BOLETIM DO INSTITUTO DE PESCA
ISSN 1678-2305 online version
Scientific Article

PARASITE DIVERSITY OF *Hoplosternum littorale* FROM THE TIETÊ-BATALHA RIVER BASIN, SOUTHEASTERN BRAZIL*

Larissa Sbeghen PELEGRINI[1,2]*
Diego Henrique Mirandola Dias VIEIRA[1]
Lucas Aparecido Rosa LEITE[1]
Thayana GIÃO[3]
Rodney Kozlowiski de AZEVEDO[4]
Vanessa Doro ABDALLAH[4]

[1] Universidade Estadual Paulista – UNESP, Instituto de Biociências, Departamento de Parasitologia. Rua Professor Doutor Antônio Celso Wagner Zanin, 250, 18.618-689, Botucatu, SP, Brazil. biolarapelegrini@gmail.com (*corresponding author)

[2] Universidade Federal do Amazonas – UFAM, Laboratório de Ictiologia e Ordenamento Pesqueiro do Vale do Rio Madeira – LIOP. Rua 29 de Agosto, 786, Centro, 69.800-000, Humaitá, AM, Brazil.

[3] Centro Universitário Sagrado Coração – UNISAGRADO. Rua Irmã Arminda 10-50, Jardim Brasil, 17.011-160, Bauru, SP, Brazil.

[4] Centro Universitário CESMAC. Rua Cônego Machado 918, Farol, 57.051-160, Maceió, AL, Brazil.

*This study was financed in part by the Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP) (grant #2012/23655-0; grant #2014/12862-0), by the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) (grant #306987/2018-0), and by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) (Finance code 001). Part of the Larissa Sbeghen Pelegrini's doctoral thesis, which is deposited in its entirety in UNESP digital repository (https://hdl.handle.net/11449/182085).

Received: March 22, 2021
Approved: June 28, 2021

ABSTRACT

A total of 53 tamboatás, *Hoplosternum littorale*, from the Batalha River, São Paulo, southeastern Brazil, were examined between February 2014 to December 2016. Seventeen species of parasites were identified, and 961 specimens were collected. The richness of each community varied from one to seven species of parasites per fish. The metacercariae of *Diplostomum lunaschiae* showed higher prevalence and mean abundance, being the core species. *Gyrodactylus* sp. obtained a higher mean intensity value. Aporocotylidae gen. sp. showed a significant negative correlation between its abundance and the standard host weight and length, while *Spiroxys* sp. showed a significant negative correlation between its abundance and the host weight. The high parasitic diversity of this host in Batalha River confirm it is an important site for maintaining local biodiversity with a relevant contribution to the knowledge of freshwater biodiversity in the State of São Paulo. Gyrodactylidae gen. sp., *Austrodiplostomum mordax*, Aporocotylidae gen. sp., *D. lunaschiae*, Diplostomidae gen. sp. 1, *Contracaecum* sp., *Dioctophyme renale*, *Porrocaecum* sp., *Pseudocapillaria* sp. 1, *Pseudocapillaria* sp. 2, *Spiroxys contortus*, *Oligobdella* sp., and *Lernaea cyprinacea* are parasites mentioned for the first time in *H. littorale*. Aporocotylidae gen. sp., Gyrodactylidae gen. sp., and *Oligobdella* sp. are new species in process of taxonomic description by the authors of the present study.

Keywords: parasitic biodiversity; ecology; tamboatá; fish parasites; freshwater fish; São Paulo.

DIVERSIDADE PARASITÁRIA DE *Hoplosternum littorale* DA BACIA HIDROGRÁFICA DO TIETÊ-BATALHA, SUDESTE DO BRASIL

RESUMO

Um total de 53 tamboatás, *Hoplosternum littorale*, coletados no rio Batalha, São Paulo, sudeste do Brasil, foram examinados entre fevereiro de 2014 a dezembro de 2016. Dezessete espécies de parasitos foram identificadas e 961 espécimes foram coletados, com riqueza parasitária de uma a sete espécies de parasitos por peixe. As metacercárias de *Diplostomum lunaschiae* apresentaram maior prevalência e abundância média, sendo a única espécie central. *Gyrodactylus* sp. obteve o maior valor de intensidade média. Aporocotylidae gen. sp. mostrou uma correlação negativa significativa entre sua abundância e o peso e comprimento padrão do hospedeiro, enquanto *Spiroxys* sp. apresentou correlação negativa significativa entre sua abundância e o peso do hospedeiro. A alta diversidade parasitária deste hospedeiro no rio Batalha confirma a importância desse local para a manutenção da biodiversidade da região, e o presente estudo traz contribuições relevantes para o conhecimento da biodiversidade de água doce no Estado de São Paulo. Gyrodactylidae gen. sp., *Austrodiplostomum mordax*, Aporocotylidae gen. sp., *D. lunaschiae*, Diplostomidae gen. sp. 1, *Contracaecum* sp., *Dioctophyme renale*, *Porrocaecum* sp., *Pseudocapillaria* sp. 1, *Pseudocapillaria* sp. 2, *Spiroxys contortus*, *Oligobdella* sp., e *Lernaea cyprinacea* são parasitos mencionados pela primeira vez em *H. littorale*. Aporocotylidae gen. sp., Gyrodactylidae gen. sp., e *Oligobdella* sp. são novas espécies em processo de descrição taxonômica pelos autores do presente estudo.

Palavras-chave: biodiversidade parasitária; ecologia; tamboatá; parasitos de peixes; peixe de água doce; São Paulo.

