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Original Article

Seasonal patterns of infestation by monogenean parasites of fish and their relationship with water parameters in two rivers with different disturbance gradients in southeastern Brazil

Padrões sazonais de infestação por parasitos monogenéticos de peixes e sua relação com os parâmetros da água em dois rios com diferentes gradientes de perturbação no sudeste do Brasil

L. A. R. Leite[a*], F. F. Januário[b], L. S. Pelegrini[c], B. Antoniassi[b], R. K. Azevedo[d] and V. D. Abdallah[d,e]

[a]Universidade Estadual Paulista – UNESP, Instituto de Biociências, Botucatu, SP, Brasil
[b]Centro Universitário do Sagrado Coração – UNISAGRADO, Pró-reitoria de Pesquisa e Pós-graduação, Bauru, SP, Brasil
[c]Universidade Federal do Amazonas – UFAM, Laboratório de Ictiologia e Ordenamento Pesqueiro do Vale do Rio Madeira, Humaitá, AM, Brasil
[d]Centro Universitário CESMAC, Programa de Pós-graduação em Análise de Sistemas Ambientais, Maceió, AL, Brasil
[e]Universidade Federal de Alagoas – UFAL, Setor de Parasitologia e Patologia, Maceió, AL, Brasil

Abstract

Here, we evaluate the relationships between the infestation rates of five monogenean parasites species with the dry and wet seasons, with the organic and inorganic parameters of the water of two rivers: the Jacaré-Pepira and Jacaré-Guaçú, and with the condition factors of its fish hosts: *Serrasalmus maculatus* and *Astronotus crassipinnis*, in the state of São Paulo, southeastern Brazil. Fish were collected between January and December 2017. *Anacanthorus serrasalmi*, *Amphithecium speirocamarotum* and *Gussevia asota* had higher abundance rates (Student's *t* test, $p \leq 0.05$) in the wet season. *Gussevia asota* had its abundance negatively correlated to nitrate in the Jacaré-Pepira River and with total nitrogen and potassium in the Jacaré-Guaçú River. Regarding the fish hosts condition factors, was observed a positive correlation with the abundances of *G. asota* in the Jacaré-Guaçú River, and with *A. serrasalmi* in the Jacaré-Pepira River. In general, wet season favored an increasing in the infestation rates of the monogeneans parasites in their host species, mainly in the river considered as the most polluted, the Jacaré-Guaçú River. Of the five parasites species analyzed in this study, only *Gussevia astronoti* and *Rhinoxenus piranhus* had no interaction with seasonality, river water variables, or fish host condition factors. On the other hand, *G. asota* had interactions both with water parameters (nitrate and total nitrogen) and with the hosts condition factors, which reflected in the abundance and intensity rates, showing itself as a species sensitive to changes in the environment and, therefore, that can be considered as a bioindicator organism.

Keywords: environmental parasitology, effect bioindication, Monogenea, fish parasitology, host-parasite relationship.

Resumo

Aqui, nós avaliamos as relações entre as taxas de infestação de cincos espécies de parasitos monogenéticos em relação aos períodos seco e chuvoso, aos parâmetros orgânicos e inorgânicos da água de dois rios: Jacaré-Pepira e Jacaré-Guaçú, e em relação aos fatores de condição das espécies de peixes hospedeiras: *Serrasalmus maculatus* e *Astronotus crassipinnis*, no estado de São Paulo, sudeste do Brasil. Os peixes foram coletados entre os meses de janeiro a dezembro de 2017. *Anacanthorus serrasalmi*, *Amphithecium speirocamarotum* e *Gussevia asota* tiveram maiores taxas de abundância (teste *t* de Student, $p \leq 0,05$) no período chuvoso. *Gussevia asota* teve sua abundância negativamente correlacionada com o nitrato no rio Jacaré Pepira e com o nitrogênio total e potássio no rio Jacaré-Guaçú. Em relação ao fator de condição dos peixes, foi observado uma correlação positiva com a abundância de *G. asota* no rio Jacaré-Guaçú e com *A. serrasalmi* no rio Jacaré-Pepira. No geral, o período chuvoso favoreceu um aumento nas taxas de infestação dos parasitos monogenéticos em seus peixes hospedeiros, especialmente no rio considerado como o mais poluído, o rio Jacaré-Guaçú. Das cinco espécies de parasitos analisadas no estudo, somente *Gussevia astronoti* e *Rhinoxenus piranhus* não tiveram nenhum tipo de interação com a sazonalidade, com as variáveis das águas dos rios ou com o fator de condição dos peixes hospedeiros. Por outro lado, *G. asota* teve interações tanto com os parâmetros da água (nitrato e nitrogênio total) quanto com os fatores de condição dos hospedeiros, que refletiram nas taxas de abundância e de infestação, mostrando que esta espécie é sensível às mudanças no ambiente e que, portanto, pode ser utilizada como um organismo bioindicador.

