)	0.73(0.46–1.16)	GI
<i>Cichlidogyrus sclerosus</i>	<i>O. niloticus</i>	12.60(0.08–0.17)	5.00(3.80–7.03)	0.62(0.38–0.98)	GI
<i>Cichlidogyrus thurstonae</i>	<i>O. niloticus</i>	7.50(0.04–0.11)	1.50(1.06–2.94)	0.11(0.06–0.24)	GI
<i>Cichlidogyrus tilapiae</i>	<i>O. niloticus</i>	1.30(0.00–0.03)	1.33(1.00–1.67)	0.01(0.00–0.04)	GI
<i>Cichlidogyrus</i> sp. 1	<i>O. niloticus</i>	1.70(0.00–0.04)	1.00*	0.01(0.00–0.03)	GI
<i>Cichlidogyrus</i> sp. 2	<i>C. orientale</i>	0.90(0.00–0.05)	1.00*	0.00(0.00–0.02)	GI
	<i>O. niloticus</i>	5.90(0.03–0.09)	1.86(1.36–2.36)	109.00(0.05–0.19)	GI
<i>Cichlidogyrus</i> sp. 3	<i>O. niloticus</i>	0.40(0.00–0.02)	1.00*	0.01(0.00–0.01)	GI
<i>Cichlidogyrus</i> sp. 4	<i>O. niloticus</i>	0.40(0.00–0.02)	1.00*	0.01(0.00–0.01)	GI
<i>Cichlidogyrus</i> sp. 5	<i>O. niloticus</i>	2.90(0.01–0.05)	2.29(1.00–4.57)	0.06(0.02–0.21)	GI
<i>Cichlidogyrus</i> sp. 6	<i>O. niloticus</i>	3.30(0.01–0.06)	1.38(1.00–1.88)	0.04(0.01–0.09)	GI
<i>Cichlidogyrus</i> sp. 7	<i>O. niloticus</i>	0.40(0.00–0.02)	1.00*	0.01(0.00–0.01)	GI
<i>Cichlidogyrus</i> spp.	<i>O. niloticus</i>	9.60(0.06–0.14)	1.91(1.43–2.48)	0.18(0.11–0.29)	GI
Dactylogyridae gen. sp. 1	<i>C. orientale</i>	0.90(0.00–0.05)	1.00*	0.00(0.00–0.02)	GI
Dactylogyridae gen. sp. 2	<i>A. bimaculatus</i>	1.10(0.00–0.03)	2.00(1.00–3.00)	0.02(0.00–0.08)	GI
	<i>H. malabaricus</i>	1.40(0.00–0.07)	1.00*	0.01(0.00–0.04)	GI
<i>Diaphorocleidus magnus</i>	<i>A. bimaculatus</i>	1.10(0.00–0.03)	1.00*	0.01(0.00–0.02)	GI
<i>Diaphorocleidus</i> sp.	<i>A. bimaculatus</i>	4.30(0.02–0.07)	1.67(1.25–2.08)	0.07(0.03–0.12)	GI
<i>Scutogyrus longicornis</i>	<i>O. niloticus</i>	5.00(0.02–0.08)	1.25(1.00–1.67)	0.06(0.03–0.10)	GI
<i>Tereancistrum curimba</i>	<i>P. brevis</i>	6.90(0.02–0.15)	1.20(1.00–1.40)	0.08(0.02–0.18)	GI
<i>Trinidactylus cichlasomatis</i>	<i>C. orientale</i>	7.50(0.03–0.14)	2.38(1.00–4.25)	0.17(0.05–0.49)	GI
	<i>G. brasiliensis</i>	1.50(0.00–0.05)	1.00*	0.01(0.00–0.03)	GI
<i>Unilatus</i> aff. <i>anoculus</i>	<i>H. pusarum</i>	3.70(0.00–0.19)	4.00*	0.14(0.00–0.44)	GI
<b>Digenea</b>					
<i>Austrodiplostomum compactum</i> (M)	<i>C. monoculus</i>	13.60(0.02–0.34)	3.33(1.00–5.00)	0.45(0.04–1.41)	EY
	<i>C. orientale</i>	14.00(0.08–0.22)	2.93(1.67–6.02)	0.41(0.18–0.93)	FI
	<i>G. brasiliensis</i>	4.40(0.01–0.09)	1.83(1.17–2.17)	0.08(0.02–0.17)	EY
	<i>H. malabaricus</i>	1.14(0.05–0.21)	21.80(2.38–67.00)	2.49(0.30–10.00)	EY
	<i>O. niloticus</i>	0.40(0.00–0.02)	1.00*	0.01(0.00–0.01)	EY
	<i>P. squamosissimus</i>	62.50(0.24–0.91)	1.40(1.00–1.60)	0.87(0.25–1.25)	EY
	<i>P. brevis</i>	1.40(0.00–0.07)	1.00*	0.01(0.00–0.05)	EY
	<i>S. brasiliensis</i>	2.00(0.00–0.10)	7.00*	0.14(0.00–0.42)	EY
<i>Clinostomum</i> sp.	<i>C. orientale</i>	1.90(0.00–0.06)	24.50(6.00–24.50)	0.45(0.00–2.08)	FI
<i>Calocladorchis ventrastomis</i>	<i>P. brevis</i>	9.70(0.04–0.19)	1.00*	0.09(0.02–0.16)	IN
<i>Dendrorchis</i> sp. 1	<i>H. malabaricus</i>	4.30(0.00–0.12)	70.70(23.00–105.00)	3.03(0.32–10.00)	IN
	<i>P. squamosissimus</i>	12.50(0.00–0.52)	2.00*	0.25(0.00–0.75)	EY
<i>Dendrorchis</i> sp. 2	<i>H. malabaricus</i>	0.01(0.00–0.07)	13.00*	0.18(0.00–0.55)	IN
Diplostomidae gen. sp. 1 (M)	<i>P. vivipara</i>	4.20(0.00–0.21)	2.00*	0.08(0.00–0.25)	IN

