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Monogenoidea parasites of *Cichla monoculus* and *Cichla pinima* (Osteichthyes: Cichlidae), sympatric fish in lower Tapajós River, Northern Brazil

Marcos Sidney Brito Oliveira[1], Edson Aparecido Adriano[2], Marcos Tavares-Dias[3], Lincoln Lima Corrêa[4]

[1]Instituto de Ciências e Tecnologia das Águas - ICTA, Universidade Federal do Oeste do Pará - UFOPA, Av. Mendonça Furtado, nº 2946, Fátima, CEP 68040-470, Santarém, Pará, Brazil
[2]Department of Ecology and Evolutionary Biology, Universidade Federal de São Paulo (UNIFESP), Rua Professor Artur Riedel, nº 275, Jardim Eldorado, CEP 09972-270, Diadema, Estado de São Paulo, Brazil
[3]Embrapa Amapá, Rodovia Juscelino Kubitschek, Km 5, nº 2600, Universidade, CEP 68903-419, Macapá, Estado do Amapá, Brazil
[4]Instituto de Ciências e Tecnologia das Águas - ICTA, Universidade Federal do Oeste do Pará - UFOPA, Av. Mendonça Furtado, nº 2946, Fátima, CEP 68040-470, Santarém, Pará, Brazil

Corresponding Author: Lincoln Lima Corrêa; e-mail: lincorre@gmail.com

ABSTRACT. The study investigated the monogenoids infracommunity from the gills of *Cichla monoculus* and *C. pinima* living sympatrically in the lower Tapajós River, State of Pará (Brazil). A total of 561 monogenoids were collected of *C. monoculus*, which was host to seven species of these parasites, and 672 monogenoids were collected of *C. pinima*, which was host to eight species of these parasites. The monogenoids infracommunities of *C. monoculus* and *C. pinima* had a high qualitative similarity (88.0%), and quantitative (87%), and were composed by *Gussevia arilla*, *G. longihaptor*, *G. tucunarense*, *G. undulata*, *Sciadicleithrum ergensi*, *S. umbilicum* and *S. uncinatum*. There was a predominance of *G. arilla* and a low level of infection by *Tucunarella cichlae.* The prevalence, intensity and abundance of monogenoids were similar for *C. monoculus* and *C. pinima*, except for the intensity of *G. undulata* that was higher in *C. monoculus*. Parasite species displayed an aggregated dispersion, but *G. longihaptor* and *S. ergensi* exhibited random dispersion. This was the first study of monogenoids for *C. pinima*, and the first record of *G. arilla*, *G. tucunarense*, *S. ergensi*, *S. umbilicum* and *S. uncinatum* for *C. monoculus*. This study therefore extended the geographic distribution of these parasites to the lower Tapajós River in eastern Amazon.

Keywords: freshwater fish, gills, ectoparasites, Tapajós River, tucunaré

Introduction

Cichlidae is one of the most diverse fish families, comprising 202 genera and more than 1,700 species [1]. It is widely geographically distributed and includes species with different life habits [2]. In general, Cichlidae are of freshwater fish, but some species support salinity variations, allowing to invade brackish waters, have a wide geographical distribution, occurring in South and Central America, India, Africa, Madagascar, Israel, Syria and Sri Lanka [1].

Cichla order are cichlids popularly known as peacock bass or tucunaré. Currently, 15 species of *Cichla* endemic to the Amazon River system are known. They are considered high-quality edible fish and is important for extractive fishing and fish farming [3–6]. *Cichla monoculus* Agassiz, 1831 is widely distributed in region and is found from Peru to French Guiana [5]. The distribution of *Cichla pinima* Kullander and Ferreira, 2006 is restricted to the Curuá-Una, Tapajós, Xingu, Capim, Araguari, Amapá Grande rivers (eastern Amazon, Brazil) and Canumă River (western Amazon, Brazil) [5, 7, 8]. *Cichla monoculus* and *C. pinima* are important fish in the lower Tapajos River in the eastern Amazon