Palavras-chave: parasitologia ambiental, bioindicação de efeito, Monogenea, parasitologia de peixes, relação parasito-hospedeiro.

*e-mail: lar.leite@unesp.br
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1. Introduction

Parasites play crucial roles in the environment and are considered as true puppeteers in the ecosystems structuring (Dougherty et al., 2016), being responsible, in some cases, for up to 78% of the interactions in the food chains (Lafferty et al., 2006) and whose biomass can scale together the host's body biomass (Poulin and George-Nascimento, 2007), and may even surpass the biomass of top chain predators (Kuris et al., 2008). Its eminent presence in the structuring of animal communities means that there is also an intrinsic relationship with the physical environment, where negative changes in several characteristics of the habitat directly affect the occurrence and distribution of parasitic species, and consequently their hosts, which can bring losses at all levels of the food chain and to the functioning of the ecosystem (Lafferty et al., 2006; Silva-Souza et al., 2006).

Environmental parasitology, which covers the use of parasites as indicators of environmental health (Sures et al., 2017), is a field that has been gaining strength in recent decades and demonstrates the different types of response of parasites due to disturbances in the environment, in addition to the high effectiveness of these organisms in detecting pollution, organic and inorganic, and other negative impacts, especially in aquatic ecosystems (freshwater and marine) (Carravieri et al., 2020; Lafferty, 2008; Marcogliese and Pietrock, 2011; Sures et al., 2017; Vidal-Martínez e Wunderlich, 2017).

Monogenea, Digenea, Nematoda, Acanthocephala, Cestoda, Hirudinea and Copepoda are the taxa commonly found parasitizing fish in Latin American waters (Lehun et al., 2020; Luque and Poulin, 2007; Luque et al., 2017). Among these groups, endoparasites, especially acanthocephalans, nematodes and cestodes are potential sentinels and pollution indicators, especially for trace metals (Duarte et al., 2020; Leite et al., 2017, 2018, 2019, 2021; Nachev et al., 2013; Sures et al., 2017; Vidal-Martínez and Wunderlich, 2017), organic pollutants (Carravieri et al., 2020), and more recently for microplastics (Hernandez-Milian et al., 2019). Ectoparasites, on the other hand, especially monogeneans, may not be the ideal group for use in studies with accumulation bioindication (Sures, 2003, 2004), but they can be very useful in another type of approach: effect bioindication.

Effect bioindication considers the physiological, behavioral, or numerical responses of the parasites to a stressor (Sures, 2006; Vidal-Martínez et al., 2010). And in this case, parasites of the Monogenea class can be very useful as bioindicators, as they tend to respond numerically, increasing or decreasing their populations, according to the increase in chemical pollution in the environment (Sanchez-Ramírez et al., 2007; Gilbert and Avenant-Oldewage, 2017), being able to respond to eutrophication and organic pollution, trace metals pollution, and pollution caused by effluents discharge (Gilbert and Avenant-Oldewage, 2017).

In Brazil, habitat, and species losses due to human negative activities is as growing reality and occurs in all biomes in the country (Coelho et al., 2020; Ferreira et al., 2015; Lima et al., 2020; Rangel, 2012; Roque et al., 2016). Identify problems that interfere with the health of the environment, even on the smallest scales, is of crucial importance in diagnosing and mitigation of these problems. In this study we evaluated the variation in prevalence, mean intensity and mean abundance rates of five monogenean parasite species in relation to the organic and inorganic water parameters of two neotropical rivers, the Jacaré-Pepira and Jacaré-Guaçú, in southeastern Brazil, and also their relationship with the condition factors of the two fish hosts species analyzed: *Serrasalmus maculatus* Kner, 1858 (Characiformes: Serrasalmidae) and *Astronotus crassipinnis* (Heckel, 1840) (Cichliformes: Cichlidae).

2. Material and Methods

2.1. Study area

Two rivers with different degrees of disturbance were selected: the Jacaré-Pepira River and the Jacaré-Guaçú River.

Both are important tributaries of the Tietê River, one of the most important rivers in the state of São Paulo, with 1,100 km in length, and inserted in the upper Paraná River basin, one of the most important Brazilian basins and a major maintainer of local biodiversity with more than 230 fish species, and 300 species of fish parasites (Langeani et al., 2007; Lehun et al., 2020).