(Continued)

Table 1. (Continued)

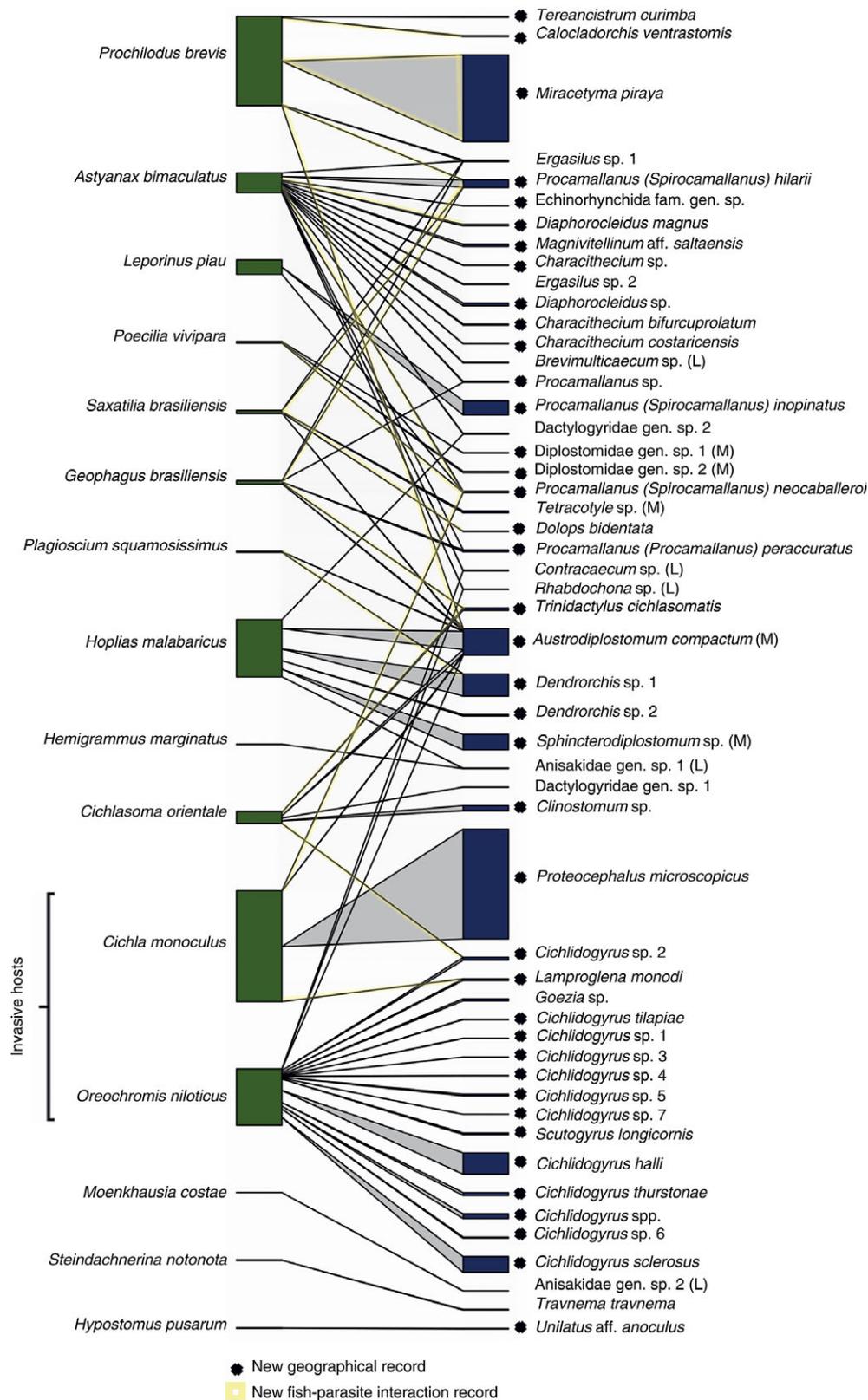
Parasite	Host	P (%) (CI)	MI (CI)	MA (CI)	IS
Diplostomidae gen. sp. 2 (M)	<i>P. vivipara</i>	25.00(0.09–0.46)	2.00(1.17–3.00)	0.50(0.16–1.04)	ME; EY
<i>Magnivittellinum</i> aff. <i>saltaensis</i>	<i>A. bimaculatus</i>	1.10(0.00–0.03)	6.67(5.00–7.67)	0.07(0.01–0.20)	IN
<i>Sphincterodiplostomum</i> sp. (M)	<i>H. malabaricus</i>	2.90(0.00–0.09)	73.50(56.00–73.50)	2.10(0.00–6.48)	EY
<i>Tetracotyle</i> sp. (M)	<i>S. brasiliensis</i>	2.00(0.00–0.10)	16.00*	0.32(0.00–0.98)	ME
<b>Cestoda</b>					
<i>Proteocephalus microscopicus</i>	<i>C. monoculus</i>	9.10(0.01–0.29)	526.00(11.00–526.00)	47.80(0.00–1.90)	IN
<b>Nematoda</b>					
Anisakidae gen. sp. 1 (L)	<i>H. marginatus</i>	1.60(0.00–0.08)	1.00*	0.01(0.00–0.04)	IN
	<i>H. malabaricus</i>	2.90(0.00–0.09)	1.00*	0.02(0.00–0.07)	GI; KI
Anisakidae gen. sp. 2 (L)	<i>M. costae</i>	33.30(0.00–0.90)	2.00*	0.66(0.00–1.33)	LI; IN
<i>Brevimulticaecum</i> sp. (L)	<i>A. bimaculatus</i>	1.10(0.00–0.03)	1.67 (1.00–2.33)	0.01(0.00–0.05)	ME
<i>Contraecum</i> sp. (L)	<i>A. bimaculatus</i>	1.10(0.00–0.03)	1.33 (1.00–1.67)	0.01(0.00–0.03)	IN; ME
	<i>O. niloticus</i>	0.40(0.00–0.02)	1.00*	0.01(0.00–0.01)	IN
<i>Goezia</i> sp.	<i>O. niloticus</i>	0.80(0.00–0.03)	9.50(1.00–9.50)	0.07(0.00–0.38)	IN; ME
<i>Procamallanus (Spirocamallanus) hilarii</i>	<i>A. bimaculatus</i>	18.40(0.14–0.23)	1.35(1.19–1.56)	0.24(0.18–0.32)	GI; GO; IN; ME; KI; EY
	<i>G. brasiliensis</i>	0.70(0.00–0.04)	1.00*	0.00(0.00–0.02)	IN
	<i>P. brevis</i>	1.40(0.00–0.07)	1.00*	0.01(0.00–0.04)	IN
	<i>S. brasiliensis</i>	2.00(0.00–0.10)	1.00*	0.02(0.00–0.06)	IN
<i>Procamallanus (Spirocamallanus) inopinatus</i>	<i>L. piau</i>	79.30(0.60–0.92)	5.87(3.65–12.60)	4.66(2.72–96.00)	SB; IC; IN; LI
