



Long-term temporal variation in the parasite community structure of metazoans of *Pimelodus blochii* (Pimelodidae), a catfish from the Brazilian Amazon

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Abstract

The Amazon represents one of the most complex biomes in the world; however, the temporal variations in parasite community structure of fishes inhabiting this region remain poorly understood. Therefore, processes generating such variations are still unknown. The present study evaluated the long-term temporal variation of community structure of metazoan parasites of *Pimelodus blochii* collected in Iaco River, State of Acre (Southwestern Brazilian Amazon). A total of 196 parasites were collected over a 6-year period (2012–2017). Twenty-four different taxa of parasites were found, of which 5 Monogenea, 11 Nematoda, 3 Digenea, 1 Acanthocephala, 1 Cestoda, and 3 Crustacea. The overall species richness ranged from 4 in 2012 to 17 in 2016, in which nematodes (larvae and adults) showed higher numerical dominance, diversity, and species richness. However, the annual species richness was similar between the study years, except in 2016, where it showed a distinctly higher value. The overall parasite diversity was also different in 2012 and 2016, whereas the overall abundance differed in 2013 and 2017. The prevalence and abundance of some infracommunities of parasites varied over time. The temporal changes in the parasite community structure of *P. blochii* are probably related to variations in host-related features, i.e., body size and shift in diet composition as well as to the occurrence of parasites with distinct life history and biology (mainly monogeneans, digeneans, and nematodes). This is the first evaluation of a long-term temporal variation in the structure of the parasite community in fish from the Amazon.

Keywords Diversity · Ecology · Helminths · Nematodes

Introduction

Several tributaries form the extensive floodplain area delimited by the Amazon basin; this large area exhibits different geomorphology and phytophysiognomy that vary according to regional rainfall patterns, resulting in a variety of rich

ecosystems supporting complex trophic webs. These characteristics exert strong influence on the communities of invertebrates and fish inhabiting these areas (Garcez et al. 2017). In this sense, zooplankton has a key role in this ecosystem, linking primary producers to higher trophic levels (planktivorous and omnivorous fish) of the food web (Nakajima et al. 2017). The numerous tributary rivers of the Amazon support a rich native fish fauna, providing food, reproduction, and nursery grounds. Moreover, the region and its ecosystems are very important to the survival of riparian populations. In recent years, with the growth of agriculture, livestock, and deforestation, together with poor sanitation, has threatened the water quality of the Amazonian ecosystems (Ríos-Villamizar et al. 2017). This scenario is very worrisome given the great importance of this region.

The Bloch's catfish, *Pimelodus blochii* (Siluriformes: Pimelodidae), is a medium-sized species with considerable economic importance, widely distributed in the Northern part of South America, feeding on invertebrates, seeds, fruit, debris, and leaves (Lundberg and Littmann 2003; Froese and Pauly

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2019). Therefore, *P. blochii* is a generalist and opportunistic fish with broad feeding plasticity (Soares et al. 2011; Froese and Pauly 2019). This fish is not in IUCN list. Regarding its parasite fauna, a recent study evaluated the influence of seasonality and environment on the parasite community structure of *P. blochii*, from the same area of the present study (Negreiros et al. 2018), but this study was a short-term approach. However, most of the parasitological surveys regarding *P. blochii* are limited to taxonomic descriptions or species checklist (Gil de Perterra 2004; Luque and Tavares 2007; Kohn et al. 2007; Luque et al. 2011; Mendoza-Palmero and Scholz 2011; Oréllis-Ribeiro and Bullard 2015; Cavalcante et al. 2017, 2018; Negreiros et al. 2019).

Long-term approaches regarding the parasite community dynamics, in regions of both temperate and tropical climates, have been well addressed (e.g., Kennedy et al. 2001; Kennedy and Moriarty 2002; Zander 2005; Vidal-Martínez et al. 2014; Villalba-Vasquez et al. 2018; Gallegos-Navarro et al. 2018; Hoshino and Tavares-Dias 2019). These dynamics have been related to seasonality (thermal, rainfall, and other environmental fluctuations) and to biological features of hosts (general behavior, phenotype, and migratory aspects) (e.g., Kennedy et al. 2001; Kennedy and Moriarty 2002; Zander 2005; Vidal-Martínez et al. 2014; Villalba-Vasquez et al. 2018; Gallegos-Navarro et al. 2018; Hoshino and Tavares-Dias 2019). However, a variation on parasite community structure can be expected over time. Information on long-term dynamics of parasite community structure of fish in the Neotropical region is restricted to marine environments (e.g., Vidal-Martínez et al. 2014; Villalba-Vasquez et al. 2018; Gallegos-Navarro et al. 2018). Recently, Hoshino and Tavares-Dias (2019) investigated short-term dynamics in the parasite community structure of *Hemibrycon surinamensis* from the eastern Amazon. Therefore, little is known about how parasites can be influenced by long-term variations in Amazonian fish, because this topic has been poorly addressed. Thus, the present study evaluated the community structure of metazoan parasites in *P. blochii*, collected in Iaco River, State of Acre, Brazil (western Amazon), in a long-term temporal scale, identifying possible factor causing changes on this structure.

Materials and methods

Study area, sampling of hosts, and parasites

From June 2012 to March 2017 (June 2012, June 2013, June 2014, June to November 2015, May to September 2016, and March 2017), 196 individuals of *P. blochii* were collected with the help of local fisherman in the Iaco River, Municipality of Sena Madureira, State of Acre, Brazil (Fig. 1). Fish were kept in small, oxygenated water tanks prior to parasitological procedures in the Laboratório de Aquicultura do

Instituto Federal de Educação, Ciência e Tecnologia do Acre (acronym IFAC), then euthanized by spinal cord section, measured, weighed, and analyzed for the presence of parasites. Gills, body surface, and digestive tract (esophagus, stomach, caeca, and intestine) were observed using a stereomicroscope. The organs were placed on individual Petri dishes containing saline (0.9% NaCl); body surface was also washed with saline and the resulting rinse analyzed. Parasites were collected, fixed, preserved, quantified, and processed for identification according to Eiras et al. (2006). Voucher specimens were deposited in the Coleção Zoológica de Referência da Universidade Federal do Mato Grosso do Sul (ZUFMS).