INTRODUCTION

The fishes of the Callichthyidae family are distributed by several countries in South America. They correspond to 7% of the species of Siluriformes in the world and can inhabit different environments, such as the muddy bottom of lakes and rivers until streams of fast waters, including those with critical levels of dissolved oxygen

(Pinheiro et al., 2013). Some genera, such as *Callichthys* Scopoli, 1777 and *Hoplosternum* Gill, 1858, developed physiological, morphological, and behavioral adaptations in response to hypoxia (Jucá-Chagas, 2004).

Hoplosternum littorale (Hancock, 1828) is one of the best-known species of callichthyids fish in the Neotropical region. Commonly called tamboatá, tamoatá, or caborja, it can be found throughout South America, encompassing several cisandine drains from the Amazon basin to the Prata river basin (Santos et al., 2009a). It is medium in size and is considered a benthonic and nocturnal fish, inhabiting ponds, and rivers of different sizes (Granado-Lorencio et al., 2005). It is an omnivorous species whose diet varies according to its ontogenetic development. Larvae and juveniles feed on microcrustaceans and small invertebrates while adult individuals use detritus, insect larvae, macroinvertebrates, algae, fish scales, seeds, and small fragments of insects associated with sediment in their food (Hahn et al., 1998; Soares et al., 2008).

Due to its ability to tolerate hypoxic or impacted environments, *H. littorale* has been considered as a potential species for breeding in confined environments (Luquet et al., 1989), since there is an appreciation of its consumption in some regions of Brazil (mainly in the states that make up the Legal Amazon) and also used as ornamental fish, exported to the USA and Europe (Graça and Pavanelli, 2007; Santos et al., 2009a; Sá-Oliveira et al., 2011; Ota et al., 2018).

Studies on parasitic fauna in natural populations of *H. littorale* have been carried out by several authors (Torres et al., 1994; São Clemente et al., 1998; Abdallah et al., 2006, 2007; Lacerda et al., 2009; Takemoto et al., 2009; Azevedo et al., 2010, 2011; Fernandes et al., 2013; Pinheiro et al., 2013; Dias et al., 2017; Núñez et al., 2017; Baia et al., 2018; Vieira et al., 2019). Most of these studies were carried out in the Southeast region of Brazil. Even in a region well studied, some areas still lack complete parasitological studies, such as the Batalha River, one of the main tributaries of the Tietê River, in the State of São Paulo.

The Batalha River, despite presenting a diverse ichthyofauna (Santos and Heubel, 2008), has been the target of few studies involving ecological analyzes of parasitic fish communities (Pedro et al., 2016; Leite et al., 2018; Negrelli et al., 2018; Pelegrini et al., 2021). Thus, this study aimed to inventory the parasitic fauna of *H. littorale* specimens from the Batalha River, São Paulo, Brazil, as well as to present considerations on the composition and structure of the parasitic communities present in this host.

MATERIAL AND METHODS

Study area and fish collections

Fish collections were carried out in two points of the Batalha River, from February 2014 to December 2015. The fish were collected at points near the municipalities of Piratininga (22º24'46"S - 49º05'05"W) and Reginópolis (21º53'17"S 49º13'31"W) (Figure 1). An amount of 53 specimens of *H. littorale* were obtained, with a standard length of 14.38 ± 2.21 cm and a weight of 129.38 ± 53.43 g.

The collections followed the guidelines of the scientific fishing license under the authorization from the Instituto Chico Mendes de Biodiversidade (ICMBio) through the Biodiversity Authorization and Information System (SISBIO - authorization nº 40998-2). For this procedure, waiting nets with different types of meshes (varying from 2 to 10 cm alternating internodes) were used, being placed during the night, and removed before dawn totaling 12 hours of exposure.

The euthanasia methodologies of the host fish were developed under the principles adopted by the National Council of the Animal Experimentation Control (CONCEA), and the research project was submitted to the Ethical Committee on Animal Use (CEUA) of the Centro Universitário Sagrado Coração (UNISAGRADO) (authorization no. 3353050417). The fish were stored individually in plastic bags so that the composition of the parasitic fauna of each specimen would not change. Then they were frozen and taken for analysis at UNISAGRADO laboratories, in Bauru, SP.

The biometric data (weight and standard length) of the hosts were obtained and then the necropsy was performed, with the analysis of the organs in a stereomicroscope. For the preparation, montage, and fixation of the collected parasites, the methods described by Eiras et al. (2006) were used. Optical microscopy and specific bibliography were used to identify the parasites.

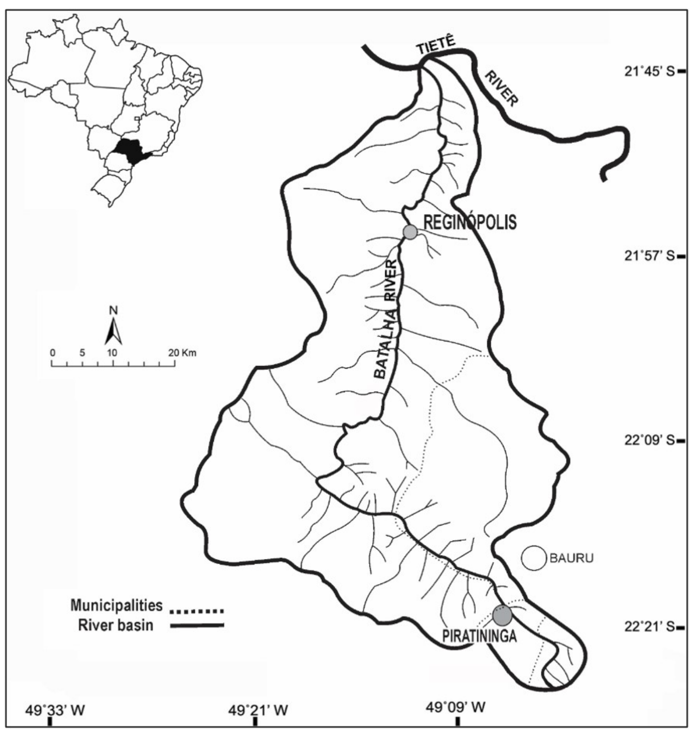

Figure 1. The Batalha river basin, within the Tietê-Batalha river basin, with the Batalha river in the center. The gray circles represent the sample points of *Hoplosternum littorale* (Siluriformes, Callichthyidae), in the municipalities of Piratininga and Reginópolis, State of São Paulo, Brazil.