<i>Procamallanus (Spirocamallanus) neocaballeroi</i>	<i>A. bimaculatus</i>	2.50(0.01–0.05)	1.00*	0.02(0.00–0.04)	IN
	<i>C. monoculus</i>	4.50(0.00–0.22)	1.00*	0.04(0.00–0.13)	IN
	<i>L. piau</i>	3.40(0.00–0.17)	2.00*	0.06(0.00–0.20)	IN
	<i>P. vivipara</i>	8.30(0.01–0.27)	1.00*	0.08(0.00–0.10)	IN
<i>Procamallanus (Procamallanus) peraccuratus</i>	<i>A. bimaculatus</i>	0.40(0.00–0.02)	1.00*	0.00(0.00–0.01)	IN
	<i>G. brasiliensis</i>	8.80(0.04–0.14)	1.33(1.00–1.67)	0.11(0.05–0.19)	IN
<i>Procamallanus</i> sp.	<i>A. bimaculatus</i>	2.50(0.01–0.05)	1.14(1.00–1.43)	0.02(0.01–0.05)	IN; GO
<i>Rhabdochona</i> sp. (L)	<i>A. bimaculatus</i>	1.10(0.00–0.03)	1.00*	0.01(0.00–0.02)	IN
	<i>O. niloticus</i>	0.40(0.00–0.02)	1.00*	0.01(0.00–0.01)	IN
<i>Travnema travnema</i>	<i>S. notonota</i>	10.50(0.01–0.33)	2.50(1.00–2.50)	0.26(0.00–0.89)	IN
<b>Acantocephala</b>					
Echinorhynchida fam. gen. sp.	<i>A. bimaculatus</i>	0.40(0.00–0.02)	1.00*	0.00(0.00–0.01)	IN
<b>Copepoda</b>					
<i>Ergasilus</i> sp. 1	<i>A. bimaculatus</i>	0.40(0.00–0.02)	2.00*	0.01(0.00–0.02)	GI
	<i>G. brasiliensis</i>	1.50(0.00–0.05)	1.00*	0.01(0.00–0.03)	GI
	<i>P. brevis</i>	2.80(0.00–0.09)	4.00(1.00–4.00)	0.11(0.00–0.51)	GI
	<i>S. brasiliensis</i>	4.10(0.00–0.14)	1.00*	0.04(0.00–0.10)	GI
<i>Ergasilus</i> sp. 2	<i>A. bimaculatus</i>	1.80(0.00–0.04)	1.40(1.00–1.60)	0.02(0.00–0.05)	GI
<i>Lamproglana monodi</i>	<i>C. monoculus</i>	0.45(0.00–0.22)	1.00*	0.04(0.00–0.13)	GI
	<i>O. niloticus</i>	2.10(0.01–0.05)	2.80(1.40–5.40)	0.06(0.01–0.18)	GI
<i>Miracetyma piraya</i>	<i>P. brevis</i>	44.40(0.32–0.56)	26.00(17.70–39.80)	11.50(7.26–18.60)	GI
<b>Argulidae</b>					
<i>Dolops bidentata</i>	<i>S. brasiliensis</i>	4.10(0.00–0.10)	1.00*	0.04(0.00–0.10)	GI