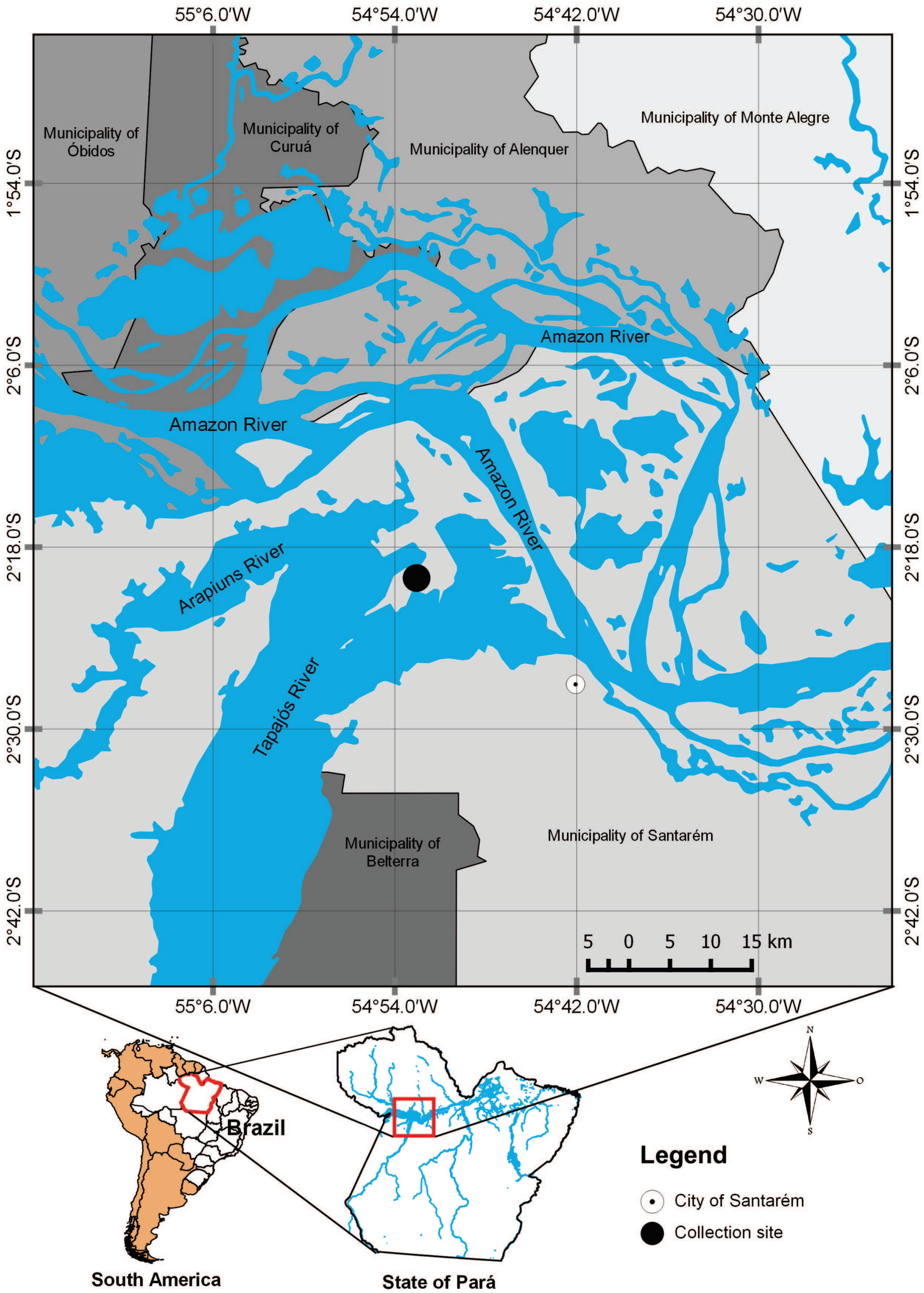

Fig. 1. Geographic location of collection sites of *Cichla monoculus* and *Cichla pinima* in the lower Tapajós River, state of Pará, in eastern Amazon (Brazil)

(northern Brazil), locality of study. Due to their importance for recreational fishing, *C. monoculus* have been introduced into other Brazilian hydrographic basins [9–12].