Data analysis

The species accumulation curve was designed to verify whether the number of hosts collected contemplated obtaining the highest proportion of parasite species that characterized the component community. The 1st order Jackknife wealth estimator was used to verify whether the expected parasite wealth was sufficient for the number of hosts analyzed in the study (Poulin, 1998; Magurran, 2013).

The ecological terminology follows Bush et al. (1997). The quantitative descriptors of parasitic infrapopulations (prevalence, mean intensity, mean abundance) were calculated (Bush et al., 1997). According to their degree of importance within the infracommunities, the parasites were classified as coreor central species (prevalence higher than 66.6%), secondary species (prevalence ranging from 33.3% to 66.6%) and satellite species (prevalence lower than 33.3%), according to their prevalence (Hanski, 1982; Bush and Holmes, 1986).

The variance of mean ratio of parasite abundance, or Dispersion Index (DI) was used to determine spatial distribution patterns for each infrapopulation (Ludwig et al., 1988), and the *d*-statistic test was also calculated to assess their significance (Rabinovich, 1980). The Green Index (GI) was calculated to verify how much the infrapopulations are grouped (Ludwig et al., 1988).

To assess the composition of parasitic communities, the following descriptors were calculated: Shannon-Wiener Diversity Index (H) (using Neperian logarithm Ln), Pielou's Equitability Index (J), Margalef Specific Richness Index (D) (Zar, 2010; Magurran, 2013), Berger-Parker Dominance Index (D_{BP}), relative dominance (number of specimens of one species/total number of specimens of all species in the infracommunity) and frequency of dominance of each parasite species (Rohde et al., 1995).

The Spearman's rank correlation coefficient (*rs*) was used to verify possible correlations between the host's biometric data (mass and standard length) and parasitic abundance, species richness, and diversity index (Zar, 2010).

SPSS Statistics and PRIMER 6 software (version 6.1.6) were used for data analysis. The tests mentioned above were applied only to parasite species with a prevalence greater than 10% (Bush et al., 1997). The results were considered significant when $p < 0.05$. Vouchers of the identified parasites were deposited in the Helminthological Collection of the Institute of Biosciences of Botucatu (CHIBB), of the Universidade Estadual Paulista (UNESP), Botucatu, São Paulo, Brazil.

RESULTS

All analyzed fish were parasitized by at least one species of parasite, in larval or adult stages. A total of 17 species of parasites were found, including mixozoans, flatworms, nematodes, crustaceans, and leeches. The parasites were found on the surface, gills, eyes, heart, and digestive tract. About 961 specimens of parasitic metazoans were collected with mean total abundance of 18.13 ± 16.11. The richness of each infracommunity ranging from 1 to 7 species of parasites per fish. The species found can be seen in Table 1.

According to the Jackknife 1st order richness estimator, the maximum number of species that would be within the expected

Table 1. Quantitative descriptors, degree of importance within the infracommunity, and fixation sites of parasites in *Hoplosternum littorale* (Siluriformes, Callichthyidae) collected in Batalha River, Tietê-Batalha basin, State of São Paulo, Brazil (P% = Prevalence; MA = Mean Abundance; MI = Mean Intensity; SE = Standard Error; VR = Variation Range; CS = Community Status; IS = Infection/Infestation Site).

Parasite Species	P%	MA±SE	MI±SE	VR	CS	IS
Myxozoa						
Henneguya guanduensis	13.21	-	-	-	Satellite	Gills
Monogenea						
Gyrodactylus sp.	49.05	5.57±1.78	11.35±3.25	1-60	Secondary	Gills, Body surface
Gyrodactylidae gen. sp.	22.64	0.70±0.19	3.08±0.72	1-8	Satellite	Gills, Body surface
Digenea						
Austrodiplostomum compactum (metacercariae)	11.32	0.15±0.07	1.33±0.33	1-3	Satellite	Eyes
Austrodiplostomum mordax (metacercariae)	1.89	0.02±0.02	1.00	1	Satellite	Eyes
Diplostomum lunaschiae (metacercariae)	84.91	8.34±1.20	9.82±1.28	1-36	Central	Eyes
Diplostomidae gen. sp. 1 (metacercariae)	3.77	0.13±0.07	1.75±1.00	1-3	Satellite	Intestine
Aporocotylidae gen. sp.	30.19	1.19±0.32	3.94±0.64	1-9	Satellite	Heart
Magnivitellinum corvitellinum	16.98	0.25±0.09	1.44±0.25	1-3	Satellite	Intestine
Nematoda						
Contracaecum sp. (larvae)	11.32	0.25±0.11	2.17±0.48	1-4	Satellite	Intestine
Porrocaecum sp. (larvae)	18.87	0.43±0.15	2.30±0.50	1-6	Satellite	Intestine
Dioctophymerenale (larvae)	3.77	0.04±0.03	1.00	1	Satellite	Intestine
Spiroxyscontortus (larvae)	28.30	0.60±0.17	2.13±0.39	1-6	Satellite	Intestine
Pseudocapillaria sp. 1	7.55	0.15±0.08	2.00±0.41	1-3	Satellite	Intestine
Pseudocapillaria sp. 2	13.21	0.21±0.08	1.57±0.30	1-3	Satellite	Intestine
Copepoda						
Lernaea cyprinacea	3.77	0.06±0.04	1.50±0.50	1-2	Satellite	Body surface
Hirudinea						
Oligobdella sp.	5.66	0.06±0.03	1.00	1	Satellite	Body surface

would be 20 species of parasites, a value very close to what was observed (17 species). These three "missing species" would be within the concept of "rare species" of parasites. Both the observed species curve and the expected species curve showed a stabilization trend (Figure 2).

