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# Helminth community of *Nectomys squamipes* naturally infected by *Schistosoma mansoni* in an endemic area in Brazil: A comparison of 22 years apart

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ABSTRACT

The municipality of Sumidouro in the state of Rio de Janeiro, southeastern Brazil, is considered an area with low endemicity of *Schistosoma mansoni*. In this municipality, the wild water rat *Nectomys squamipes* is a wild reservoir of *S. mansoni*. A helminth community survey was carried out on *N. squamipes* populations in Sumidouro from 1997 to 1999. In the present study, we compared the helminth fauna and the helminth community structure of *N. squamipes* with a recent survey after a 22-year time interval, considering that the prevalence of *S. mansoni* infection in humans remained stable and that the area showed the same environmental characteristics. Seventy-three host specimens of *N. squamipes* collected between 1997 and 1999 and 21 specimens collected in 2021 were analyzed in this study. Seven helminth species were found in each collection period. The nematode *Syphacia evaginata* was recorded for the first time in *N. squamipes* in 2021. *Syphacia venteli* was the most abundant species in both periods and the most prevalent in 2021. During the period from 1997 to 1999, the most prevalent species was *Hassalstrongylus epsilon*. Significant differences in prevalence and abundance in relation to host sex were observed only for *S. mansoni* in 1997–1999. Significant differences in the abundance of the helminth species over time were observed only in *Physaloptera bispiculata*. *Hassalstrongylus epsilon*, *S. venteli* and *S. mansoni* were the dominant species in both periods. *Litomosoides chagasfilhoi, Echinostoma paraensei paraensei* and *P. bispiculata* became dominant, codominant and subordinate, respectively, over time. In conclusion, the helminth community of *N. squamipes* remained stable, with similar species richness, prevalence and abundance values and low beta-diversity over time. The occurrence of *S. mansoni* in the water rat has remained stable for decades, highlighting its importance for schistosomiasis control.

## 1. Introduction

Schistosomiasis is a neglected tropical disease caused by digenean trematodes of the genus *Schistosoma* Weiland, 1858. This disease is transmitted across 78 countries in a wide range of tropical and subtropical regions (Hotez, 2009; LoVerde, 2019). The parasite species associated with the disease in the Americas is *Schistosoma mansoni* Sambon, 1907, which causes intestinal schistosomiasis, of which ten countries and territories are considered endemic. In northeastern Brazil and central Venezuela, which are the most prevalent areas of intestinal schistosomiasis in the Americas, 25 million people are at risk (PAHO, 2017). In Brazil, schistosomiasis occurs more intensely in the northeast region, in the states of Rio Grande do Norte, Paraíba, Pernambuco, Alagoas, Sergipe and Bahia, and in the southeast region, mainly in Minas Gerais state and in isolated in the states of Espírito Santo, Rio de Janeiro and São Paulo (Brasil, 2014; da Silva et al., 2022).

In addition to humans, wild rodents are also infected by *S. mansoni* (Gentile et al., 2012; Catalano et al., 2018, 2020). In Brazil, the species

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of the genera *Nectomys* Peters, 1861, and *Holochilus* Brandt, 1835 are the most important species recognized as wild reservoirs (Picot, 1992; Gentile et al., 2012; Amaral et al., 2016). Biological and ecological studies on wild rodent populations infected by *S. mansoni* suggest that these rodents may contribute to the maintenance of schistosomiasis in some local focuses in Brazil, because these animals demonstrate high susceptibility to infection, eliminate viable eggs and have high infection rates compared to the human population (Maldonado et al., 1994; D'Andrea et al., 2000; 2002; Gentile et al., 2006).

The municipality of Sumidouro, state of Rio de Janeiro, southeastern Brazil, is considered an area of low endemicity of schistosomiasis where the first surveys date back to 1959. In this region, the wild water rat *Nectomys squamipes* Brants, 1827, has been found to be naturally infected with *S. mansoni.* This rodent is considered a wild reservoir of this trematode, is capable of maintaining the transmission of the disease in endemic areas, and is a biological indicator of schistosomiasis (Carvalho, 1982; Silva and Andrade, 1989; Picot, 1992; Maldonado et al., 2006; Gentile et al., 2006, 2010).

From the 1980s onward, the importance of water rat populations in the epidemiology of schistosomiasis began to be investigated in the municipality of Sumidouro (Carvalho, 1982; Gentile et al., 2012). Since the 1990s, several multidisciplinary studies have been conducted aiming to understand the role of *N. squamipes* in the dynamics of schistosomiasis transmission in the locality of Pamparrão in Sumidouro (Gentile et al., 2010, 2012). The studies included *S. mansoni* diagnosis in *N. squamipes* by serological and parasitological methods, monitoring of the rodent population, population studies of the intermediate host (*Biomphalaria glabrata,* Say, 1818; Giovanelli et al., 2001), health education programs, and diagnoses in the human population by parasitological methods followed by chemotherapy treatment with praziquantel (Oliveira et al., 2008; Igreja et al., 2018). Those studies showed that the prevalence of *S. mansoni* in the water rat was always high (D'Andrea et al., 2000), although the prevalence in humans was always close to 10% (M.S. Soares, personal communication).