Fish can be natural hosts for several species of parasites, including Monogenoidea, which are ectoparasites generally found in the gills, integument, fins and nasal cavities of fish, although some species are endoparasites, inhabiting the intestine, stomach and urinary bladder of hosts. Monogenoidea communities provide good model to explore questions regarding interspecific interactions, and the

Table 1. Monogenoid species from the gills of *Cichla* spp. from the South America

Host species	Monogenoidea	Locality	References
Cichla kelberi	*Gussevia arilla*	Paraná River, PR (Brazil)	[52]
	Gussevia tucunarense	Lajes Reservoir, RJ (Brazil)	[53]
		Paranapanema River, PR and Rosana Reservoir, SP (Brazil)	[42]
	Gussevia longihaptor	Paraná River, PR (Brazil)	[52]
	Gussevia undulata	Lajes Reservoir, RJ (Brazil)	[53]
		Paraná River, PR (Brazil)	[52]
		Rosana Reservoir, SP and Paranapanema River, PR (Brazil)	[42]
	Sciadicleithrum ergensi	Lajes Reservoir, RJ (Brazil)	[53]
		Paranapanema River, PR and Rosana Reservoir, SP (Brazil)	[42]
Cichla melaniae	*Gussevia undulata*	Araguari, AP and Xingu, PA Rivers (Brazil)	[51]
	Sciadicleithrum umbilicum	Araguari, AP and Xingu, PA Rivers (Brazil)	
	Sciadicleithrum uncinatum	Araguari, AP and Xingu, PA Rivers (Brazil)	
	Tucunarella cichlae	Xingu River, PA (Brazil)	
Cichla monoculus	*Gussevia longihaptor*	Momon River, Iquitos (Peru)	[27]
	Tucunarella cichlae	Nanay River, Iquitos (Peru)	
	Gussevia undulata	Momon River, Iquitos (Peru)	
		Fish farm, Iquitos (Peru)	[50]
Cichla ocellaris	*Gussevia arilla*	Negro River, AM (Brazil)	[25]
	Gussevia longihaptor	Amazon River, AM (Brazil)	
	Gussevia tucunarense	Guandu River, RJ (Brazil)	[49]
		Negro River, AM (Brazil)	[25]
	Gussevia undulata	Guandu River, RJ (Brazil)	[49]
		Negro River, AM (Brazil)	[25]
	Sciadicleithrum ergensi	Guandu River, RJ (Brazil)	[49]
		Negro River,AM (Brazil)	[26]
	Sciadicleithrum uncinatum	Negro River, AM (Brazil)	
	Sciadicleithrum umbilicum	Negro River, AM (Brazil)	
Cichla piquiti	*Gussevia tucunarense*	Sǎo Salvador and Lajeado Reservoirs, TO (Brazil)	[42]
	Gussevia undulata	Lajes Reservoir, PR (Brazil)	[53]
		Itaipu, PR and Lajeado Reservoirs, TO (Brazil)	[42]
	Sciadicleithrum ergensi	Lajes Reservoir, PR (Brazil)	[53]
		Itaipu Reservoir, PR, Sǎo Salavador and Lajeado Reservoirs, TO (Brazil)	[42]
	Sciadicleithrum umbilicum	Sǎo Salvador and Lajeado Reservoirs, TO (Brazil)	[42]
	Sciadicleithrum uncinatum	Lajes Reservoir, PR (Brazil)	[53]
		Itaipu, PR, Sǎo Salvador and Lajeado Reservoirs, TO (Brazil)	[42]
Cichla temensis	*Gussevia undulata*	Araguari, AP and Xingu Rivers, PA (Brazil)	[51]
	Sciadicleithrum umbilicum	Araguari, AP and Xingu Rivers, PA (Brazil)	
	Sciadicleithrum uncinatum	Araguari, AP and Xingu Rivers, PA (Brazil)	

determinants of species richness or diversity in phylogenetically close hosts and living in sympatry that tend to have high similarity in the structure of their parasite infracommunities [13–19]. These ectoparasites exhibit high host specificity compared to other helminth species, because studies shows that species of congenic fish species share the same species of monogenoids [20–21].