**Figure 4.** (a) New geographical record of *Cichlidogyrus* sp. 2, parasitizing *O. niloticus* and new interaction with *C. monoculus*; (b) New geographical record of *Unilatus* aff. *anoculus*, parasitizing *H. pularum*; (c) New geographical record of *Dendrochis* sp. 1, parasitizing *H. malabaricus* and a new interaction with *P. squamosissimus*.

region, the parasite diversity is hardly documented; the first studies considering fish parasite communities were developed in the state of Ceará along the Jaguaribe River Basin (Falkenberg *et al.* 2024a; Falkenberg *et al.* 2024b). Although the region is highly dependent

on reservoirs, there is no data on the fish parasite fauna in these freshwater systems, nor in the state of Paraíba at a community level. That is why this study represents the first steps towards unveiling the fish-parasite diversity of a unique freshwater system under



**Figure 5.** Fish-parasite interactions of reservoirs in Paraíba state, highlighting new geographical records and new interactions.

anthropogenic impact, which may alter the structure and processes of an entire aquatic ecosystem and its fauna. This work builds on information we have in the proximal Jaguaribe River Basin (Falkenberg *et al.* 2024a; Falkenberg *et al.* 2024b), the Amazon

region (Thatcher 2006), and the Upper Paraná River floodplain (Takemoto *et al.* 2009), and wider information about Brazilian freshwater ichthyoparasitology (Eiras *et al.* 2011). Furthermore, it contributes to the continental knowledge, adding to data on South

American and Neotropical fish parasites (Cohen *et al.* 2013; Kohn *et al.* 2007; Luque & Poulin 2007; Luque *et al.* 2017; Moravec 1998).

High abundances of invasive fish species are found on the Brazilian semi-arid, such as the Nile tilapia (*Oreochromis niloticus*), which has been well-established in the Paraíba reservoirs since the introduction in the 1950s, when fisheries were started in the Brazilian Northeast (Ramos *et al.* 2018). An endemic cichlid from the Brazilian Northeast, *Cichlasoma orientale*, popularly known as 'cará' or 'cará preto', occupies the same niche as *O. niloticus* (Berbel-Filho *et al.* 2016). *Cichlasoma orientale* presented a low parasite diversity in this study, even when compared to its invasive competitor *O. niloticus*. Furthermore, the Amazon species *Cichla monoculus*, popularly known as 'tucunaré', has been introduced in the semi-arid reservoirs (Attayde *et al.* 2011, Chellappa *et al.* 2003) and showed a high abundance of parasites per host individual, although the lower diversity compared to *O. niloticus*. The cestode species *P. microscopicus* was identified in *C. monoculus*, indicating the parasite was introduced with the Amazonian cichlid, as already documented for the Tocantins River with the invasive host *Cichla piquiti* (Lacerda *et al.* 2013a). To better evaluate the host-parasite dynamics of biological invasions in the region, it is necessary to combine molecular studies at the invaded community level and biogeographical studies on the parasite fauna of hosts in their native range (Lacerda *et al.* 2013a).

Native host species can be under-represented, due to difficulty of capturing or even the decrease of their populations due to competition with the invasive species (Reid *et al.* 2019), reducing the sampling of parasites on those hosts. Hence, the absence of parasites in *P. fasciatus*, *S. marmoratus*, and *T. signatus* in the present study does not necessarily indicate that these species are not parasitized, but instead indicates the need to increase the efforts on these species. The most abundant species in this study, *A. bimaculatus*, was the native host species that showed the highest parasite diversity for the semi-arid reservoirs, reinforcing the correlation between the parasitic richness and the abundance of dominant fish species (Poulin and Morand 2004; Telfer and Bown 2012).

High prevalence values were observed for the following interactions: *M. piraya* (Copepoda) in *P. brevis* (44.4%), *A. compactum* (Digenea) in *P. squamosissimus* (62.5%), *Anisakidae* sp. 2 (Nematoda) in *M. costae* (33.3%), and *P. (S.) inopinatus* (Nematoda) in *L. piau* (79.3%). Despite the high prevalence of other groups, the most species-rich of freshwater parasites is the Class Monogenea (Luque & Poulin 2007), which presented 23 taxa recorded in this study. This is a group of ectoparasites known for their high host specificity (Poulin 1992), corroborated by our results, as only two monogenean taxa were found in more than one host species. The highest richness of this group was in the genus *Cichlidogyrus*, parasites of Nile tilapia (*O. niloticus*), of which we recorded 12 species. Although its host has well-established populations as an invasive species, its parasites are only starting to be identified in the Brazilian semi-arid. In the last years, a few studies approached new descriptions of Monogenean group (Diniz *et al.* 2025; Silva *et al.* 2021; Silva *et al.* 2025; Yamada *et al.* 2024), and we look forward to have the relations of parasites with native hosts, such as *Cichlasoma orientale*, that was found infected with one individual of *Cichlidogyrus* sp. 2, clarified in further studies with its implications to the native fish fauna.

Cestodes were found to be strongly abundant when present, besides showing the highest intensity among the parasite community, showing a highly aggregated distribution in the host population. In most fish, the cestodes were found in their encysted form,

suggesting that the analysed fish serve as an important intermediate component in the life cycle of those parasites.