Henneguya guanduensis Abdallah, Azevedo, Luque & Do Bonfim, 2007 was the only myxozoan species found in this host. The metacercariae of *Diplostomum lunaschiae* Locke, Drago, Núñez, Rangel e Souza & Takemoto, 2020 showed higher prevalence and mean abundance, and the only species considered central, while *Gyrodactylus* sp. obtained the higher mean intensity value (Table 1). This monogenetic was the only species considered secondary, while the other species showed prevalence below 30% (satellites).

Margalef's specific richness index was higher (0.95) than that of Shannon (0.82) and Pielou (0.75), indicating that the species are irregularly distributed among the hosts (Table 2). This scene was confirmed by the dispersion index (DI), which indicated an aggregate pattern for all parasite species found, and *Gyrodactylus* sp. obtained the highest degree of aggregation among species (GI = 0.55). *Diplostomum lunaschiae* was also responsible for the value obtained in the Berger-Parker dominance since this digenetic was dominant in the analyzed infracommunities (RD = 0.46) (Table 3).

Regarding the Spearman rank coefficient, Aporocotylidae gen. sp. showed a significant negative correlation between its abundance and the weight and standard length of the host, while *Spiroxys contortus* (Rudolphi, 1819) showed a significant negative correlation between its abundance and the host weight. Shannon's diversity of infracommunities showed a negative correlation both with the length and weight of the hosts, while the richness had a negative correlation only with the host weight. All significant correlations obtained showed negative *rs* in an interval between - 0.48 and - 0.30, being considered as weak to moderate (Table 4).

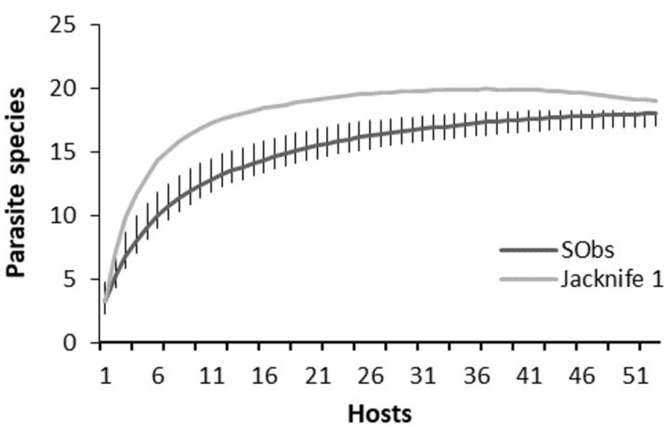

Figure 2. Species accumulation curves (1st order Jackknife estimator [Jacknife 1] and Species Observed [Sobs]) of parasites of *Hoplosternum littorale* (Siluriformes, Callichthyidae) collected in Batalha River, Tietê-Batalha basin, State of São Paulo, Brazil.

Table 2. Body measures and characteristics of the component community of the parasites of *Hoplosternum littorale* (Siluriformes, Callichthyidae) collected in Batalha River, Tietê-Batalha basin, State of São Paulo, Brazil (mean values followed by standard error and minimum and maximum values in parentheses).

Parameters	***Hoplosternum littorale***
Weight (g)	14.38±0.30 (35.26 - 281.55)
Standard length (cm)	129.38±7.34 (9.00 - 19.00)
Total of Female/Male	19/34
Parasite species richness	3.30±0.22 (1 - 7)
Margalef Index (D)	0.95±2.21 (0.25 - 2.40)
Shannon Diversity Index (H)	0.82±0.06 (0.12 - 1.73)
Pielou Equitability Index (J)	0.75±0.03 (0.18 - 1.00)
Berger-Parker Dominance (D_{BP})	0.46
Total parasite number	961 (1 - 73)
Total parasite species	17
Ectoparasites species	4
Endoparasites species	13
Adult stage	9
Larval stage	8

Table 3. Dispersion Index (DI), *d*-statistic, Aggregation Index (GI), dispersion pattern, dominance frequency (DF%) and relative dominance (RD) for the parasite infracommunities of *Hoplosternum littorale* (Siluriformes, Callichthyidae) collected in Batalha River, Tietê-Batalha basin, State of São Paulo, Brazil.

Parasite species	**DI**	***d***	**GI**	**Dispersion**	**DF%**	**RD**
Gyrodactylus sp.	29.56	45.34	0.55	Aggregated	20.76	0.31
Gyrodactylidae gen. sp.	4.40	11.30	0.07	Aggregated	5.66	0.04
Austrodiplostomum compactum	1.63	2.91	0.01	Aggregated	1.89	0.01
Diplostomum lunaschiae	8.68	19.94	0.15	Aggregated	56.60	0.46
Aporocotylidae gen. sp.	4.37	11.22	0.06	Aggregated	5.66	0.07
Magnivitellinum corvitellinum	1.64	2.84	0.01	Aggregated	3.77	0.01
Contracaecum sp.	2.49	5.89	0.03	Aggregated	3.77	0.01
Porrocaecum sp.	2.88	7.20	0.04	Aggregated	3.77	0.02
Spiroxyscontortus	2.57	6.25	0.03	Aggregated	3.77	0.03
Pseudocapillaria sp. 2	1.73	3.31	0.01	Aggregated	3.77	0.01

Table 4. Spearman's Rank Correlation Coefficient (rs) of *Hoplosternum littorale* (Siluriformes, Callichthyidae) collected in Batalha River, Tietê-Batalha basin, State of São Paulo, Brazil.