The most of the species of monogenoids freshwater fish from Brazil are Dactylogyridae and Gyrodactylidae [19]. However, only species of dactylogyrids has reported in species of Brazilian cichlids [22], of which species of *Gussevia, Sciadicleithrum* and *Tucunarella* are known to infect *Cichla* spp. Three species of monogenoids have been reported infecting *C. monoculus*, but the species parasitizing *C. pinima* are not known (Table 1). In addition, there are no studies on the monogenoid infracommunities of *C. monoculus* and *C. pinima* to know the degree of similarity of these parasites between sympatric populations of hosts. Thus, this study compared the infracommunities of monogenoid on gills of *C. monoculus* and *C. pinima* living sympatrically in the lower Tapajós River, State of Pará, northern Brazil.

Materials and Methods

In March 2015, 19 specimens of *C. monoculus* measuring 37.4 ± 2.6 cm and weighing 657.5 ± 142.5 g and 20 specimens of *C. pinima* measuring 30.4 ± 6.2 cm and weighing 190.0 ± 90.0 g, were captured in the Jari do Socorro Lake (2°20’2.58”S 54°52’34.08”W), in the region of the lower Tapajós River, in the municipality of Santarém, in the State of Pará, Brazil (Fig. 1), for parasitological analysis. The Jari do Socorro Lake is a channel that connects the Amazon River with the Tapajós River and is strongly influenced by the waters of these rivers. Gill nets that were 30 m long, 2.5 m high, and had mesh sizes of 30, 35 and 40 mm between knots, were used to capture the fish. The fish were identified according to Kullander and Ferreira [5].

After collection, each fish was euthanized by the spinal cord transection method, and the standard length (cm) and total weight (g) were measured. The fish were then necropsied and the gills were removed and transferred to a vessel containing heated water (60–70°C) and stirred vigorously [23]. The collected monogenoids were fixed in formalin (5%) for 24 h, and preserved in 70% ethanol. The methodology recommended by Eiras et al. [24] was used for the quantification and preparation of the parasites for identification. The identification of the parasites was performed in accordance with Kritsky and Boeger [25,26], and Mendoza-Franco et al. [27]. The prevalence, mean intensity, mean abundance [28] and frequency of dominance [29] were determined for each infracommunity of monogenoid. Voucher specimens were deposited at the Platyhelminthes of the Zoology Museum (ZUEC) from the Universidade Estadual de Campinas (Brazil), under accession number 94, 100–103, 106, 107, 110, 112–114, 116–122, 126–129, 135–138.

To test the differences between the monogenoid communities of *C. monoculus* and *C. pinima* of Tapajós River, the ANOSIM test was used with 999 permutations to evaluate the Jaccard (J) similarity index (presence/absence of species), and dissimilarity index of Bray-Curtis (B) (abundance) [30].

The Spearman coefficient (*rs*) was used to determine possible correlations between the abundance of each species of monogenoids. The Green dispersion index was used to evaluate the degree of dispersion of each infracommunity of monogenoid with prevalence > 10%. The index of