The Jacaré-Pepira River (-21.904128S, -48.842116W), is the river considered as the most conserved of the two, has characteristics very similar to those found in the Brazilian Pantanal, with wetlands and swampy areas in the rainy seasons, its role as a maintainer of the biodiversity makes this river inserted into an area of environmental protection.

The Jacaré-Guaçú River (-21.808657S, -48.871903W), as it is closer to an urban area, the municipality of Ibitinga, in the state of São Paulo, receives loads of domestic and industrial sewage and is also influenced by areas of agriculture and livestock. It is considered a more polluted river with high concentrations of pesticides, metals, and fecal coliforms (Rodríguez, 2001; Esguícero and Arcifa, 2011).

2.2. Fish and parasites collection

Fish collections were carried out in between January and December 2017, totaling 12 samplings of *S. maculatus* and *A. crassipinnis* (Table 1). Fish collections followed the guidelines of the scientific fishing license, under the authorization of the Instituto Chico Mendes de Biodiversidade (ICMBio), through the Biodiversity Authorization and Information System (SISBIO), represented by the number 55914-1. Fish captures was carried out with the help of local fishermen, who used simple waiting nets of different meshes sizes and placed at varying heights.

After collected, fish were stored in individual plastic bags to avoid contamination in their parasitic fauna and then transported in a thermic box to the laboratory where they were kept refrigerated in a freezer for a maximum period of one month until parasite collection. At the time of analysis, the standard length (cm), sex and total weigh (g) of the hosts were recorded.

Table 1. Number of specimens (N), standard length (SL) and total weight (TW) of the two fish hosts species collected from the Jacaré-Pepira and Jacaré-Guaçú rivers, Tietê-Jacaré sub-basin, state of São Paulo, Brazil.

Fish species	Jacaré-Pepira			Jacaré-Guaçú		
	N	SL (cm)	TW (g)	N	SL (cm)	TW (g)
S. maculatus	40	15.73 ± 0.44	198.36 ± 15.85	40	14.95 ± 1.97	169.99 ± 66.8
A. crassipinus	22	19.11 ± 2.70	400.23 ± 143.97	40	18.75 ± 2.03	372.9 ± 98.3

For the monogenean parasites sampling, fish specimens had their body surfaces, gills and nostrils washed and the contents were sieved with 53 µm. After that, the filtered content was placed in petri dishes and looked at under a stereomicroscope. Collected parasites were stored in glass tubes with 70% alcohol.

For species identification, parasites were mounted using Gray and Wess for clarification of the sclerotized structures or stained with Gomori's trichrome and mounted with Canada balsam.

2.3. River water analysis

Water samples were collected on the surface and bottom of the Jacaré-Pepira and Jacaré-Guaçú rivers and transported to the laboratory according to the Standard methods for the examination of water and wastewater (APHA, 2012). Samples were collected from January and December 2017, in monthly terms, totaling 12 samples from each analyzed river.

Chemical analyzes of water samples were performed according to the methodology described in the standard methods for examination of water and wastewater (APHA, 2012). The analyzed parameters were Ammonia ($N\text{-}NH_4$ mg/L^{-1}), Nitrate ($N\text{-}NO_3$ mg/L^{-1}), Total phosphorus (TP) (mg/L^{-1}) and Potassium (mg/L^{-1}) by a Multiparameter Photometer for Nutrient Analysis (Hanna - HI 83225), Total Kjeldahl Nitrogen (TKN) by titration (4500-N_{org}B) and Nitrite (mg/L^{-1}) using a Spectrophotometer (DR 2500, ODYSSEY - HACH).

The classification of water samples was performed according to the values established by CONAMA Resolution 357/2005 for class 1 freshwater bodies (Brasil, 2005).

2.4. Statistical analysis

The quantitative descriptors of parasitism of prevalence, mean abundance and mean intensity of infestation were calculated according to Bush et al. (1997). The Student's *t*-test was used to visualize statistical variation between the parasitic descriptors and seasonality (dry and wet seasons) and also to test the variation between the water parameters in the two different rivers and according to the season, results were considered statistically significant if $p \leq 0.05$.

The Principal Component Analysis (PCA) was used to correlate the river water parameters of both rivers according to the season, and to correlate parasitic abundances with the river water parameters and with the condition factors (K) of the fish hosts. For correlation, was used the Spearman's Rank Correlation Coefficient.