Variables	Standard length		Weight	
	rs	***p***	***rs***	***p***
Gyrodactylus sp.	0.12	0.39	-0.01	0.96
Gyrodactylidae gen. sp.	-0.05	0.71	-0.11	0.43
Austrodiplostomum compactum	0.10	0.46	0.07	0.62
Diplostomum lunaschiae	0.02	0.87	-0.02	0.89
Aporocotylidae gen. sp.	-0.40	<0.001*	-0.48	<0.001*
Magnivitellinum corvitellinum	-0.09	0.52	-0.14	0.32
Contracaecum sp.	0.24	0.08	0.18	0.19
Porrocaecum sp.	0.13	0.37	0.16	0.26
Spiroxys contortus	-0.37	0.01*	-0.21	0.13
Pseudocapillaria sp. 2	-0.10	0.50	-0.03	0.83
Parasite species richness	-0.23	0.09	-0.30	0.03*
Diversity (Shannon Index)	-0.29	0.04*	-0.32	0.02*

**p* value <0.05.

DISCUSSION

*Hoplosternum littoral*e presented species of parasites in both larval and adult stages, emphasizing their importance in the intermediate positions of the food chains. The Diplostomidae metacercariae (mainly *D. lunaschi*) were quite prevalent in the present study. By relying on three hosts in their cycles (first intermediate host: mollusk; second intermediate host: fish; and final host: fish and/or piscivorous bird), they are good indicators of local biodiversity (Désilets et al., 2013). Although they can parasite different organs and tissues, the preferred site of infection is the eyes of the second intermediate hosts. They have low parasitic specificity, and infect different eye structures, causing decreased visual capacity, cataracts, blindness, and making the fish susceptible to predators, ending the cycle of transmission to the definitive hosts (Grobbelaar et al., 2015). In the present study, the clear separation of the infection site of one species found was observed: *D. lunaschiae* was present only in the lens, whereas *Austrodiplostomum compactum* (Lutz, 1928) Dubois, 1970 and *A. mordax* Szidat & Nani, 1951 were identified only in the aqueous or vitreous humor. Probably the low prevalence and intensity of these two species occurred because of the overlap of niches between them, while *D. lunaschiae* is alone in the lens.

The richness of species found in the present study differs from other studies carried out with this host in Brazil and Argentina. The composition is also quite different. Abdallah et al. (2006) in the Guandu River, RJ, registered eight species, and all were different from those found in the present study, while Dias et al. (2017) in a study conducted in Peixe River, SP, found only nine species and four of these were common to those found in the present study. This variation may be linked to the environmental integrity conditions of each location, as well as the presence of intermediate and/or final hosts responsible for the perpetuation of the life cycles of the heteroxene parasites (Luque and Poulin, 2007). Another factor is the presence of generalist species (such as *A. compactum*) and specific species of *H. littorale* (such as *Magnivitellinum corvitellinum* Lacerda et al., 2009). This occurrence of general and specific species in this host indicates the high richness observed. We might expect specialist parasites to occur mainly in host species with rich parasite faunas. The result would be species-poor parasite faunas consisting of generalist parasites only, and species-rich parasite faunas comprising both generalist and specialist parasites (Poulin, 1997).

The number of species of endoparasites (13) prevailed over ectoparasites (4). The omnivorous habit of this host includes in its diet potential early intermediate hosts of the cycles of many parasites (such as mollusks, crustaceans, and insect larvae) (Hahn et al., 1998; Santos et al., 2009a), which would explain this difference. Concerning nematodes (all found in the intestinal lumen), the presence of four species in the larval stage in this host (*Contracaecum* sp., *Porrocaecum* sp., *Dioctophyme renale* (Goeze, 1782), and *S. contortus*) also shows its importance as an intermediate and paratenic host. The L3 larvae of *Contracaecum* sp. belong to the family Anisakidae. Some species of this family are known for their proven zoonotic potential of some of their larvae (Salati et al., 2013), although there are no reports in the literature on human contamination by larvae of *Contracaecum* sp. In the case of *S. contortus* and *D. renale*, the fish will act as a paratenic host, since they will use copepods and oligochaetes worms as intermediate hosts, respectively (Mace and Anderson, 1975; Santos et al., 2009b).

The aggregate pattern allows the largest encounter between the parasite specimens, facilitating their reproduction. However, if the parasites are heteroxenes, the aggregation can be explained by the susceptibility and tolerance of the host organisms to infections, and by the different forms of contact between the hosts and the parasites (Anderson and Gordon, 1982), such as the process which determines how the parasite will enter the host. Parasitic species that enter passively (usually through ingestion with food), tend to exhibit higher levels of aggregation and average parasitic load. Still, about tropically transmitted endoparasites, the preferential benthic habit of the host species makes them present a general diet (mainly in *H. littorale*), and this habit allows greater aggregation of their parasites when compared to pelagic species (Amarante et al., 2015).

In the present study, it was observed that the Margalef richness index (D = 0.95) was higher than the Shannon diversity (H = 0.82) and Pielou's equitability (J = 0.75). Studies carried out with other hosts on the Batalha River have obtained different results. Pelegrini et al. (2021), in a study with four species of *Hypostomus* spp. observed higher values of the Shannon diversity index when compared to equitability and richness. Pelegrini et al. (2018), also observed this pattern in a study with *Proloricaria prolixa* (Isbrücker & Nijssen, 1978), where the diversity index was higher (0.94) than the Margalef Index (0.83) and Pielou Index (0.60). In the study by Pedro et al. (2016) with *Acestrorhynchus lacustris* (Lütken, 1875), this pattern was also observed (H = 1.42; D = 1.28; J = 0.75). As the present study, Leite et al. (2018) in an analysis of *Prochilodus lineatus* (Valenciennes, 1837), obtained greater Margalef Index (1.83) than diversity (0.81). Although lower than the other two indexes, Pielou's equitability values are not considered low, since this index varies from 0 to 1, different from the other indexes that do not have this limitation.