Data and statistical analysis

The Shapiro–Wilk test was applied to determine whether data to be tested fitted to a normal distribution. Differences in fish length and weight were tested between the years (2012–2017) using the Kruskal–Wallis test, followed by the Tukey's post hoc test (Zar 2010).

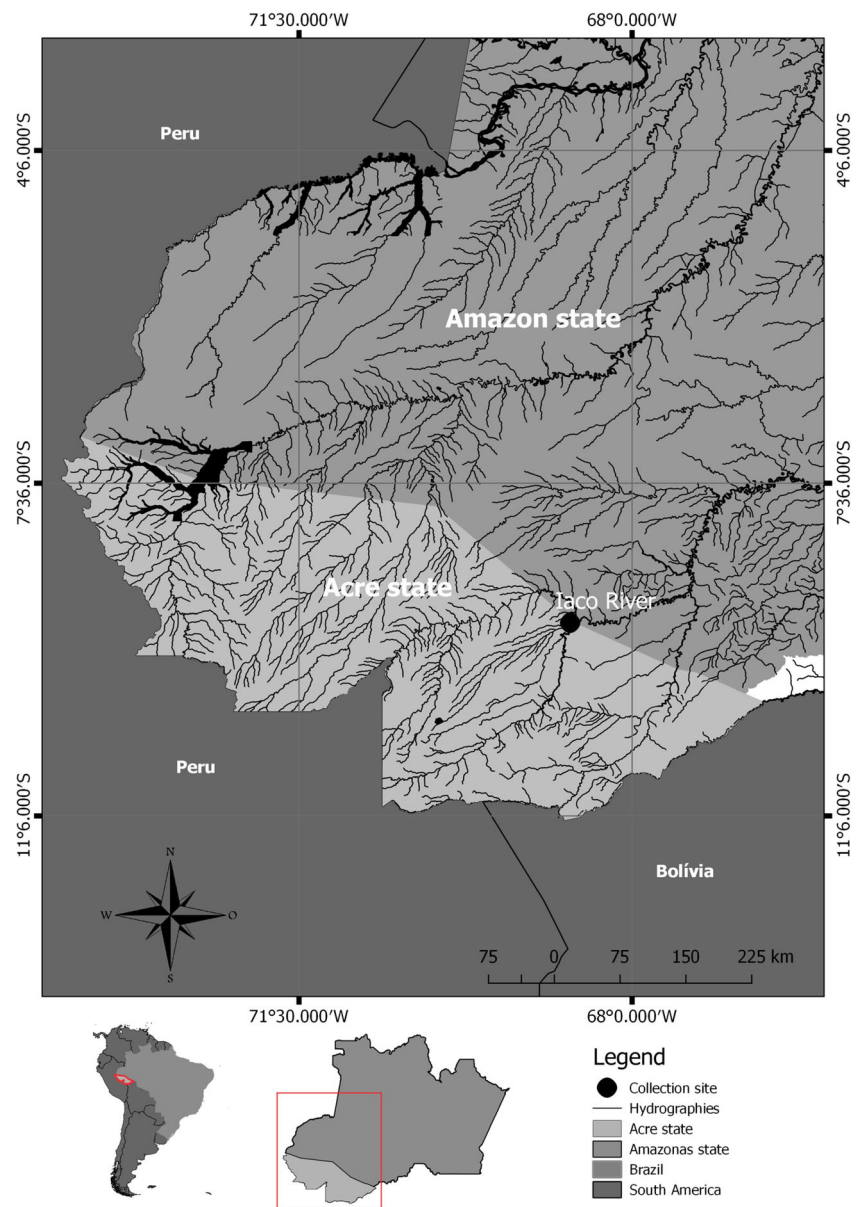
A non-parametric species accumulation curve was generated with 100 replications, in order to evaluate if host sampling was enough for recovering all or most of the parasite species over time.

Parasitological terminology used herein follows Bush et al. (1997). The frequency of dominance (percentage of infracommunities in which a parasite species is numerically dominant) was estimated according to Rohde et al. (1995). The following descriptors for the parasite community were calculated using the Diversity software (Pisces Conservation Ltd., UK): species richness, Shannon–Wiener diversity index (H'), and evenness (E) (Magurran 2004). Annual differences in the Shannon–Wiener diversity index, evenness, and species richness were tested using Kruskal–Wallis test, followed by Tukey's post hoc test (Zar 2010).

For component community of parasites, the asymptotic richness was examined based on the Clench's model equation (Soberon and Llorente 1993), as well as the final slope of the randomized species accumulation curve.

Differences in similarity of the parasite component communities were tested using the analysis of similarities (ANOSIM), between the years (2012–2017). ANOSIM was based on ranked matrixes, generated from Jaccard index and Bray–Curtis distance (Magurran 2004), with 10,000 permutations. This analysis was performed using PAST software (Hammer et al. 2001). In order to evaluate the differences in the Bray–Curtis distances between the years, the dissimilarity matrices were ranked and subjected to a Permutational Multivariate Analysis of Variance (PERMANOVA) using 9999 permutations and TukeyHSD post hoc test (Anderson et al. 2006). The test was based on the distances from each year to the group centroid in the full dimensional space calculated in a Principal Coordinates Analysis (PCoA). The Bray–Curtis dissimilarity

Fig. 1 Collection site of *Pimelodus blochii* in Iaco River, Acre state, in Brazilian Amazon region



matrix was also used to perform this test on 9999 permutations. As the use of non-metric dissimilarity coefficients produced principal coordinate axes with negative eigenvalues, we computed the square root of distances prior to the analyses (Legendre and Legendre 1998). Additionally, the data were ordered using non-metric multidimensional scaling (NMDS) Bray–Curtis index. All these statistical procedures were performed in R version 3.5.0 (R Core Team 2018) with the vegan package (Oksanen et al. 2017).

Results

The length of *P. blochii* collected in 2014 was lower than individuals collected in 2012, 2013, and 2017. The weight

of *P. blochii* collected in 2013 was higher than those collected in 2014, 2015, and 2016 (Fig. 2).