For the calculation of the fish relative condition factors, a standard length/weight relationship was created, and through the coefficient angular equation, the expected weight (EW) of the fish individuals was estimated through the expression $EW = SL.y^x$, where SL represents the standard length of the individuals, and X and Y are in coefficient angular equation. The Condition Factors (KN) was obtained through $K = EW/W$, where EW is the expected weight and W the observed weight of the fish individuals (Nassh et al., 2005).

3. Results

Tables 2 and 3 show the quantitative descriptors of prevalence, mean intensity, and mean abundance of the five monogenean species in dry and wet seasons. Except for *Rhinoxenus piranhus* Kritsky, Boeger and Thatcher, 1988, which was collected from the host's nostrils, all species were collected from the fish gills. Numerically, in most species, are observed higher values for mean abundance and intensity in wet season compared to the dry season in both rivers. Student's *t*-test, however, show that in the Jacaré-Pepira River only *Anacanthorus serrasalmi* Van Every and Kritsky, 1992 had mean values of abundance and intensity statistically different ($p \leq 0.05$) between seasons, with higher infestation rates in the wet season. In the Jacaré-Guaçú River, *Gussevia asota* Kritsky, Thatcher and Boeger, 1989 and *Amphithecium speirocamarotum* Boeger and Jégu, 1997 had their abundances higher also in the wet season ($p \leq 0.05$). Remaining cases had no statistically significant differences ($p \geq 0.05$).

Figure 1 show the mean values of the concentrations (mg/L^{-1}) of the inorganic and organic variables of the waters sampled from both rivers in dry and wet seasons. In the PCA (Figure 2) it is possible to observe the variables well discriminated between the rivers (Figure 2A), and it also shows that of all variables, only nitrite was in higher concentrations in the samples from Jacaré-Pepira River (Figure 2B). The rest was in higher concentrations in the waters of the Jacaré-Guaçú River.

Analyzing the water variables of each river according to the season, it its observed that, except for potassium in the Jacaré-Guaçú waters, there was no variance between the concentrations of the parameters (Student's *t*-test $p \geq 0.05$). But when comparing the rivers, it is possible to observe a variation for all variables, indicating a statistically significant difference ($p \leq 0.05$) for ammonia, phosphorus, nitrate, nitrite, and total nitrogen. So, except for nitrite that was found in higher concentrations ($p \leq 0.05$) in the

Table 2. Prevalence, mean intensity and mean abundance of the monogenean parasites of *Astronotus crassipinnis* and *Serrasalmus maculatus* in dry and wet seasons in the Jacaré-Pepira River, Tietê-Batalha river basin, state of São Paulo, Brazil.

Species		Prevalence (%)		Mean Intensity		Mean Abundance	
		Dry	Wet	Dry	Wet	Dry	Wet
A. crassipinnis	*G. astronoti*	81	100	12 ± 3	13 ± 1	9 ± 3	13 ± 1
	G. asota	69	100	5 ± 1	4 ± 2	4 ± 1	4 ± 2
S. maculatus	*A. serrasalmi*	81	100	6 ± 1	10 ± 1	5 ± 1	10 ± 1
	R. piranhus	57	100	6 ± 1	6 ± 1	4 ± 1	6 ± 1

Table 3. Prevalence, mean intensity, and mean abundance of the monogenean parasites of *Astronotus crassipinnis* and *Serrasalmus maculatus* in dry and wet seasons in the Jacaré-Guaçú River, Tietê-Batalha river basin, state of São Paulo, Brazil.

Species		Prevalence (%)		Mean Intensity		Mean Abundance	
		Dry	Wet	Dry	Wet	Dry	Wet
A. crassipinnis	*G. astronoti*	90	95	12 ± 2	11 ± 1	10 ± 2	11 ± 1
	G. asota	85	75	4 ± 1	8 ± 2	3 ± 1	7 ± 2
S. maculatus	*A. serrasalmi*	100	100	10 ± 1	7 ± 1	10 ± 1	7 ± 1
	A. speirocamarotum	75	100	2 ± 1	5 ± 1	3 ± 1	5 ± 1

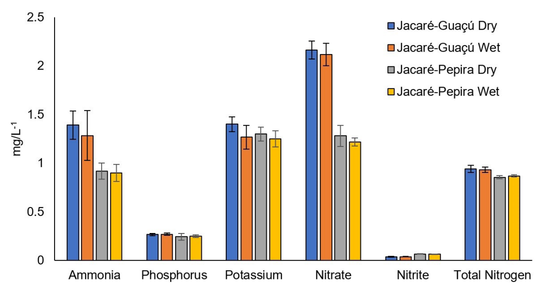

Figure 1. Concentrations (mg/L^{-1}) of the inorganic and organic variables analyzed from the waters of the Jacaré-Pepira and Jacaré-Guaçú rivers in dry and wet seasons.

waters of the Jacaré-Pepira River, all other parameters were higher, regardless of the period, in the Jacaré-Guaçú River.