The significant negative correlations of endoparasites (Aporocotylidae gen. sp. and *S. contortus*) in *H. littorale* are linked to the ingestion of an infected host. It can be assumed that this host varies its diet throughout its ontogenetic development. This decrease in parasitic load may occur due to the different prey chosen as the fish grows, or the migration of these fish to a new environment, with a different composition of potential intermediate hosts (Scott, 1982). Considering the low migration rate of this fish, the first hypothesis may be the most plausible, added to the changes in the processes of immune defense as the fish ages.

CONCLUSIONS

Based on the data obtained, we conclude that the Batalha River is an important site for maintaining local biodiversity with a relevant contribution to the knowledge of freshwater biodiversity in the State of São Paulo. It was possible to observe the high parasitic diversity of this host in this river, mainly in comparison with studies carried out with this host in other regions. However, further studies and follow-up are necessary, considering the constant dynamics of the parasitic communities, in addition to the anthropic actions that can influence the distribution of the parasites among the hosts. Gyrodactylidae gen. sp., *A. mordax*, Aporocotylidae gen. sp., *D. lunaschiae*, Diplostomidae gen. sp. 1, *Contracaecum* sp., *D. renale*, *Porrocaecum* sp., *Pseudocapillaria* sp. 1, *Pseudocapillaria* sp. 2, *S. contortus*, *Oligobdella* sp., and *Lernaea cyprinacea* Linnaeus, 1758 are parasites mentioned for the first time in *H. littorale*. Aporocotylidae gen. sp., Gyrodactylidae gen. sp., and *Oligobdella* sp. are new species that are in the process of taxonomic description by the authors of the present study.

ACKNOWLEDGEMENTS

We would like to thank the FAPESP (Fundação de Amparo à Pesquisa do Estado de São Paulo) for the research project grant of Vanessa D. Abdallah (2012/23655-0) and Rodney K. Azevedo (2014/12862-0), and the CAPES (Coordenação de Aperfeiçoamento de Pessoal de Nível Superior) for the scholarship of Larissa S. Pelegrini.

REFERENCES

Abdallah, V.D.; Azevedo, R.K.; Luque, J.L. 2006. Ecologia da comunidade de metazoários parasitos do tamboatá *Hoplosternum littorale* (Hancock, 1828) (Siluriformes: Callichthyidae) do Rio Guandu, Estado do Rio de Janeiro, Brasil. Acta Scientiarum. Biological Sciences, 28(4): 413-419. https://doi.org/**10.4025/actascibiolsci.v28i4.407**.

Abdallah, V.D.; Azevedo, R.K.; Luque, J.L.; Bomfim, T.C. 2007. Two new species of *Henneguya* Thélohan, 1892 (Myxozoa, Myxobolidae), parasitic on the gills of *Hoplosternum littorale* (Callichthyidae) and *Cyphocharax gilbert* (Curimatidae) from the Guandu River, State of Rio de Janeiro, Brazil. Parasitología Latinoamericana, 62(1-2): 35-41. https://doi.org/**10.4067/s0717-77122007000100006**.

Amarante, C.F.D.; Tassinari, W.D.S.; Luque, J.L.; Pereira, M.J.S. 2015. Factors associated with parasite aggregation levels in fishes from Brazil. Revista Brasileira de Parasitologia Veterinária, 24(2): 174-182. https://doi.org/**10.1590/s1984-29612015031**.

Anderson, R.M.; Gordon, D.M. 1982. Processes influencing the distribution of parasite numbers within host populations with special emphasis on parasite-induced host mortalities. Parasitology, 85(2): 373-398. https://doi.org/**10.1017/s0031182000055347**.

Azevedo, R.K.; Abdallah, V.D.; Luque, J.L. 2010. Acanthocephala, Annelida, Arthropoda, Myxozoa, Nematoda and Platyhelminthes parasites of fishes from the Guandu river, Rio de Janeiro, Brazil. Check List, 6(4): 659-667. https://doi.org/**10.15560/6.4.659**.

Azevedo, R.K.; Abdallah, V.D.; Luque, J.L. 2011. Biodiversity of fish parasites from Guandu River, southeastern Brazil: an ecological approach. Neotropical Helminthology, 5(2): 185-199.

Baia, R.R.J.; Florentino, A.C.; Silva, L.M.A.; Tavares-Dias, M. 2018. Patterns of the parasite communities in a fish assemblage of a river in the Brazilian Amazon region. Acta Parasitologica, 63(2): 304-316. https://doi.org/**10.1515/ap-2018-0035**.

Bush, A.O.; Holmes, J.C. 1986. Intestinal helminths of lesser scaup ducks: an interactive community. Canadian Journal of Zoology, 64(1): 142-152. https://doi.org/**10.1139/z86-023**.

Bush, A.O.; Lafferty, K.D.; Lotz, J.M.; Shostak, A.W. 1997. Parasitology meets ecology on its own terms: Margolis et al. revisited. The Journal of Parasitology, 83(4): 575-583. https://doi.org/**10.2307/3284227**.

Désilets, H.D.; Locke, S.A.; McLaughlin, J.D.; Marcogliese, D.J. 2013. Community structure of *Diplostomum* spp.(Digenea: Diplostomidae) in eyes of fish: main determinants and potential interspecific interactions. International Journal for Parasitology, 43(11): 929-939. https://doi.org/**10.1016/j.ijpara.2013.07.002**.