In 2017, the Paraíba River Basin received an inter-basin water transfer from the São Francisco River transposition (SF-IWT), to ensure water security in the semi-arid region of Paraíba (Silva *et al.* 2020). Water quality and environmental parameters have been shown to be changing under the SF-IWT in the Paraíba reservoirs (Barbosa *et al.* 2021). For aquatic organisms, such as fish, parasite transmission is altered by conditions in the aquatic environment, and initial results have shown that these might be impacting host-parasite relationships (Falkenberg *et al.* 2024a). Water transfers can also result in species introductions, including fishes and their parasites (Dobson and May 1987), as recorded for the Paraíba Basin with the introduction of *Moenkhausia costae* after the SF-IWT (Ramos *et al.* 2021; Sousa *et al.* 2025). New interactions present unknown consequences for native fauna, potentially causing environmental imbalances or even extinction of endemic species (Lacerda *et al.* 2013b).

Although in this study we expanded our understanding of parasite communities, providing new geographical records (67–86% of taxa identified) for the region, it is important to recognize that several species could not be identified as species level, due to low abundance of the parasites/hosts, or due to complex taxonomic identification that requires integrative taxonomy efforts, as evidenced by recent studies that describe new species in Brazilian semi-arid aquatic ecosystems (Diniz *et al.* 2025; Silva *et al.* 2021; Silva *et al.* 2025; Yamada *et al.* 2024). Considering this, there is an urgent need to expand studies on fish parasite biodiversity, as the first steps to monitor and understand the ecological impacts of significant anthropogenic alterations in these critically important freshwater ecosystems.

**Acknowledgements.** The authors acknowledge the LAHMP/UFPB team Marcylenne Santana, Gilson do Nascimento Melo, and Igor Winkeler for their help with the lab procedures.

**Financial support.** This work is supported by Paraíba State Research Foundation, FAPESQ-PB, Brazil, as part of the doctoral thesis of V.M.M.L. (grant 16/2022), supervised by A.C.F.L. (grants FAPESQ Universal 3090/2021; CNPq/CONFAP-FAPs/PELD n° 23/2024, PELD RIPA 445968/2024-9; CNPq/MCTI/FNDCT/CT-Hidro n° 63/2022, 409348/2022-8, PRO-NEX/FAPESQ-PB 027-2023) and F.M.W. The sampling collection was supported by Universal/CNPq (R.F.M., Process Number: 421997/2018-4); This work was also supported by FUNCAP through postdoctoral fellowships (J.M. F., grant 0213-00077.01.01/23), (P.O.F.Y., grant FPD-0213-00301.01.01/23); by CNPq (F.H.Y., 304502/2022-7 and 174814/2023-2; T.P.A.R. 02654/2024-7); and by SNI-ANII and PEDECIBA (F.T.M.).

**Competing interest.** The authors declare none.

## References

- Anderson TK and Sukhdeo MVK (2010) Abiotic versus biotic hierarchies in the assembly of parasite populations. *Parasitology* 137, 743–754.
- Attayde JL, Brasil J and Menescal RA (2011) Impacts of introducing Nile tilapia on the fisheries of a tropical reservoir in North-eastern Brazil. *Fisheries Management and Ecology* 18, 437–443.
- Barbosa JE de L, Medeiros ESF, Brasil J, Cordeiro R da S, Crispim MCB and Silva GHG da (2012) Aquatic systems in semi-arid Brazil: Limnology and management. *Acta Limnologica Brasiliensia* 24(1), 103–118. <https://doi.org/10.1590/s2179-975x2012005000030>.
- Barbosa JE, Severiano J, Cavalcante H, Lucena-Silva D de, Mendes CF, Barbosa VV, Silva RD, Oliveira DA and Molozzi J (2021) Impacts of inter-basin water transfer on the water quality of receiving reservoirs in a