A total of 24 parasite species were collected, but only *Demidospermus peruvianus*, *Demidospermus striatus*, *Demidospermus leptosynophallus*, *Ameloblastella amazonica*, *Procamallanus (S.) pimelodus*, *Cucullanus pinnai*, Anisakidae gen. sp., and *Dadaytrema oxycephala* were frequent over years. In all years, the dominance was of helminth species. In 2013, it was collected the highest number of parasites and in 2012 and 2014, it was collected the lowest number of parasites (Table 1). The NMDS presented a good ordination (stress = 0.0568, $r^2 = 0.5129$) and showed that the parasite community of 2013 was formed by a differentiated group due to the presence of *Orientattractis moraveci*, *Scleroductus yuncens*, and Anisakidae gen. sp. (Fig. 3).

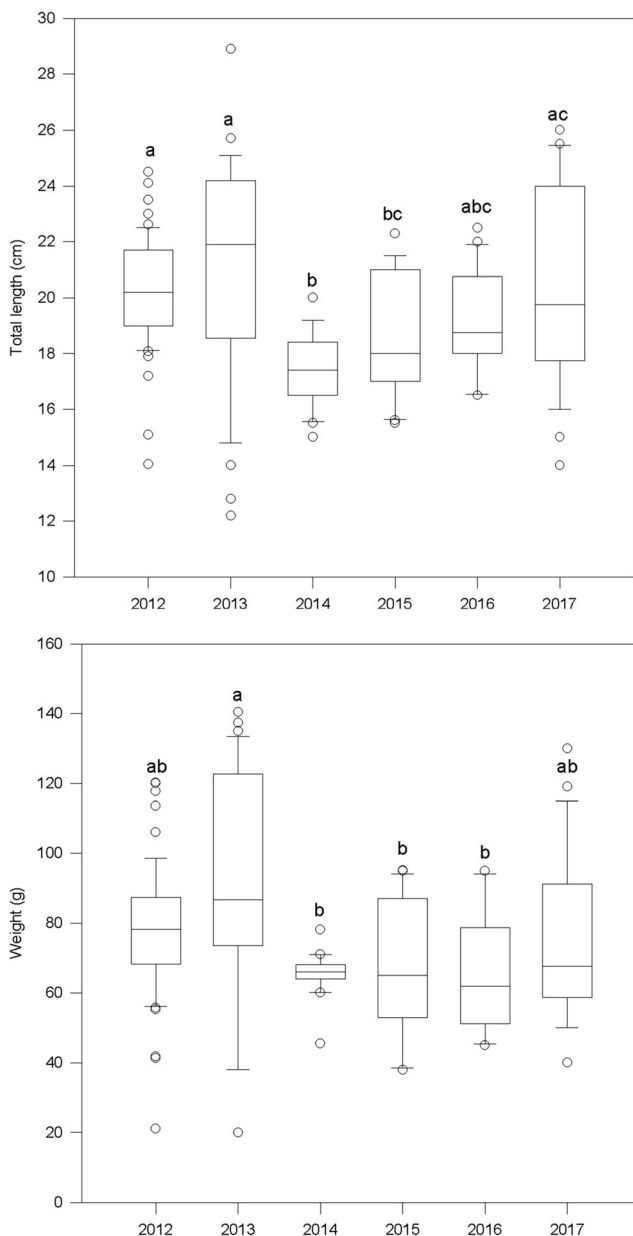


Fig. 2 Body size of *Pimelodus blochii* from the Iaco River, in Brazilian Amazon region (box plots represent medians, interquartile ranges, minimum–maximum ranges, and outliers). Different letters indicate differences among medians according to the Tukey test ($p < 0.001$)

Most hosts were infected with no parasite species (Fig. 4). The species accumulation curve showed that most of the parasite species from component community were sampled (Fig. 5).

In *P. blochii* gills, the abundance of *D. peruvianus* was higher in 2013, while abundance of *D. leptosynophallus* was higher in 2013 and 2014. In intestine, the abundance of *O. moraveci* was higher in 2013 and *P. (S.) pimelodus* was higher in 2016 and 2017, but the abundance of *R. rondoni* was higher in 2016. The abundance of Anisakidae gen. sp. was higher in 2012 and abundance of *D. oxycephala* was higher in 2016 (Table 2).

Shannon–Wiener diversity and evenness in hosts collected in 2012 were lower than in the other years, while Shannon–Wiener diversity and species richness of parasites were higher in 2016 (Fig. 6). In host populations, component communities of parasites exhibited, in general, similarity qualitative between 2017 with 2012 and 2016 according to Jaccard index (Table 3). ANOSIM detected differences in the composition and abundance of parasite species between host populations of 6 years ($R_{\text{Jaccard}} = 1.067$, $p = 1.00$). The pattern of abundance of the parasites varied significantly among years (PERMANOVA $F[2.7] = 2.33$, $p < 0.05$) and Tukey’s HSD test indicated differences ($p < 0.05$) between parasite communities of 2013 and 2015, indicating that the fish assemblages have distinct composition of parasite species in these years (Fig. 7).

Discussion

Parasites play an intrinsic but hidden role in freshwater ecosystems. Hence, the understanding of many aspects of parasite ecology in freshwater fish from many tropical regions is hindered by a paucity of long-term datasets and studies on almost all aspects of environment–host–parasite interactions (Hoshino and Tavares-Dias 2019). Therefore, there is an urgent need for long-term dataset to our understanding on the aspects of parasite ecology in Amazon fish, a large biome from South America. Here, we focused our efforts on a long-term study on parasites of *P. blochii* from the Iaco River, in western Amazon region, northern Brazil, in which we used quantitative analyses that are baseline, besides multivariate analyses. In long-term studies, it is seldom practicable to collect samples in many months, especially in the Amazon region. Preferably, it should be collected samples in the same months for such studies. The assumption is that this minimizes seasonal effects on community diversity, and the samples are therefore representative of the community diversity in that year (Kennedy 1997). Therefore, it seems reasonable to accept that our samples collected over 6 years are representative of the parasite community diversity in *P. blochii*. In addition, the species accumulation curve supported the hypothesis that the majority of parasite species of the component community in *P. blochii* were collected.