Dias, K.G.A.; Alves, C.A.; Silva, R.J.; Abdallah, V.D.; Azevedo, R.K. 2017. Parasitic communities of *Hoplosternum littorale* (Hancock, 1828) as indicators of environmental impact. Anais da Academia Brasileira de Ciências, 89(suppl. 3): 2317-2325. https://doi.org/**10.1590/0001-3765201720160792**.

Eiras, J.C.; Takemoto, R.M.; Pavanelli, G.C. 2006. Métodos de estudo e técnicas laboratoriais em parasitologia de peixes. Maringá: Eduem. 199p.

Fernandes, B.M.; Malta, J.C.; Morais, A.M. 2013. *Porangatus ceteyus* n. gen., n. sp. (Digenea: Zoogonidae): a parasite of *Hoplosternum littorale* (Pisces: Callichthyidae) from Amazonas State, Brazil. Comparative Parasitology, 80(2): 203-209. https://doi.org/**10.1654/4631.1**.

Graça, W.J.; Pavanelli, C.S. 2007. Peixes da planície de inundação do alto rio Paraná e áreas adjacentes. 1st ed. Maringá: Eduem. 241p.

Granado-Lorencio, C.; Lima, C.R.A.; Lobón-Cerviá, J. 2005. Abundance – distribution relationships in fish assembly of the Amazonas floodplain lakes. Ecography, 28(4): 515-520. https://doi.org/**10.1111/j.0906-7590.2005.04176.x**.

Grobbelaar, A.; Van As, L.L.; Van As, J.G.; Butler, H.J. 2015. Pathology of eyes and brain of fish infected with diplostomids, southern Africa. African Zoology, 50(2): 181-186. https://doi.org/**10.1080/15627020.2015.1055701**.

Hahn, N.S.; Agostinho, A.A.; Gomes, L.C.; Bini, L.M. 1998. Estrutura trófica da ictiofauna do reservatório de Itaipu (Paraná-Brasil) nos primeiros anos de sua formação. Interciencia, 23(5): 299-305.

Hanski, I. 1982. Dynamics of regional distribution: the core and satellite species hypothesis. Oikos, 38(2): 210-221. https://doi.org/**10.2307/3544021**.

Jucá-Chagas, R. 2004. Air breathing of the neotropical fishes *Lepidosiren paradoxa, Hoplerythrinus unitaeniatus* and *Hoplosternum littorale* during aquatic hypoxia. Comparative Biochemistry and Physiology. Part A, Molecular & Integrative Physiology, 139(1): 49-53. https://doi.org/**10.1016/j.cbpb.2004.06.019**.

Lacerda, A.; Takemoto, R.; Pavanelli, G. 2009. A new trematode species parasitizing the catfish *Hoplosternum littorale* (Osteichthyes, Callichthyidae) from Paraná River, Brazil, with an emendation of the diagnosis of *Magnivitellinum* (Trematoda, Macroderoididae). Acta Parasitologica, 54(1): 37-40. https://doi.org/**10.2478/s11686-009-0007-5**.

Leite, L.A.R.; Pelegrini, L.S.; Agostinho, B.N.; Azevedo, R.K.D.; Abdallah, V.D. 2018. Biodiversity of the metazoan parasites of *Prochilodus lineatus* (Valenciennes, 1837) (Characiformes: Prochilodontidae) in anthropized environments from the Batalha River, São Paulo State, Brazil. Biota Neotropica, 18(3): 1-10. https://doi.org/**10.1590/1676-0611-bn-2017-0422**.

Ludwig, J.A.; Quartet, L.; Reynolds, J.F.; Reynolds, J.F. 1988. Statistical ecology: a primer in methods and computing. USA: John Wiley & Sons. 368p.

Luque, J.L.; 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**.

Luquet, P.; Boujard, T.; Planquette, P.; Moreau, Y.; Hostache, G. 1989. The culture of *Hoplosternum littorale:* state of the art and perspectives. Advances in Tropical Aquaculture, 9: 511-516.

Mace, T.F.; Anderson, R.C. 1975. Development of the giant kidney worm, *Dioctophyma renale* (Goeze, 1782) (Nematoda: Dioctophymatoidea). Canadian Journal of Zoology, 53(11): 1552-1568. https://doi.org/**10.1139/z75-190**.

Magurran, A.E. 2013. Measuring biological diversity. Oxford: John Wiley & Sons. 287p.

Negrelli, D.C.; Abdallah, V.D.; Azevedo, R.K. 2018. Metazoan parasites of the lambari *Astyanax altiparanae* collected in the Batalha River, State of São Paulo, Brazil. Brazilian Journal of Biology = Revista Brasileira de Biologia, 78(3): 535-539. https://doi.org/**10.1590/1519-6984.172601**.

Núñez, M.O.; Arredondo, N.J.; Pertierra, A.A.G. 2017. Adult Trematodes (Platyhelminthes) of freshwater fishes from Argentina: a checklist. Revue Suisse de Zoologie, 124(1): 91-113. https://doi.org/**10.5281/zenodo.322669**.

Ota, R.R.; Deprá, G.C.; Graça, W.J.; Pavanelli, C.S. 2018. Peixes da planície de inundação do alto rio Paraná e áreas adjacentes: revised, annotated and updated. Neotropical Ichthyology, 16(2): e170094. https://doi.org/**10.1590/1982-0224-20170094**.

Pedro, N.H.O.; Pelegrini, L.S.; Azevedo, R.K.; Abdallah, V.D. 2016. First record of *Rhipidocotyle santanaensis* (Digenea) parasitizing *Acestrorhynchus lacustris* from Batalha River, Brazil. Brazilian Journal of Biology = Revista Brasileira de Biologia, 76(4): 878-883. https://doi.org/**10.1590/1519-6984.02515**.