- tropical semi-arid region. *Hydrobiologia* **848**(3), 651–673. <https://doi.org/10.1007/s10750-020-04471-z>.
- Berbel-Filho WM, Martinez PA, Ramos TPA, Torres RA and Lima SMQ** (2016) Inter- and intra-basin phenotypic variation in two riverine cichlids from northeastern Brazil: Potential eco-evolutionary damages of São Francisco interbasin water transfer. *Hydrobiologia* **766**(1), 43–56. <https://doi.org/10.1007/s10750-015-2440-9>.
- Boxshall GA and Montú MA** (1997) Copepoda parasitic on Brazilian coastal fishes: A handbook. *Nauplius* **5**(1), 225.
- Britton JR** (2013) Introduced parasites in food webs: New species, shifting structures? *Trends in Ecology & Evolution* **28**(2), 93–99. <https://doi.org/10.1016/j.tree.2012.08.020>.
- Chao A, Gotelli NJ, Hsieh TC, Sander EL, Ma KH, Colwell RK and Ellison AM** (2014) Rarefaction and extrapolation with Hill numbers: A framework for sampling and estimation in species diversity studies. *Ecological Monographs* **84**, 45–67.
- Chalkowski K, Lepczyk CA and Zohdy S** (2018) Parasite ecology of invasive species: Conceptual framework and new hypotheses. *Trends in Parasitology* **34**(8), 655–663. <https://doi.org/10.1016/j.pt.2018.05.008>.
- Chellappa S, Câmara MR, Chellappa NT, Beveridge MCM, Huntingford FA** (2003) Reproductive ecology of a neotropical cichlid fish, *Cichla monoculus* (Osteichthyes: Cichlidae). *Brazilian Journal of Biology*, **63**(1), 17–26. <https://doi.org/10.1590/S1519-69842003000100004>.
- Cohen SC, Justo MCN and Kohn A** (2013) *South American Monogenoidea Parasites of Fishes, Amphibians and Reptiles*. Rio de Janeiro: Oficina de Livros.
- Dantas JC, da Silva RM and Santos CAG** (2020) Drought impacts, social organization, and public policies in northeastern Brazil: A case study of the upper Paraíba River basin. *Environmental Monitoring and Assessment* **192**(5). <https://doi.org/10.1007/s10661-020-8219-0>.
- Diniz MFBG, Sousa WBB, Yamada POF and Yamada FH** (2025) *Ancistrohaptor forcifata* sp. n. (Monopisthocotyla, Dactylogyridae): A new parasite of *Tripurtheus signatus* (Characiformes, Tripurtheidae) from the Salgado River, Brazil. *Parasitologia* **5**, 3. <https://doi.org/10.3390/parasitologia5010003>.
- Dormann CF, Gruber B and Frund J** (2008) Introducing the bipartite package: Analysing Ecological Networks. *R News* **8**(2).
- Dobson AP and May RM** (1987) The effects of parasites on fish populations—theoretical aspects. *International Journal for Parasitology* **17**(2), 363–370. [https://doi.org/10.1016/0020-7519\(87\)90111-1](https://doi.org/10.1016/0020-7519(87)90111-1).
- Eiras JC, Takemoto RM and Pavanelli GC** (2006) *Métodos de estudo e técnicas laboratoriais em parasitologia de peixes*, 2nd edn. Maringá: Eduem.
- Eiras JC, Takemoto RM, Pavanelli GC and Adriano EA** (2011) About the biodiversity of parasites of freshwater fish from Brazil. *Bulletin of the European Association of Fish Pathologists* **31**(4), 161–168.
- Falkenberg JM, de Lima VMM, Yamada FH, Ramos TPA and Lacerda ACF** (2024a) Drivers of richness and abundance of parasites of fishes from an intermittent river before and after an interbasin water transfer in the Brazilian semi-arid region. *Parasitology Research* **123**:328. <https://doi.org/10.1007/s00436-024-08332-9>.
- Falkenberg JM, de Lima VMM, Yamada FH, Ramos TPA and Lacerda ACF** (2024b) Changes in parasite communities of fishes from an intermittent river in the Brazilian semi-arid, after a major interbasin water transfer. *Aquatic Ecology* **58**(3), 895–916. <https://doi.org/10.1007/s10452-024-10112-7>.
- Falkenberg JM, Golzio JESA, Pessanha A, Patrício J, Vendel AL and Lacerda ACF** (2019) Gill parasites of fish and their relation to host and environmental factors in two estuaries in northeastern Brazil. *Aquatic Ecology* **53**(1), 109–118. <https://doi.org/10.1007/s10452-019-09676-6>.
- Frainer A, McKie BG, Amundsen PA, Knudsen R and Lafferty KD** (2018) Parasitism and the biodiversity-functioning relationship. *Trends in Ecology and Evolution* **33**(4), 260–268. <https://doi.org/10.1016/j.tree.2018.01.011>.
- Gibson DI, Bray RA and Jones A** (2002) *Keys to Trematoda, Volume 1*. Wallingford: CAB International and The Natural History Museum.
- Goater TM, Goater CP and Esch GW** (2014) *Parasitism: The Diversity and Ecology of Animal Parasites*, 2nd edn. Cambridge: Cambridge University Press.
- Hsieh TC, K Ma KH and Chao A** (2024) iNEXT: iNterpolation and EXTrapolation for species diversity. R package version 3.0.1. <http://chao.stat.nthu.edu.tw/wordpress/software-download/>.