One of the most important results of this study is related to the species richness of parasites that was found during the 6 years in the assemblages of *P. blochii* from the Iaco River. In this host, collected predominately in the rainy seasons during 6 years, the component community was composed of 24 species, mainly helminth species 87.5% and crustacean species 12.5%, which had low parasitic infection levels and with sporadic occurrence. There was a variation in the number of parasites between the years sampled (4 to 17 species), and the highest species richness was found in hosts in 2016,

Table 1 Long-term temporal variation of parasites in *Pimelodus blochii* from the Iaco River, in Brazilian Amazon

Parasites species	2012			2013			2014			2015			2016			2017			
	P (%)	TNP	FD (%)	P (%)	TNP	FD (%)	P (%)	TNP	FD (%)	P (%)	TNP	FD (%)	P (%)	TNP	FD (%)	P (%)	TNP	FD (%)	
Mono genera																			
<i>Demidospermus peruvianus</i>	0	0	0	48.6	50	2	20.0	24	25	20.0	22	23	35.0	8	2	13.3	5	4	
<i>Demidospermus striatus</i>	0	0	0	10.8	5	0.2	20.0	9	9	10.0	22	23	15.0	6	2	3.3	1	0.9	
<i>Demidospermus leptosomophallus</i>	0	0	0	40.5	29	1	25.0	20	21	6.7	5	5	10.0	6	2	3.3	1	0.9	
<i>Ameloblastella amazonica</i>	0	0	0	2.7	3	0.1	10.0	4	4	10.0	4	4	15.0	4	1	0	0	0	
<i>Scleroductus yuencens</i>	0	0	0	2.7	1	-	0	0	-	0	0	0	0	0	0	0	0	0	
Nematoda																			
<i>Procamallanus</i> (S.) <i>rarus</i>	0	0	0	0	0	-	0	0	-	3.3	3	3	15.0	7	2	13.3	6	5	
<i>Procamallanus</i> (S.) <i>pimelodus</i>	6.8	5	3	21.6	57	2	30.0	26	27	20.0	23	24	60.0	106	32	53.3	83	73	
<i>Cucullianus pinnai</i>	0	0	0	8.1	8	0.3	15.0	6	6	3.3	1	1	30.0	8	2	6.7	2	2	
<i>Orientatracis moraveci</i>	0	0	0	8.1	2149	91	0	0	0	0	0	0	5.0	1	3	0	0	0	
<i>Philometroides acraeanensis</i>	0	0	0	0	0	-	0	0	0	0	0	0	10.0	6	2	0	0	0	
<i>Rondonia rondoni</i>	0	0	0	2.7	2	0.1	0	0	0	3.3	3	3	20.0	88	26	10.0	4	0.3	
<i>Raphidascaris</i> sp. (larvae)	0	0	0	0	0	-	0	0	0	0	0	0	5.0	1	3	0	0	0	
Dioctophymatidae gen. sp. (larvae)	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	3.3	1	0.9	
Anisakidae gen. sp. (larvae)	33.9	161	87	21.6	51	2	0	0	0	10.0	6	6	20.0	9	3	0	0	0	
Pharyngodontidae gen. sp. (larvae)	0	0	0	2.7	2	0.01	0	0	0	0	0	0	25.0	5	1	0	0	0	
Spinuroidea gen. sp. (larvae)	8.5	15	8	0	0	-	0	0	0	0	0	0	15.0	4	1	0	0	0	
Digenea																			
<i>Prosthentystera obesa</i>	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	3.3	2	2	
<i>Dadantrema oxycephala</i>	0	0	0	13.5	11	0.3	10.0	4	4	13.3	23	24	35.0	70	21	13.3	6	5	
Metacercariae type- <i>Diplostomulum</i>	0	0	0	0	0	-	0	0	0	0	0	0	5.0	1	3	0	0	0	
Cestoda																			
<i>Monicella magna</i>	0	0	0	0	0	-	10.0	2	2	6.7	3	3	15.0	5	1	10.0	3	3	
Acanthocephala																			
<i>Echinorhynchus</i> sp.	1.7	4	2	0	0	-	0	0	0	0	0	0	0	0	0	0	0	0	
Crustacea																			
<i>Minilernaea floricapitella</i>	0	0	0	0	0	-	0	0	0	3.3	1	1	0	0	0	0	0	0	
<i>Dipteropeltis</i> sp.	0	0	-	0	0	0	0	0	0	3.3	1	0.01	0	0	0	0	0	0	
<i>Ergasilus</i> sp.	0	0	-	0	0	0	0	0	0	3.3	1	1	0	0	0	0	0	0	
Number of examined fish	59			37			20			30			20			30			
Total number of parasites	185			2369			95			97			333			114			
Number of parasite species	4			12			8			13			17			11			
Number of helminth species	3			12			8			11			17			11			

P prevalence, FD frequency of dominance, TNP total number of parasites

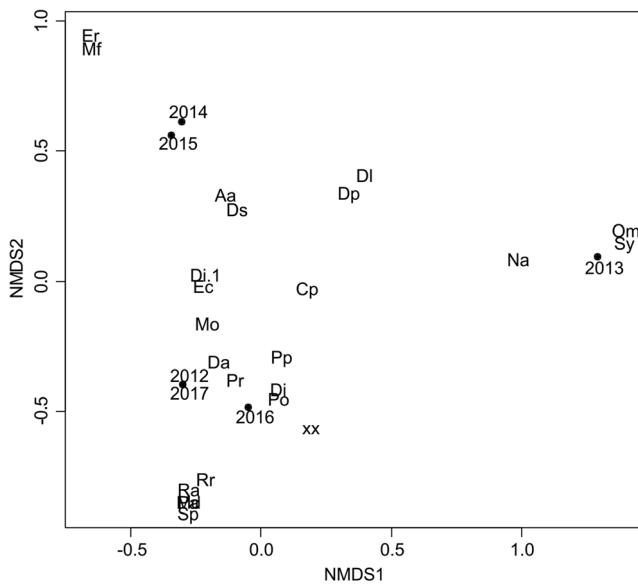


Fig. 3 Non-metric multidimensional scaling (NMDS) on Bray–Curtis index of *Pimelodus blochii* collected during 6 years in the Iaco River, in Brazilian Amazon region. Am, *Ameloblastella amazonica*; Dp, *Demidospermus peruvianus*; Ds, *Demidospermus striatus*; DI, *Demidospermus leptosynophallus*; Sy, *Scleroductus yuncens*; Er, *Ergasilus* sp.; Mf, *Minilernaea floricapitella*; Md, Metacercariae type-*Diplostomulum*; Cp, *Cucullanus pinnai*; Om, *Orientattractis moraveci*; Pp, *Procamallanus* (*S.*) *pimelodus*; Pr, *Procamallanus* (*S.*) *rarus*; Pa, *Philometroides acreanensis*; Rr, *Rondonia rondoni*; Na, Anisakidae gen. sp.; Sp, Spiruroidea gen. sp.; Di, Dioctophymatidae gen. sp.; Ra, *Raphidascaris* sp.; Po, *Prosthenhystera obesa*; Da, *Dadaytrema oxycephala*; Mo, *Monticellia magna*; Ec, *Echinorhynchus* sp.; Di, *Dipteropeltis* sp.