Analyzing the water variables of each river according to the season, it its observed that, except for potassium in the Jacaré-Guaçú waters, there was no variance between the concentrations of the parameters (Student's *t*-test $p \geq 0.05$). But when comparing the rivers, it is possible to observe a variation for all variables, indicating a statistically significant difference ($p \leq 0.05$) for ammonia, phosphorus, nitrate, nitrite, and total nitrogen. So, except for nitrite that was found in higher concentrations ($p \leq 0.05$) in the waters of the Jacaré-Pepira River, all other parameters were higher, regardless of the period, in the Jacaré-Guaçú River.

In the PCA that correlates the chemical variables of the water with the abundance of parasites, *G. asota* correlated negatively with nitrate in the Jacaré-Pepira River (rs = -0.659, $p \leq 0.05$) (Figure 3A) and also in the Jacaré-Guaçú River (rs = -0.633, $p \leq 0.05$) (Figure 3B), and with

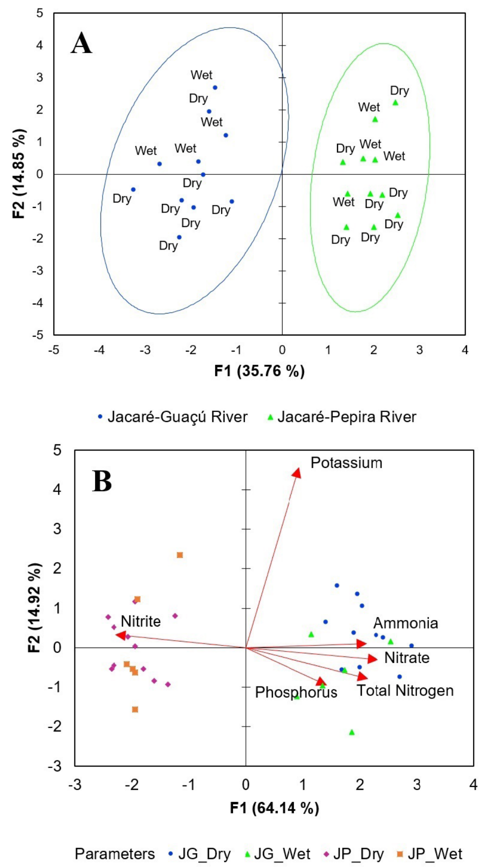

Figure 2. Principal Component Analysis that shows the distribution of organic and inorganic variables of the water samples from the Jacaré-Pepira and Jacaré-Guaçú rivers, according to the seasonality (dry and wet seasons) (A) and also their correlations (B).

total nitrogen in Jacaré-Guaçú River (rs = -0.428, p ≤ 0.05) (Figure 3B). *Amphithecium speirocamarotum* also had a negative correlation with potassium (rs = -0,605, p ≤ 0.05) (Figure 3B) in the Jacaré-Guaçú River. Which means that, as the concentrations of nitrate, total nitrogen and potassium in the water increased, the abundance of *G. asota* and *A. speirocamarotum* tended to decrease, or vice-versa.

There was no statistically significant variation between the condition factors (Figure 4) of *A. crassipinnis* and *S. maculatus* in the two rivers and in the different periods analyzed (Student's *t*-test p ≥ 0.05). Regarding to the relationships between condition factors and parasitic species abundance, the PCA indicated a positive relationship between the abundance of *G. asota* in the Jacaré-Guaçú River (rs = 0.736, p ≤ 0.05) (Figure 5B) and for *A. serrasalmi* in the Jacaré-Pepira River (rs = 0.350, p ≤ 0.05) (Figure 6A), indicating that fish with higher condition factors are more likely to be parasitized by these monogenean species than fish with lower ones.