- Hudson PJ, Dobson AP and Lafferty KD** (2006) Is a healthy ecosystem one that is rich in parasites? *Trends in Ecology and Evolution* **21**(7), 381–385. <https://doi.org/10.1016/j.tree.2006.04.007>.
- Kelly DW, Paterson RA, Townsend CR, Poulin R and Tompkins DM** (2009) Parasite spillback: A neglected concept in invasion ecology? *Ecology* **90**(8), 2009, 2047–2056.
- Kohn A, Fernandes BMM and Cohen SC** (2007) *South American Trematodes Parasites of Fishes*. Rio de Janeiro: Imprinta Express Ltda.
- Lacerda ACF, Roubbedakis K, Bereta Junior JGS, Nuñez APO, Petrucio MM and Martins ML** (2018) Fish parasites as indicators of organic pollution in southern Brazil. *Journal of Helminthology* **92**(3), 322–331. <https://doi.org/10.1017/S0022149X17000414>.
- Lacerda ACF, Takemoto RM, Poulin R and Pavanelli GC** (2013a) Parasites of the fish *Cichla piquiti* (Cichlidae) in native and invaded Brazilian basins: Release not from the enemy, but from its effects. *Parasitology Research* **112**(1), 279–288. <https://doi.org/10.1007/s00436-012-3135-z>.
- Lacerda ACF, Yamada FH, Antonucci AM and Dias MT** (2013b) Peixes introduzidos e seus parasitos. In Pavanelli GC, Takemoto RM and Eiras JC (org.), *Parasitologia de peixes de água doce do Brasil*. Maringá: Eduem, 169–193.
- Lacerda ACF and de Lima VMM** (2025) *Parasitos de peixes da Paraíba depositados na CIPY/UFPB. DATAPB, v. 3, João Pessoa*. <https://doi.org/10.48472/DATAPB/BGIVG6>
- Llalaria-Robledillo M, Balbuena JA, Sarabeev V and Llopis-Belenguer C** (2022) Changes in native and introduced host–parasite networks. *Biological Invasions* **24**, 543–555. <https://doi.org/10.1007/s10530-021-02657-7>.
- Lima SMQ, Ramos TPA, Silva MJ da and Rosa R de S** (2017) *Diversity, Distribution, and Conservation of the Caatinga Fishes: Advances and Challenges*. Springer Cham.
- Lucena CA, Calegari B, Pereira E and Dallegre E** (2013) O uso de óleo de cravo na eutanásia de peixes. *Boletim Sociedade Brasileira de Ictiologia* **105**, 20–24.
- Luque JL, Pereira FB, Alves PV, Oliva ME and Timi JT** (2017) Helminth parasites of South American fishes: Current status and characterization as a model for studies of biodiversity. *Journal of Helminthology* **91**(2), 150–164. <https://doi.org/10.1017/S0022149X16000717>.
- Luque JL and Poulin R** (2007) Metazoan parasite species richness in Neotropical fishes: Hotspots and the geography of biodiversity. *Parasitology* **134**(6), 865–878. <https://doi.org/10.1017/S0031182007002272>.
- Malabarba LR and Reis RE** (1987) Manual de técnicas para a preparação de coleções zoológicas. *Sociedade Brasileira de Zoologia* **36**, 1–14.
- Marcogliese DJ** (2005) Parasites of the superorganism: Are they indicators of ecosystem health? *International Journal for Parasitology* **35**, 705–1600. <https://doi.org/10.1016/j.ijpara.2005.01.015>.
- Moravec F** (1998) *Nematodes of Freshwater Fishes of the Neotropical Region*. Prague: Academia Praha.
- Morley NJ** (2007) Anthropogenic effects of reservoir construction on the parasite fauna of aquatic wildlife. *EcoHealth* **4**(4), 374–383. <https://doi.org/10.1007/s10393-007-0130-4>.
- Oksanen J, Simpson G, Blanchet F, Kindt R, Legendre P, Minchin P, O'Hara R, Solymos P, Stevens M, Szoecs E, Wagner H, Barbour M, Bedward M, Bolker B, Borcard D, Carvalho G, Chirico M, De Caceres M, Durand S, Evangelista H, FitzJohn R, Friendly M, Furneaux B, Hannigan G, Hill M, Lahti L, McGlenn D, Ouellette M, Ribeiro Cunha E, Smith T, Stier A, Ter Braak C and Weedon J** (2024) vegan: Community Ecology Package. R package version 2.6-6.1. <https://CRAN.R-project.org/package=vegan>.
- Oliveira-Silva L, Ramos TPA, Carvalho-Rocha YGP, Viana KMP, Avellar R da C and Ramos RT da C** (2018) Ichthyofauna of the mamanguape river basin, Northeastern, Brazil. *Biota Neotropica* **18**(3). <https://doi.org/10.1590/1676-0611-bn-2017-0452>.
- Palm HW** (2011) Fish parasites as biological indicators in a changing world: Can we monitor environmental impact and climate change? In Mehlhorn H (ed), *Progress in Parasitology. Parasitology Research Monographs 2*. Berlin: Springer-Verlag Berlin Heidelberg, 223–250. [https://doi.org/10.1007/978-3-642-21396-0\\_12](https://doi.org/10.1007/978-3-642-21396-0_12).
- Poulin R** (1992) Determinants of host-specificity in parasites of freshwater fishes. *International Journal for Parasitology* **22**(6), 753–758. [https://doi.org/10.1016/0020-7519\(92\)90124-4](https://doi.org/10.1016/0020-7519(92)90124-4).