suggesting that the component community was far richer at the end of the period investigated. The parasite community of hosts collected in 2013 was different when compared with other years due to the presence of *O. moraveci*, *S. yuncens*, and Anisakidae gen. sp. Similarly, for this same host species from the rivers Iaco and Acre, the metazoan parasite community consisted of 22 taxa, with predominance of 86.4% helminth species and 13.6% crustacean species (Negreiros et al. 2018). In addition, we observed that *P. blochii* had a

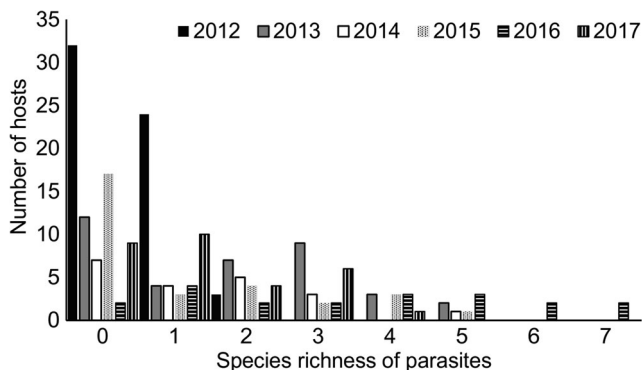


Fig. 4 Distribution of the species richness in the parasite infracommunities of *Pimelodus blochii* from the Iaco River, in Brazilian Amazon region

dominance of nematode species in adult stages (*Anisakidae* gen. sp., *O. moraveci*, *P. (S.) pimelodus*, and *R. rondoni*), which varied between the years, while nematodes in larval stages were only sporadic over the years. This result was not expected, since digeneans are the most abundant and diverse group of helminth parasites in fish in tropical regions (Villalba-Vasquez et al. 2018). Monogeneans were the numerically the second most diverse taxon of parasites, but *D. peruvianus*, *D. striatus*, and *D. leptosynophallus* were the most frequent over the years. Previous studies in *P. blochii* from the Iaco River reported that the species composition in the metazoan parasite community and species richness do not vary between the rainy and dry seasons, since only *D. peruvianus* increased during the dry season (Negreiros et al. 2018). Therefore, the communities and infracommunities of metazoan parasites in *P. blochii* do not change in response to rainfall levels in the Amazon region. In contrast, other studies on parasites from the tropical region showed that changes in rainfall patterns lead to changes in the proportion of hosts infected with a number of parasite species (Violante-González et al. 2009; Pech et al. 2010; Vidal-Martínez et al. 2014).

Studies on communities of parasites in fish populations are useful for the knowledge they provide on community structure and dynamics (Violante-González et al. 2009; Pech et al. 2010; Gallegos-Navarro et al. 2018). For parasitological comparisons between fish populations, the body size of hosts (age) is an important factor that can affect the infection levels and species richness of parasites (Zander 2004; Violante-González et al. 2009; Gallegos-Navarro et al. 2018; Villalba-Vasquez et al. 2018). In *P. blochii* from the Iaco River, the hosts were larger and lighter across years, probably because they were preparing for the breeding season. Therefore, the size of hosts can be a secondary factor influencing the parasite communities and should not be disregarded.

Our results indicated that the infracommunities, species richness, and diversity of parasites in *P. blochii* depended heavily on the occurrence of a distinctive set of component species such as monogeneans *D. peruvianus*, *D. striatus*, and *D. leptosynophallus*; nematodes *P. (S.) pimelodus*, *C. pinai*, and Anisakidae gen. sp.; and digenean *D. oxycephala*; all parasites whose frequency varied between the years. Considering that endohelminths have indirect life cycle that requires a variety of invertebrate and vertebrate hosts (Violante-González et al. 2009; Villalba-Vasquez et al. 2018; Gallegos-Navarro et al. 2018; Hoshino and Tavares-Dias 2019), the communities of these parasites on the host of this study reflect the presence of other organisms in the Iaco River ecosystem. Recent studies also reported that variations in infracommunity composition of parasites over time could be associated with variations in the prevalence and/or abundance of dominant taxa (Villalba-Vasquez et al. 2018; Gallegos-Navarro et al. 2018; Hoshino and Tavares-Dias 2019). In