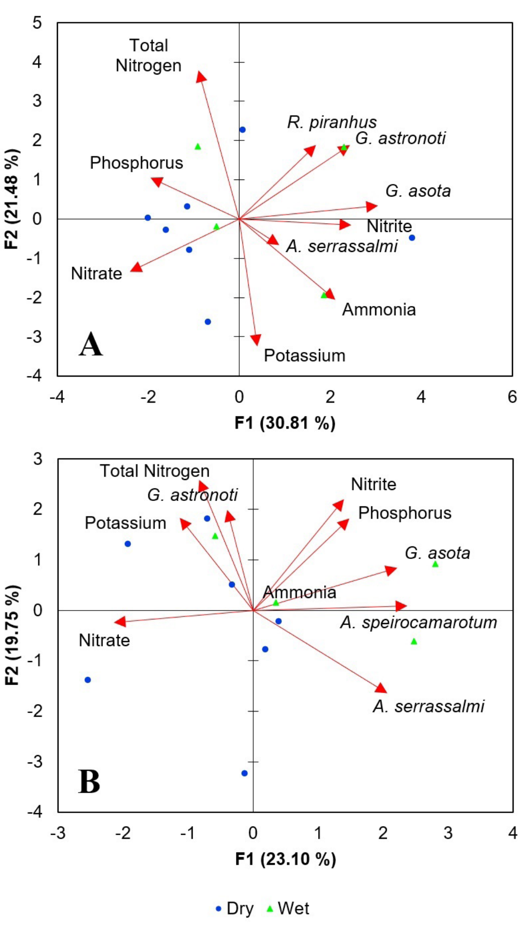

Figure 3. Principal Component Analysis that correlates the abundance of the monogenean parasites of *Astronotus crassipinnis* and *Serrasalmus maculatus* with inorganic and organic variables analyzed from the waters, in dry and wet seasons, of the Jacaré-Pepira (A) and Jacaré-Guaçú (B) rivers, Tietê-Batalha River basin, southeastern Brazil.

4. Discussion

In effect bioindication, among the several parasite's response mechanisms against an environmental stressor (in a general way), the complexity of the live cycle has always been a factor that apparently favored heteroxenous species (Dias et al., 2017) since their life cycles allow a broad view of the functioning of the ecosystem at different trophic levels. In Blanar et al. (2009) meta-analysis, however, was observed that monoxenous parasites had effect sizes higher than heteroxenous against several types of pollutants. One of the reasons for this is that fish ectoparasites are in direct contact with water and consequently with pollutants, which can directly affect their abundances, since the host's immune response can also be affected (Falkenberg et al., 2019; Madi and Ueta, 2009). In the present study, a significant response of monoxenous cycle parasites could also be visualized, since that some of the monogenean species of the two fish hosts analyzed had significant variation in their abundances and infestation rates according to the season, water variables and to the host's condition factor.

Recently, a meta-analysis conducted by Poulin (2020) about the seasonal dynamics in parasite infections in aquatic ecosystems shows, in a general way, that the wet season in tropical aquatic ecosystems peaks in parasitic abundance, but with a closer look at specific groups, freshwater monogeneans had no statistical difference between seasons, only coastal fish monogeneans had significant difference in the prevalence rates but peaking in the dry season. In the present study, was

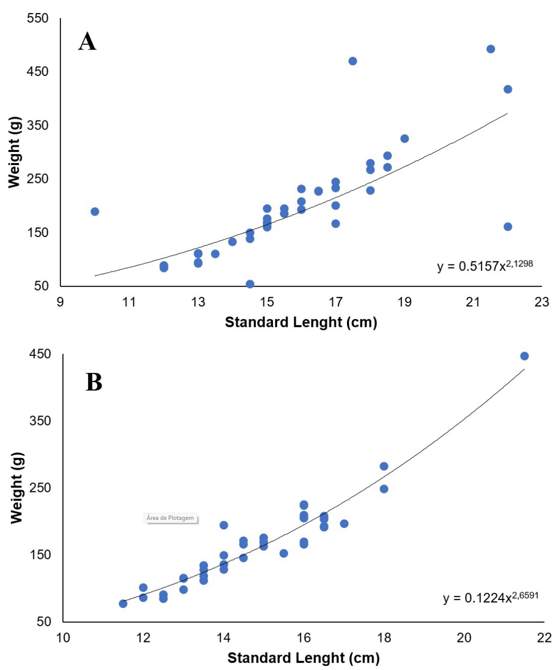

Figure 4. Condition factor of the specimens of *Serrasalmus maculatus* from the Jacaré-Pepira (A) and Jacaré-Guaçú (B) river, Tietê-Batalha River basin, southeastern Brazil.