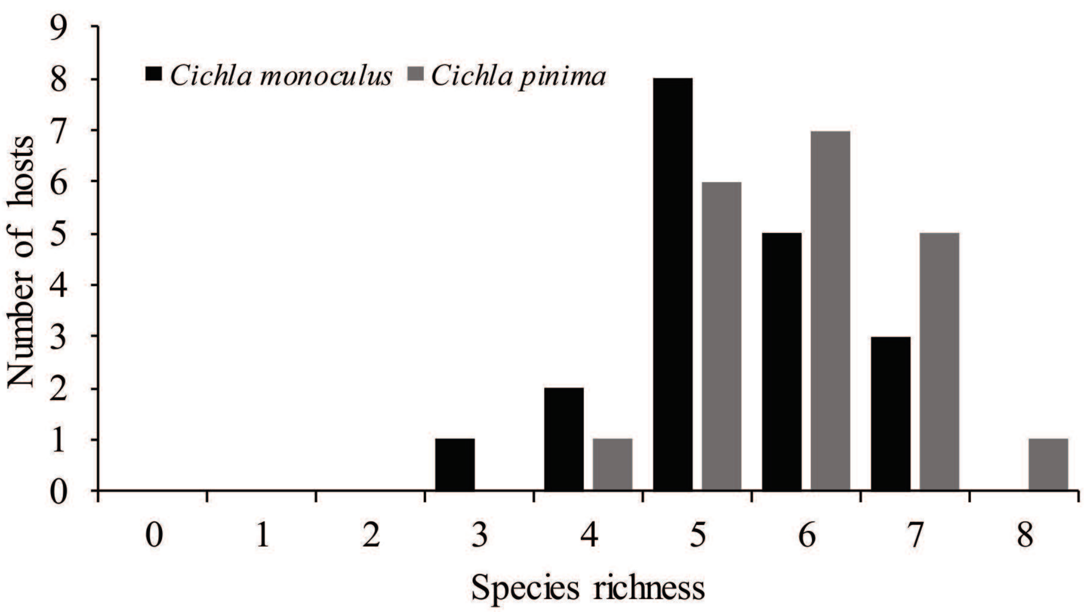

Fig. 2. Species richness of monogenoids in *Cichla monoculus* and *Cichla pinima* from the lower Tapajós River, state of Pará, in eastern Amazon (Brazil)

Table 2. Monogenoids species and infection levels in the gills of *Cichla monoculus* and *Cichla pinima* from the lower Tapajós River, state of Pará, in eastern Amazon (Brazil)

	Cichla monoculus (N = 19)					*Cichla pinima* (N = 20)				
Parasite species	P (%)	MI	MA	FD (%)	TNP	P (%)	MI	MA	FD (%)	TNP
Gussevia arilla	100	10.8	10.8	36.3	205	100	13.6	13.6	40.4	272
Gussevia longihaptor	42.1	2.4	1.0	3.4	19	60	1.9	1.2	3.4	23
Gussevia tucunarense	100	4.1	4.1	13.8	78	90	4.4	4.0	11.9	80
Gussevia undulata	36.8	2.7	1.0	3.4	19	80	1.0	0.8	2.4	16
Sciadicleithrum ergensi	94.7	4.7	4.5	5.0	85	95	3.9	3.8	11.1	75
Sciadicleithrum umbilicum	100	5.9	5.9	20.0	113	100	6.1	6.1	18.1	122
Sciadicleithrum uncinatum	68.4	3.2	2.2	7.4	42	90	4.6	4.2	12.3	83
Tucunarella cichlae	–	–	–	–	–	5	1.0	0.1	0.3	1
Total	100	1.4	1.4	–	561	100	1.7	1.7	–	671

P: Prevalence; MI: Mean intensity: MA: Mean abundance; FD: Frequency of dominance; TNP: total number of parasites

dispersion (ID) was tested using the *d*- statistical test: $d > 1.96$ = aggregated dispersion; $d < -1.96$ = uniform dispersion; $-1.96 < d < 1.96$ = random dispersion [31]. The Williams G-Test (G) was used to compare the prevalence of each species of monogenoids between both host species. The Mann-Whitney (*U*) test was used to compare the abundance and intensity of each species of monogenoids between the two hosts [32].

Results

All the fish examined were parasitized by species of monogenoids. In total of 1,233 parasites were collected, being 561 monogenoids of *C. monoculus* and 672 monogenoids of *C. pinima*. These parasites were distributed into the following taxa: *Gussevia arilla* Kritsky, Thatcher and Boeger, 1986; *G. longihaptor* Kritsky, Thatcher and Boeger, 1986; *G. tucunarense* Kritsky, Thatcher and Boeger, 1986; *G. undulate* Kritsky, Thatcher and Boeger, 1986; *Sciadicleithrum ergensi* Kritsky, Thatcher and Boeger, 1989; *S. umbilicum* Kritsky, Thatcher and Boeger, 1989; *S. uncinatum* Kritsky, Thatcher and Boeger, 1989 and *Tucunarella cichlae* Mendoza-Franco, Scholz and Rozkošná, 2010. However, *G. arilla* was dominant in both hosts, followed by *S. umbilicum* (Table 2).