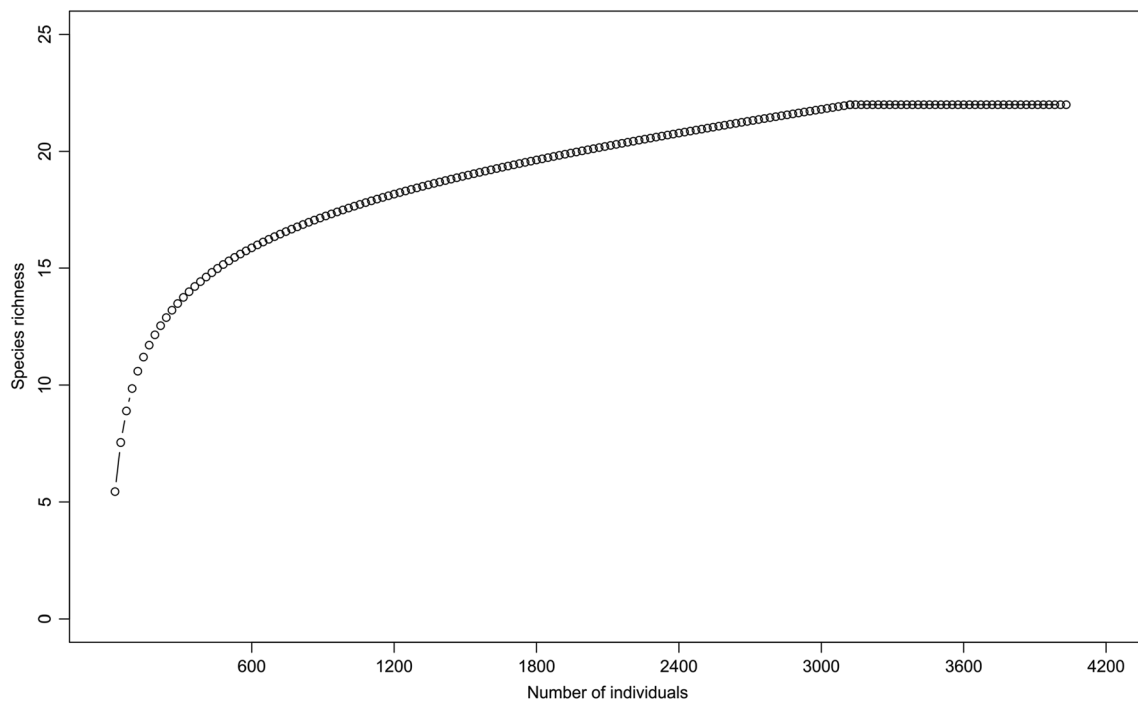


Fig. 5 Species accumulation curve for component communities of parasites in *Pimelodus blochii* sampled during 6 years in the Iaco River, in Brazilian Amazon region

Table 2 Mean abundance (MA \pm SD) of the long-term temporal variation of parasites in *Pimelodus blochii* from the Iaco River, in Brazilian Amazon

Years	2012	2013	2014	2015	2016	2017
Parasites species	MA \pm SD	MA \pm SD	MA \pm SD	MA \pm SD	MA \pm SD	MA \pm SD
<i>Demidospermus peruvianus</i>	0	1.4 \pm 2.1	1.2 \pm 3.1	0.7 \pm 2.6	0.4 \pm 0.6	0.2 \pm 0.5
<i>Demidospermus striatus</i>	0	0.1 \pm 0.4	0.5 \pm 1.1	0.1 \pm 0.4	0.3 \pm 0.8	0.03 \pm 0.2
<i>Demidospermus leptosynophallus</i>	0	0.8 \pm 1.4	1.1 \pm 2.1	0.2 \pm 0.6	0.2 \pm 0.7	0.03 \pm 0.2
<i>Ameloblastella amazonica</i>	0	0.08 \pm 0.5	0.2 \pm 0.6	0.1 \pm 0.4	0.2 \pm 0.5	0
<i>Scleroductus yuncens</i>	0	0.03 \pm 0.2	0	0	0	0
<i>Procamallanus (S.) rarus</i>	0	0	0	0.1 \pm 0.5	0.3 \pm 0.9	0.2 \pm 0.6
<i>Procamallanus (S.) pimelodus</i>	0.08 \pm 0.3	1.5 \pm 4.0	1.3 \pm 1.6	0.8 \pm 1.9	5.3 \pm 9.7	2.8 \pm 6.0
<i>Cucullanus pinnai</i>	0	0.2 \pm 0.8	0.3 \pm 0.8	0.03 \pm 0.2	0.4 \pm 0.7	0.07 \pm 0.3
<i>Orientatractis moraveci</i>	0	58.1 \pm 343.6	0	0	0.05 \pm 0.2	0
<i>Philometroides acreanensis</i>	0	0	0	0	0.3 \pm 1.1	0
<i>Rondonia rondoni</i>	0	0 ^a	0	0.03 \pm 0.2	4.4 \pm 19.0	0.1 \pm 0.4
<i>Raphidascaris</i> sp.	0	0	0	0	0.05 \pm 0.2	0
Diactophymatidae gen. sp.		0	0	0	0	0.03 \pm 0.2
Anisakidae gen. sp.	2.7 \pm 10.7	1.4 \pm 4.2	0	0.2 \pm 0.7	0.4 \pm 1.1	0
Pharyngodonidae gen. sp.	0	0.05 \pm 0.3	0	0	0.2 \pm 0.4	0
Spiruroidea gen. sp.	0.3 \pm 0.9	0	0	0	0	0
<i>Prosthenhystera obesa</i>	0	0	0	0	0	0.07 \pm 0.4
<i>Dadaytrema oxycephala</i>	0	0.3 \pm 0.8	0.2 \pm 0.7	0.8 \pm 2.3	3.5 \pm 8.2	0.2 \pm 0.6
Metacercariae type- <i>Diplostomulum</i>	0	0	0	0	0.05 \pm 0.2	0
<i>Monticellia magna</i>	0	0	0.1 \pm 0.3	0.1 \pm 0.4	0.2 \pm 0.7	0.1 \pm 0.3
<i>Echinorhynchus</i> sp.	0.1 \pm 0.5	0	0	0	0	0
<i>Dipteropeltis</i> sp.	0	0	0	0	0	0
<i>Ergasilus</i> sp.	0	0	0	0.03 \pm 0.2	0	0
<i>Minilernaea floricapitella</i>	0	0	0	0.03 \pm 0.2	0	0