- Poulin R** (2014) Parasite biodiversity revisited: Frontiers and constraints. *International Journal for Parasitology* **44**(9), 581–589. <https://doi.org/10.1016/j.ijpara.2014.02.003>.
- Poulin R and Morand S** (2004) *Parasites Biodiversity*. Washington: Smithsonian Books.
- Poulin R, Presswell B, Bennett J, de Angeli Dutra D and Salloum PM** (2023) Biases in parasite biodiversity research: Why some helminth species attract more research than others. *International Journal for Parasitology: Parasites and Wildlife* **21**, 89–98. <https://doi.org/10.1016/j.ijppaw.2023.04.010>.
- R Core Team** (2024). *R: A Language and Environment for Statistical Computing*. R Foundation for Statistical Computing, Vienna, Austria. <https://www.R-project.org/>.
- Ramos TPA, Lima JA de S, Costa SYL, da Silva MJ, Avellar R da C and Oliveira-Silva L** (2018) Continental ichthyofauna from the paraíba do norte river basin pre-transposition of the são francisco river, northeastern Brazil. *Biota Neotropica* **18**(4), 1–10. <https://doi.org/10.1590/1676-0611-bn-2017-0471>.
- Ramos TPA, Lustosa-Costa SY, Lima RMO, Barbosa JEL and Menezes RF** (2021) First record of *Moenkhausia costae* (Steindachner 1907) in the Paraíba do Norte basin after the São Francisco River diversion. *Biota Neotropica* **21**(2), e20201049. <https://doi.org/10.1590/1676-0611-BN-2020-1049>.
- Reid AJ, Carlson AK, Creed IF, Eliason EJ, Gell PA, Johnson PTJ, Kidd KA, MacCormack TJ, Olden JD, Ormerod SJ, Smol JP, Taylor WW, Tockner K, Vermaire JC, Dudgeon D and Cooke SJ** (2019) Emerging threats and persistent conservation challenges for freshwater biodiversity. *Biological Reviews* **94**(3), 849–873. <https://doi.org/10.1111/brv.12480>.
- Schatz AM and Park AW** (2023) Patterns of host–parasite coinvasion promote enemy release and specialist parasite spillover. *Journal of Animal Ecology* **92**, 1029–1041. <https://doi.org/10.1111/1365-2656.13910>.
- Silva BAF, Silva RJ and Yamada FH** (2021) *Characithecium* spp. (Monogenea: Dactylogyridae) from *Astyanax bimaculatus* (Characiformes: Characidae) in Northeast Brazil, with description of a new species. *Acta Parasitologica* **66**, 1307–1315. <https://doi.org/10.1007/s11686-021-00379-3>.
- Silva BAF, Falkenberg JM and Yamada FH** (2025) Diversity of parasites in two sympatric species of Brazilian tetras (Characiformes: Characidae) in the Caatinga Domain, northeastern Brazil. *Parasitologia* **5**, 8. <https://doi.org/10.3390/parasitologia5010008>.
- Silva MJ, Ramos TPA, Carvalho FR, Brito MFG, Ramos RTC, Rosa RS, Sánchez-Botero JI, Novaes JLC, Costa RS and Lima SMQ** (2020) Freshwater fish richness baseline from the São Francisco Interbasin Water Transfer Project in the Brazilian Semi-arid. *Neotropical Ichthyology* **18**(4), 1–25. <https://doi.org/10.1590/1982-0224-2020-0063>.
- Sousa JWG, Falkenberg JM, Lima VMM, Winkler IE, Ramos TPA, Lustosa-Costa SY, Menezes RF and Lacerda ACF** (2025) Revealing the first records of endoparasitic interactions in the non-native fish *Moenkhausia costae* within a reservoir in Northeastern Brazil. *An Acad Bras Cienc* **97**(1), e20240651, 1–12. <https://doi.org/10.1590/0001-3765202520240651>.
- Sures B, Nachev M, Schwelm J, Grabner D and Selbach C** (2023) Environmental parasitology: Stressor effects on aquatic parasites. *Trends in Parasitology* **39**(6), 461–474. <https://doi.org/10.1016/j.pt.2023.03.005>.
- Takemoto RM, Pavanelli GC, Lizama MAP, Lacerda ACF, Yamada FH, Moreira LHA, Ceschini TL, Bellay S** (2009) Diversity of parasites of fish from the Upper Paraná River floodplain, Brazil. *Brazilian Journal of Biology* **69**(2), 691–705. <https://doi.org/10.1590/S1519-69842009000300023>.
- Telfer S and Bown K** (2012) The effects of invasion on parasite dynamics and communities. *Functional Ecology* **26**(6), 1288–1299. <https://doi.org/10.1111/j.1365-2435.2012.02049.x>.
- Thatcher E** (2006) *Amazon Fish Parasites Parasitology*, 2nd edn. Manaus: Instituto Nacional de Pesquisas da Amazônia. <https://doi.org/10.1017/s003118200600134x>.
- Wickham H** (2016). *ggplot2: Elegant Graphics for Data Analysis*. New York: Springer-Verlag.
- Wickham H, François R, Henry L, Müller K and Vaughan D** (2023). *dplyr: A Grammar of Data Manipulation*. R package version 1.1.4. <https://CRAN.R-project.org/package=dplyr>.
- Xavier RA, Dornellas P da C, Maciel J dos S and Bú JC do** (2012) Caracterização do regime fluvial da bacia hidrográfica do Rio Paraíba - PB. *Revista Tamoios* **8**(2), 15–28. <https://doi.org/10.33448/rsd-v10i17.24461>.
- Yamada FH, Bongiovani MF, Yamada POF and Da Silva RJ** (2017) Parasite infracommunities of *Leporinus friderici*: A comparison of three tributaries of the jurumirim reservoir in southeastern Brazil. *Anais Da Academia Brasileira de Ciências* **89**(2), 953–963. <https://doi.org/10.1590/0001-3765201720160554>.
- Yamada POF, Diniz MFBG, Sousa WBB, Yamada FH and Tavares-Dias M** (2024) A new species of *Anacanthorus* (Dactylogyridae, Anacanthorinae) parasitizing gills of *Hoplias aff. malabaricus* (Bloch, 1794) (Characiformes, Erythrinidae) from the Caatinga Domain. *Acta Parasitologica* **69**(4), 1729–1735. <https://doi.org/10.1007/s11686-024-00864-5>.
- Yamaguti S** (1963) *Systema Helminthum*, Volume IV: Monogenea and Aspidocotylea. New York: Inter Science Publishers, Inc.