The monogenoid infracommunities of both host species exhibited an aggregated dispersion pattern, but *G. longihaptor* and *S. ergensi* in *C. pinima* had a random dispersion (Table 3). There was a

Table 3. Dispersion index (D), *d*-statistical test, Green index (G) for the infracommunities of monogenoid in *Cichla monoculus* and *Cichla pinima* from the lower Tapajós River, state of Pará, in eastern Amazon (Brazil)

	Cichla monoculus (N = 19)			*Cichla pinima* (N = 20)		
Parasite species	D	*d*	G	D	*d*	G
Gussevia arilla	4.56	6.89	0.20	7.72	11.04	0.35
Gussevia longihaptor	2.56	3.68	0.09	1.40	1.21	0.02
Gussevia tucunarense	3.65	5.55	0.15	1.76	2.10	0.04
Gussevia undulata	2.99	4.46	0.11	5.05	7.77	0.21
Sciadicleithrum ergensi	2.22	3.03	0.07	1.00	0.08	0.00
Sciadicleithrum umbilicum	2.27	3.12	0.07	5.83	8.80	0.25
Sciadicleithrum uncinatum	3.15	4.73	0.12	4.32	6.73	0.17

Table 4. Williams test (*G*), and Man-Whitney (U), considering ($p \leq 0.05$), for levels of monogenoids infection in the gills of *Cichla monoculus* and *Cichla pinima* of the Tapajós River, state of Pará, in eastern Amazon (Brazil)

Parasite species	P (%)		MI		MA	
	G	*p*	*U*	*p*	*U*	*p*
Gussevia arilla	–	–	167.0	0.527	167.5	0.527
Gussevia longihaptor	1.208	0.271	42.0	0.643	162.0	0.431
Gussevia tucunarense	2.217	0.136	149.0	0.357	168.0	0.536
Gussevia undulata	3.117	0.077	13.5	**0.023**	180.5	0.789
Sciadicleithrum ergensi	–	–	137.0	0.301	156.0	0.346
Sciadicleithrum umbilicum	–	–	164.0	0.465	164.0	0.465
Sciadicleithrum uncinatum	2.699	0.100	95.0	0.378	129.0	0.089

P (%): prevalence; MI: mean intensity; MA: mean abundance

predominance of individuals infected by five or six species of monogenoids in both *C. monoculus* and *C. pinima* (Fig. 2). The monogenoid infracommunities of the populations of *C. monoculus* and *C. pinima* were similar in accordding to similarity analysis (ANOSIM) using the qualitative Jaccard index (J = 0.88) ($R = 0.253$, $p = 0.001$) and Bray-Curtis index (B = 0.87) ($R = 0.131$, $p = 0.004$). The infection levels of each monogenoid infracommunity did not differ between *C. monoculus* and *C. pinima* (Table 4).

In *C. monoculus*, the abundance of *G. arilla* shown positive correlation with the abundance of *S. uncinatum* ($rs = 0.554$; $p = 0.014$) and *G. tucunarense* ($rs = 0.681$; $p = 0.013$), just as the abundance of *S. uncinatum* correlated positively with the abundance of *G. tucunarense* ($rs = 0.613$; $p = 0.005$) and *S. ergensi* ($rs = 0.622$; $p = 0.004$). For *C. pinima*, there was positive correlation between the abundance of *G. arilla* and the abundance of *G. ergensi* ($rs = 0.610$; $p = 0.004$) and between the abundance of *S. umbilicum* ($rs = 0.690$; $p = 0.0007$) and *S. uncinatum* ($rs = 0.692$; $p = 0.0007$).

Discussion

Host fish that are closely phylogenetically related and live in the same environment tend to have greater similarity in the richness of parasites species than unrelated host species [13–15]. In terms generals, the infection levels of monogenoids were similar for *C. monoculus* and *C. pinima*, except for the mean intensity of *G. undulata* which was statistically higher in *C. monoculus* (see Table 4). Of the eight monogenoids species found in this study, seven were shared by the congeneric and sympatric species of *C. monoculus* and *C. pinima*, indicating that the species of monogenoids are adapted to both hosts that seem to present coevolution with these ectoparasites [33,21]. The monogenoid infracommunities of *C. monoculus* and *C. pinima* showed high similarity in the composition according to similarity analysis (ANOSIM) using Jaccard index (88.0%), and Bray-Curtis (87%) as expected for congeneric host species [20,21]. In contrast, studies with congenic and sympatric fish species from the Amazon basin, infected with ecto and endoparasites, showed a high quantitative and qualitative similarity among parasite communities due to the high overlap of ecological niches [14,15].