MA, mean abundance, SD, standard deviation

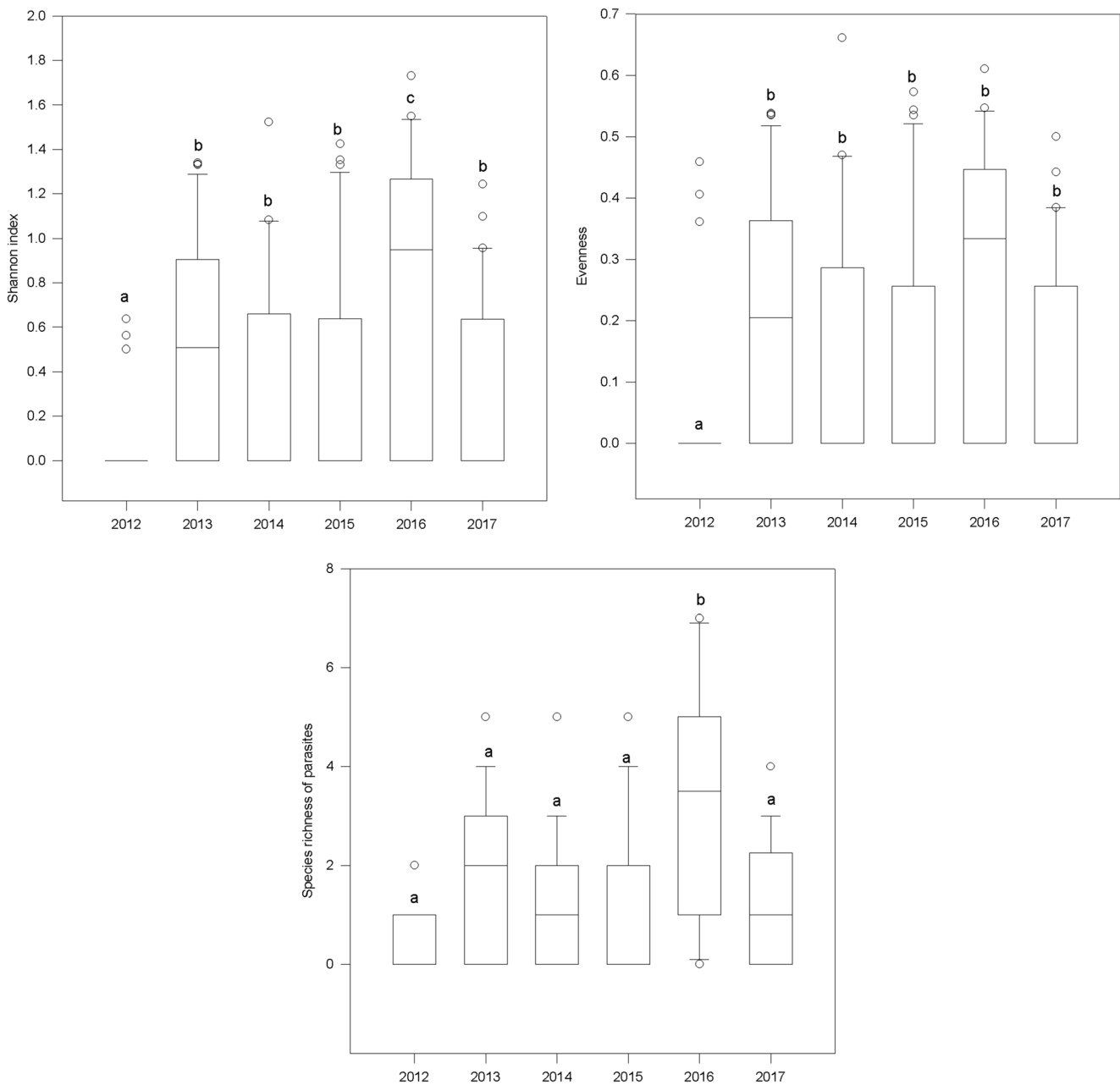


Fig. 6 Diversity parameters of *Pimelodus blochii* from the Iaco River, in Brazilian Amazon region (box plots represent medians, interquartile ranges, minimum–maximum ranges, and outliers). Different letters indicate differences among medians according to the Tukey test ($p < 0.001$)

general, we also observed that for *P. blochii* from the Iaco River, values of the Jaccard index similarity were high between most of the years sampled. However, the multivariate analyses (PCoA) indicated a dissimilarity in the parasite community composition between 2013 and 2015.

The general characteristics of component communities of endohelminths in *P. blochii* from the Iaco River, especially in 2016, were very similar to those described by Negreiros et al. (2018), for this same host from the rivers Iaco and Acre, both tributaries of the Purus River, western Amazon. In addition, for *P. blochii*, temporal differences in species richness,

component communities, and infracommunities of parasites revealed less variation than expected, with a low species richness of parasites, almost stable over the years, except in 2016, but the Shannon–Wiener diversity and evenness increased over the years. Similarly, findings unexpected were also reported for the helminth *Anguilla anguilla* from a small stream from the Clyst River (Kennedy 1993) and from an isolated river in England (Kennedy 1997) and for metazoan parasites of *Parapseuttus panamensis* from the Mexican Pacific coast (Villalba-Vasquez et al. 2018). For *H. surinamensis* from the eastern Amazon, it was also reported low short-term variation

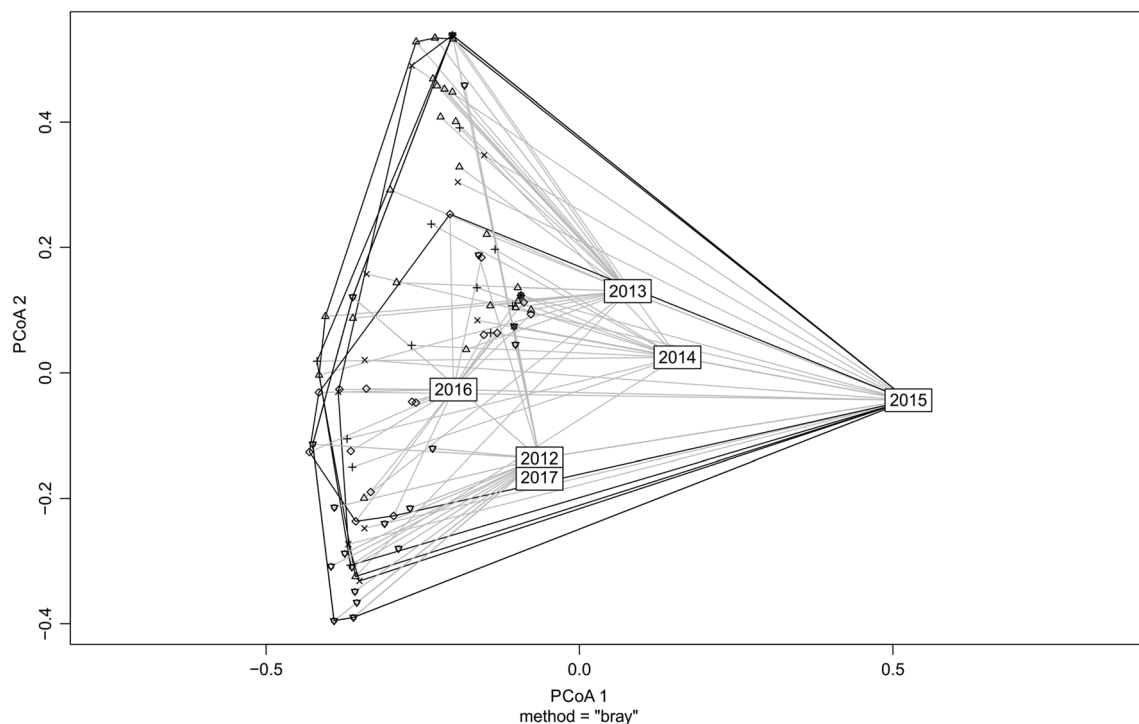
Table 3 Pairwise similarity Jaccard index of component community of parasites in *Pimelodus blochii* from the Iaco River, in Brazilian Amazon