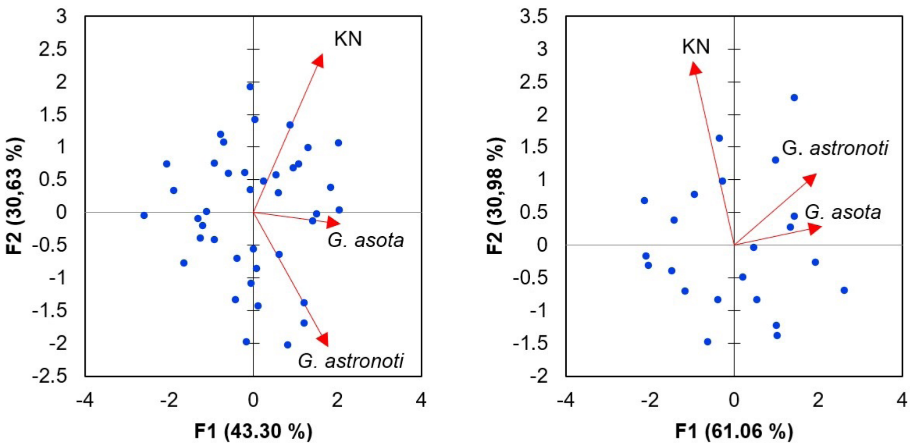

Figure 5. Principal Component Analysis that correlates the condition factors (KN) of *Astronotus crassipinnis* and the abundance of its monogenean parasites in the Jacaré-Pepira (A) and Jacaré-Guaçú (B) rivers, Tietê-Batalha River basin, southeastern Brazil.

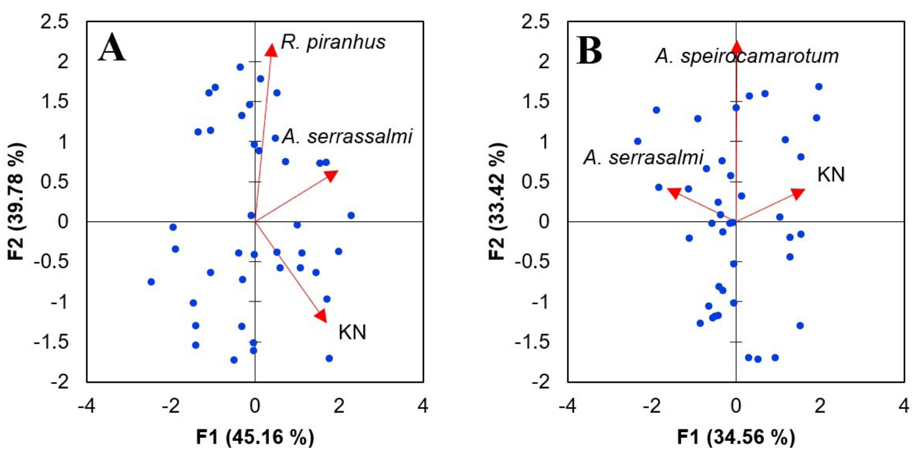

Figure 6. Principal Component Analysis that correlates the condition factors (KN) of *Serrasalmus maculatus* and the abundance of its monogenean parasites in the Jacaré-Pepira (A) and Jacaré-Guaçú (B) rivers, Tietê-Batalha River basin, southeastern Brazil.

observed a different pattern, *A. serrasalmi*, *G. asota* and *A. speirocamarotum* had significantly higher abundance rates in wet season and the same pattern was also observed for dactylogyrids in the Brazilian Amazon, were *Wittingtonocotyle caetei*, *W. jeju*, *Urucleidoides* sp., *U. eremitus* and *Anacanthorus* sp. parasitizing *Hoplerythrinus unitaeniatus* and *Hoplias malabaricus* (Characiformes: Erythrinidae) had higher rates of prevalence and abundance in the wet season (Gonçalves et al., 2016). In parasites of the family Dactylogyridae, structural characteristics of the habitat have no consequences on the prevalence and abundance of species, although abiotic factors are important to the occurrence and distribution of monogeneans, they alone are not determining factors in the season changes or patterns of occurrences. Water temperature still the major determinant, since these parasites have a high sensitivity to temperature changes, which in the species reproductive dynamics plays an important role in egg production (Buchmann, 1988; Chubb, 1977; Lacerda et al., 2018). In another study, Igeh et al. (2021) assessing the season variation along with water and sediment variables in the infestation patterns of *Cichlidogyrus philander* Douëllou, 1993 infecting the gills of *Pseudocrenilabrus philander* (Cichliformes: Cichlidae) in a dam in South Africa, found no relationship between the chemical variables of water and sediments and the monogenean infestation rates, observing only a seasonal influence, which had the highest peaks of infection in wet season. Thus, despite the clear influence of the seasonality, especially related to the temperature, in the rates of abundance and intensity of infestation of the monogenean parasites, seasonality alone cannot be considered as the only cause in the infrapopulations variations (Igeh et al., 2021).