Pelegrini, L.S.; Januário, F.F.; Azevedo, R.K.; Abdallah, V.D. 2018. Biodiversity and ecology of the parasitic infracommunities of *Loricaria prolixa* (Siluriformes: Loricariidae) from the Tietê-Batalha Basin, SP, Brazil. Acta Scientiarum. Biological Sciences, 40(1): e36294. https://doi.org/**10.4025/actascibiolsci.v40i1.36294**.

Pelegrini, L.S.; Leite, L.A.R.; Gião, T.; Bueno, R.M.R.; Serrano, T.D.; Silva, R.J.; Azevedo, R.K.; Abdallah, V.D. 2021. Diversity, similarity, and host–parasite relationships in parasitic infracommunities of *Hypostomus* spp. from the Tietê-Batalha river basin, southeastern Brazil. Studies on Neotropical Fauna and Environment, 56: 1-14. https://doi.org/**10.1080/01650521.2020.1870033**.

Pinheiro, D.A.; Tavares-Dias, M.; Dias, M.K.R.; Santos, E.F.; Marinho, R.D.G.B. 2013. Primeiro registro da ocorrência de protozoários em tamoatá *Hoplosternum littorale* no Brasil. Boletim do Instituto de Pesca, 39(2): 169-177.

Poulin, R. 1997. Parasite faunas of freshwater fish: the relationship between richness and the specificity of parasites. International Journal for Parasitology, 27(9): 1091-1098. https://doi.org/**10.1016/s0020-7519(97)00070-2**.

Poulin, R. 1998. Comparison of three estimators of species richness in parasite component communities. The Journal of Parasitology, 84(3): 485-490. https://doi.org/**10.2307/3284710**.

Rabinovich, J.E. 1980. Introducción a la ecología de poblaciones animals. México: Continental. 313p.

Rohde, K.; Hayward, C.; Heap, M. 1995. Aspects of the ecology of metazoan ectoparasites of marine fishes. International Journal for Parasitology, 25(8): 945-970. https://doi.org/**10.1016/0020-7519(95)00015-T**.

Salati, F.; Meloni, M.; Cau, M.; Angelucci, G. 2013. Presence of *Contracaecum* spp. in teleosts cultured and fished in Sardinia. Veterinary Parasitology, 196(3-4): 382-387. https://doi.org/**10.1016/j.vetpar.2013.03.014**.

Santos, F.D.S.; Heubel, M.T.C.D. 2008. Composição da comunidade ictiológica e biometria taxonômica na lagoa de captação de água do DAE no rio Batalha (Bauru, SP). Revista Salusvita, 27(1): 29-44.

Santos, G.M.; Ferreira, E.J.G.; Zuanon, J.A.S. 2009a. Peixes comerciais de Manaus. Manaus: Editora INPA. 146p.

Santos, M.D.; Albuquerque, M.C.; Monteiro, C.M.; Martins, A.N.; Ederli, N.B.; Brasil-Sato, M.C. 2009b. First report of larval *Spiroxys* sp. (Nematoda, Gnathostomatidae) in three species of carnivorous fish from Três Marias Reservoir, São Francisco River, Brazil. Pan-American Journal of Aquatic Sciences, 4(3): 306-311.

São Clemente, S.D.; Matos, E.; Tortelly, R.; Lima, F.C. 1998. Histopatologia do parasitismo por metacercárias de *Clinostomum* sp. em tamoatá, *Hoplosternum littorale* (Hancock, 1828). Parasitología al Día, 22(1-2): 38-40. https://doi.org/**10.4067/S0716-07201998000100007**.

Sá-Oliveira, J.C.; Chellappa, S.; Vasconcelos, H.C.G. 2011. Estrutura populacional, relação peso-comprimento e fator de condição de *Hoplosternum littorale* (Hancock, 1828) (Siluriformes: Callichthyidae) da área de proteção ambiental do Rio Curiaú, Macapá-AP. Biota Amazônia, 1: 38-41. https://doi.org/**10.18561/2179-5746/biotaamazonia**.

Scott, J.S. 1982. Digenean parasite communities in flatfishes of the Scotian Shelf and southern Gulf of St. Lawrence. Canadian Journal of Zoology, 60(11): 2804-2811. https://doi.org/**10.1139/z82-359**.

Soares, M.G.M.; Costa, E.L.; Siqueira-Souza, F.K.; Anjos, H.D.B.; Yamamoto, K.C.; Freitas, C.E.C. 2008. Peixes de lagos do médio Rio Solimões. Manaus: Instituto Piatam. 160p.

Takemoto, R.M.; Pavanelli, G.C.; Lizama, M.A.P.; Lacerda, A.C.F.; Yamada, F.H.; Moreira, L.H.A.; Ceschini, T.L.; Bellay, S. 2009. Diversity of parasites of fish from the Upper Paraná River floodplain, Brazil. Brazilian Journal of Biology = Revista Brasileira de Biologia, 69(suppl. 2): 691-705. https://doi.org/**10.1590/s1519-69842009000300023**.

Torres, A.; Matos, E.; Azevedo, C. 1994. Fine structure of *Henneguya amazonica* (Myxozoa) in ovarian follicles of *Hoplosternum littorale* (Teleostei) from the Amazon river. Diseases of Aquatic Organisms, 19: 169-172. https://doi.org/**10.3354/dao019169**.

Vieira, D.H.M.D.; Pelegrini, L.S.; Abdallah, V.D.; Azevedo, R.K. 2019. Supplementary studies on *Henneguya guanduensis* (Cnidaria: Myxosporea) infecting gills and intestine of *Hoplosternum littorale* in Brazil: ultrastructural and molecular data. Parasitology International, 70: 27-32. https://doi.org/**10.1016/j.parint.2019.01.009**.

Zar, J.H. 2010. Biostatistical analysis. 5th ed. New Jersey: Prentice-Hall International Editions. 944p.