Aggregated dispersion is a typical pattern of ecto-and-endoparasites in freshwater fish [14,34] and that has been also reported for monogenoid species in Neotropical fish [14,15,22,35–37]. This pattern of parasite distribution may be influenced by the dimensions of the ecological niches, environmental heterogeneity, or the immunological and behavioral differences among individual hosts [14,17,36,38-40]. In contrast, *G. longihaptor* and *S. ergensi* infections in *C. pinima* had random dispersion, which may be related to the colonization strategy of each parasite species, as monogenoids ectoparasites can migrate between hosts [41].

The infections of monogenoids in *C. monoculus* and *C. pinima* presented infection levels varying from low to moderate. In addition, parasites richness was high, with *C. monoculus* infected by seven species and *C. pinima* infected by eight species of monogenoids. There are few studies on monogenoids *C. monoculus*, which are restricted to the Peruvian Amazon (Table 1); thus, this was the first report of *S. ergensi S. umbilicum*, *S. uncinatum*, *G. arilla* and *G. tucunarense* for *C. monoculus* and the first study on the monogenoids for *C. pinima*. For *C. monoculus*, there was a predominance of hosts infected by five species of monogenoids, while for *C. pinima* the fish were predominantly infected by six species. In contrast, for *C. piquiti* collected from the Paraná River basin, in the State of Paraná (Brazil), infection by five species of monogenoids was reported [42]. The high diversity of monogenoids in these hosts suggests that the environment was conducive to the development of these helminths with a direct life cycle, and that the behavior of the hosts contributed to the levels of infection, because their behavior sedentary propitiates this parasitism.

The competition among species of monogenoids has been analyzed by the negative correlation between their abundance [33]. However, in *C. monoculus* and *C. pinima* only positive correlations were found between the abundance of the monogenoids species, demonstrating that there was no competition among these parasite species, this because possibly they occupied different micro-habitats in the gills of hosts [43]. Similar results were reported for three species Dactylogyridae from the gills of *Piaractus brachypomus* (Cuvier, 1818) [37], as well as for nine species of *Gyrodactylidae* from the gills of *Rutilus rutilus* (Linnaeus, 1758) [33].

Parasitic specificity of species of monogenoids is a subject that has discussed [20,21,44]. Most families or orders of fish have a unique composition of genera of monogenoids [21], as recorded for *Cichla* spp. of South America, which are parasitized by eight species belonging to the genus *Gussevia*, *Sciadicleithrum* and *Tucunarella* (Table 1 and 2). Thus, *G. arilla* was reported also parasitizing the cichlid *Cichlassoma bimaculatum* (Linnaeus, 1758) [45,46] and *G. tucunarense* parasitizing the cichlid *Chaetobranchus semifasciatus* Steindachner, 1875 [47]. Hence, *G. arilla* and *G. tucunarense* appear to be monogenoid generalists [48]. Therefore, these fish from the Cichlidae family may share the same species of monogenoids due to a phylogenetic proximity [21, 44]. This may be related to the evolution and adaptation mechanism of the monogenoids, because by means of adaptations to a greater number of host species, these helminths may be more likely to thrive in the environment [20].

In summary, this study showed a high species richness and high similarity of monogenoid infracommunities in *C. monoculus* and *C. pinima*, as expected for congeneric and sympatric host species. This was the first study of monogenoids for *C. pinima*, and the first record of *G. arilla, G. tucunarense, S. ergensi, S. umbilicum* and *S. uncinatum* for *C. monoculus*. This study extended therefore the geographic distribution of these parasitic species to the lower Tapajós River, northern Brazil. Finally, studies on the seasonal variation of monogenoids for *C. monoculus* and *C. pinima* are need for understand the parasites ecology in these hosts.

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