The chemical parameters in the waters of the two rivers did not differentiate between dry and wet seasons, but two of them were in concentrations above that allowed by the current Brazilian legislation (Brasil, 2005): ammonia, on the Jacaré-Pepira and Jacaré-Guaçú rivers, and phosphorus on the Jacaré-Pepira River. Ammonia is naturally present in surface waters and liquid effluents. Its concentration is generally low in groundwater, because of the adsorption of soil and clay particles and is not easily leached from soils. It is produced largely by deaminating organic compounds containing nitrogen and by hydrolysis of urea. The high concentrations of the ammonium ion found can have major ecological implications, such as: influencing the amount of oxygen dissolved in the water. Another form of action can be at basic pH, where this ion turns into ammonia gas (free, gaseous NH_3), which, depending on the concentration, can be toxic to fish. According to Esteves (2011), concentrations equal to or higher than 0.5 mg/L^{-1} of ammonia are considered lethal to fish. In the case of phosphorus, despite values slightly above what is allowed, and due to its direct connection with eutrophication mechanisms, this value just fairly above will not affect the overgrowth of algae that could cause eutrophication (APHA, 2012; Sperling, 1996).

In addition to the parameters found in concentrations above the allowed by the legislation, others, such as nitrate, total nitrogen, and potassium, had an influence on the abundance of two of the five monogenean species analyzed: *G. asota* and *A. speirocamarotum*. Nitrate is a common nutrient in freshwater environments and usually comes from areas of agriculture or sewage disposal (Pacheco and Fernandes, 2016; Padilla et al., 2018), and can be toxic to the aquatic biota, including fish species (Camargo et al., 2005; Freitag et al., 2015). In the present study, it was observed that the abundance of *G. asota* decreased significantly as the nitrate concentrations in water increased. While high concentrations of nitrate can cause the death of the fish, non-lethal concentrations can alter their epidermal structure and ensure a significant reduction in infestation rates of monogenean species. Smallbone et al. (2016) found that nitrate concentrations ranging from 50 to 250 mg/L significantly reduced the gyrodactylid *Gyrodactylus turnbulli* Harris, 1986 infrapopulations in two populations of *Poecilia reticulata* (Cyprinodontiformes: Poeciliidae), suggesting that nitrate protects the host against infestations/infections. Although there is no study that directly links the effect of increasing or decreasing concentrations of total nitrogen and potassium on monogenetic parasites abundance rates, a negative relationship between the concentrations of these water parameters and the abundance of monogenean species is already commonly observed (Blanar et al., 2009; Lacerda et al., 2018). In addition, our study shows that even at not so high concentrations (from a toxicological point of view) changes in concentrations already reflect directly on the distribution of the parasites, showing how sensitive these organisms are to changes in the aquatic environment.

An intrinsic relationship between the fish condition factors and the organic and inorganic parameters of the water and also with the dry and wet seasons was not observed, even knowing that some of these variables can directly affect the fish development (Gonçalves et al., 2016; Lizama et al., 2006). On the other hand, it was observed that the abundances of *G. asota* and *A. serrasalmi* were positively correlated with the condition factors of their fish hosts. Falkenberg et al. (2019) assessing the relationships between fish gill parasites and environmental factors in two estuarine environments in Brazil also found a positive relationship between fish condition factors and the abundance of parasites, which was attributed to the fact that the higher the condition factor, the larger the available surface, which can provide an increase in infestation rates, therefore, larger fish can tolerate higher levels of parasitism (Igeh et al., 2021; Falkenberg et al., 2019; Lizama et al., 2006). In addition, the age of the host causes changes in its biology that can directly influence in the trophic levels of the food web and consequently in its associated parasitic fauna (Dogiel et al., 1961).

5. Conclusions

In general, wet season favored an increasing in the infestation rates of the monogeneans parasites in their host species, mainly in the river considered as the most polluted, the Jacaré-Guaçú River. Of the five parasites species analyzed in this study, only *Gussevia astronoti* Kritsky, Thatcher and Boeger, 1989 and *R. piranhus* had no interaction with river water variables or fish host condition factors. On the other hand, *G. asota* had interactions both with water parameters (nitrate and total nitrogen) and with the hosts condition factors, which reflected in the abundance and intensity rates, showing itself a species sensitive to changes in the environment and, therefore, that can be considered as a bioindicator organism.

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