Pairwise	2012	2013	2014	2015	2016	2017
2012	-	0.69	0.60	0.61	0.43	0.69
2013	0.69	-	1.00	0.61	0.59	0.69
2014	0.69	1.00	-	0.61	0.59	0.69
2015	0.60	0.61	0.61	-	0.68	0.60
2016	0.43	0.59	0.59	0.68	-	0.43
2017	1.00	0.69	0.69	0.60	0.43	-

in the parasite community structure dynamics (Hoshino and Tavares-Dias 2019). In contrast, large temporal variations were reported in studies on the component communities, infracommunities, and species richness of parasites in other wild fish populations, which were linked to the feeding behavior and body size of hosts, and occurrence of a set of parasite species (Villalba-Vasquez et al. 2018; Gallegos-Navarro et al. 2018). The Iaco River basin, environment of this study, is characterized as a river system with extensive floodplains that constitute physical systems connected via a silted-up river that forms a drain for freshwater. During the rainy season, the waters are rich in nutrients because of the fast decomposition of grass and animal remains, and because the layer of humus that the forest produces is spread across the floodplain. This leads to a large growth of vegetation and invertebrate biomass (e.g., crustaceans and mollusks), which

are used as food by fish species. This basin is not subjected to intense human activities, such as sewer and garbage disposal, urbanization, agriculture, and livestock, which results in suspended organic and inorganic debris. The vegetation is formed by species that form the floodplain forest along the waterways, along with species of macrophytes (Pereira and Morais 2014; Negreiros et al. 2018).

Trophic niche is another important factor that may influence the composition of component and infracommunities of parasites and may explain the question as to which parasite species can exist together in host populations (Zander 2003). The complexity of the food web structure in Iaco River (Silva et al. 2012; Nakajima et al. 2017; Negreiros et al. 2018) should be also a factor influencing the species richness of parasites in *P. blochii*, as well as the variation in diversity of parasites over the years, since food variations are known to affect species richness and diversity of endoparasites in host fish (Zander 2003, 2004; Villalba-Vasquez et al. 2018; Gallegos-Navarro et al. 2018; Hoshino and Tavares-Dias 2019). The assemblages of invertebrates, which are intermediate hosts for diverse endohelminths (Villalba-Vasquez et al. 2018; Gallegos-Navarro et al. 2018) from the Amazon region, are highly diverse and have a high density and biomass (Silva et al. 2012; Nakajima et al. 2017), but the density of mollusks should be low in Iaco River, because few digenean species (3 species) were found in *P. blochii*. Given the conditions of aquatic environments in Amazon, naturally dynamic, and as consequence, rivers, floodplains, and lakes suffer profound changes over the

**Fig. 7** Principal Coordinates Analysis (PCoA) on Bray–Curtis dissimilarity matrix of *Pimelodus blochii* sampled during 6 years in the Iaco River, in Brazilian Amazon region

years (Silva et al. 2012; Nakajima et al. 2017; Garcez et al. 2017; Hoshino and Tavares-Dias 2019); thus, shifts in host–parasite interactions also can occur. These changes could affect the parasites in a direct or indirect way by influencing their free-living infective stages or their host range. Hence, environmental changes can result in gain or loss of parasite species as well as in increased or decreased host susceptibility. Therefore, the variations, over the years, in diversity of helminth parasites in *P. blochii*, a generalist and opportunistic fish that feeds on invertebrates, seeds, fruits, debris, and leaves (Soares et al. 2011; Froese and Pauly 2019), could be also related to fluctuations related to changes in diet of the host populations, which increase or decrease the opportunity for transmission of the parasite species.

A comparison of the component communities of parasites in *P. blochii* during 6 years showed a low number of individuals and consequently a low parasite prevalence and abundance levels. In addition, the prevalence and abundance of helminth species varied over the years, and such fluctuations seem to be also related to variations in the availability of infective stages of parasites in environments from the Iaco River. For *Sciades guatemalensis* from Mexico, long-term studies reported that the infection parameters of the four most frequent and abundant species of helminths suggest that the parasite transmission process was attributed to temporal fluctuations related to changes in the availability of intermediate hosts in the environment. The main factors structuring the parasite infracommunities and component communities were the feeding behavior and seasonal variation in the availability of infective stages, both influenced by the seasonal dry/rainy cycle (Violante-González et al. 2009).

In summary, as nematode helminth larvae are transmitted to their definitive hosts by predation, *P. blochii* is an intermediate host for *Raphidascaris* sp., Dioctophymatidae gen. sp., Anisakidae gen. sp., Pharyngodonidae gen. sp., and Spiruroidea gen. sp., and a definitive host for the other species of endoparasites was found. The occurrence of many species of metazoan parasites in *P. blochii* was not constant and the dominant species was little regular over the years, except the nematode and monogenean species, which were numerically dominant species. At the component community level, the parasite species richness increased from 2012 to 2017, suggesting that this was far richer at the end of the period. The infracommunities of parasites exhibited low infection levels, i.e., low prevalence and abundance. Furthermore, the structure and species composition of the parasite communities little varied between the sampling years. Such variations seem to be the result of factors linked to host features, such as body size, besides the occurrence of a set of distinctive parasite species in the component communities, and possible variations in the availability of infective stages over the years.

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Compliance with ethical standards

Ethical Disclosures All procedures involving animals were authorized by the Instituto Chico Mendes para Conservação da Biodiversidade (acronym SISBIO, No. 60899-1) and were strictly according to the protocols and rules of the Committee on Ethics of Animal Use of the Embrapa Amapá (Protocol No. 002-CEUA-CPAFAP).

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