In addition to those studies, a helminth community survey was carried out in *N. squamipes* populations in Pamparrão and Porteira Verde from 1997 to 1999 (Maldonado et al., 2006). In that study, the helminth fauna of *N. squamipes* was fully described, as well as the parasitological indices of each species and the community structure. Recently, in 2021, a new survey of the helminth community of the water rat was conducted, together with diagnoses of the human population in the same area. The helminth community of *N. squamipes* has been investigated in other areas (Gomes et al., 2003; Kuhnen et al., 2012; Panisse et al., 2017; Kersul et al., 2020; Costa et al., 2022); however, this is the only study carried out in an endemic area of schistosomiasis where this rodent was found to be infected by *S. mansoni*. In this context, the aim of this study was to compare the helminth fauna and their community structure in *N. squamipes* after a 22-year time interval in Sumidouro. Herein, we investigated whether helminth species richness, community structure and parasitological parameters changed. Considering that the prevalence of *S. mansoni* infection in humans has remained stable over time (Brito, 2021) and that the area has the same environmental characteristics of small rural areas merged with a few forest fragments, we expected to find the same helminth community structure over time, confirming the maintenance of the *S. mansoni* cycle in rodents.

## 2. Materials and methods

### 2.1. Study area

This study was conducted in two localities in the municipality of Sumidouro (22°02′59″ S; 42°40′29″ W) at 355 m of altitude, Pamparrão (20° 2′ S; 43° 8′ W) and Porteira Verde (22° 02′ 25,2″ S; 42° 39′ 24,9″ W), which are interconnected by two small streams. Sumidouro is located in the central mountain region of the state of Rio de Janeiro and has small fragments of Atlantic Forest with watercourses. The local population is 15,206 inhabitants (IBGE, 2022), and the municipality occupies an area of 413,407 km$^2$. The main economic activity of the region is the agriculture of vegetables and dairy cattle breeding carried out in small rural areas, where the population uses water bodies for crop irrigation, domestic consumption and leisure activities (Gentile et al., 2010). The land use did not change over time. However, there are more houses in the area at present. Sumidouro is located in the Piabanha Hydrographic Basin – Hydrographic Region IV, which has an area of approximately 4484 km$^2$. The Piabanha Basin and the subbasins of the Paquequer and Preto Rivers are among the major subbasins that form the Paraíba do Sul River. Rodent collections were carried out in two different time periods. In the localities of Pamparrão and Porteira Verde, collections were carried out between 1997 and 1999 (Maldonado et al., 2006). In 2021, collections were carried out only in Pamparrão. Thus, the data obtained between 1997 and 1999 were reanalyzed and compared with those obtained in 2021.

### 2.2. Nectomys squamipes sampling and helminth recovery

Capture transects were established along streams, which are the natural habitat of *N. squamipes*. Adult specimens of *N. squamipes* were captured using Tomahawk® Live Traps (Hazelhurst, Wisconsin) model 201 (16" × 5" × 5″) baited with a mixture of peanut butter, banana, oats, and bacon. The trapping points were spaced 10 m apart. The animals were euthanized by exsanguination (full bleeding) under deep anesthesia by cardiac puncture. The anesthetic protocols included ketamine (100 mg/mL) combined with acepromazine (10 mg/mL) at a ratio of 9:1 (dose of 0.15 mL/100 g body weight). Rodents were captured under authorization of the Brazilian Government's Chico Mendes Institute for Biodiversity and Conservation (ICMBIO, license 13373). All procedures followed the guidelines for the capture, handling, and care of animals of the Ethical Committee on Animal Use of the Oswaldo Cruz Foundation (CEUA, license L-036/2018). Biosafety procedures and personal protective equipment, including biosafety level 3 respirators, were used during all procedures involving animal handling and biological sampling (Lemos & D'Andrea, 2014).

Perfusion of the portal-hepatic system was performed with citrate saline (0–85% sodium chloride; 1–5% sodium citrate) according to Smithers and Terry (1965) to recover adult specimens of *S. mansoni* in the mesenteric and portal veins. The stomach, thoracic and abdominal cavities, and small and large intestines of the rodents were examined separately under a stereoscopic microscope for helminth collection. The helminths were washed in 0.85% saline solution to remove tissue debris and fixed in 70% ethanol solution for molecular analysis. The nematodes were cleared in lactophenol. The cestodes were stained in Carmine, Langeron, and dehydrated in an increasing alcohol series according to the method described by Amato (1985). The specimens were counted, sexed, and identified using a Zeiss Standard 20 light microscope (Zeiss, Jena, Germany). The species were identified using morphological keys based on adult helminth specimens according to Yamaguti (1961), Yorke and Maplestone (1969), Vicente et al. (1997), and Anderson (2000).

### 2.3. Data analysis

The mean abundance, mean intensity and prevalence of each helminth species were calculated according to Bush et al. (1997) for each collection period. The helminth species richness was determined as the number of species found in the component community. The component community was considered as all of the individuals of all the helminth species found in *N. squamipes* population in the study area, according to Bush et al. (1997). The total estimated species richness was calculated using the Chao1 index (Magurran, 2004) for each period. The mean species richness was estimated for each period considering the number of helminth species in each single host. The difference in mean species richness between periods was investigated using the Mann-Whitney test.

The beta-diversity index of Whittaker (1972) was estimated to compare species diversity over time. A beta-diversity value close to zero indicates minimum diversity, and a value close to one indicates maximum diversity (Magurran, 2004). The mean abundance was calculated as the total number of helminths of a given species divided by the number of hosts analyzed. The mean intensity was considered the total number of helminths of a given species divided by the number of hosts infected by that species. The prevalence was the ratio between the number of infected hosts and the total number of hosts analyzed.

Abundance and prevalence were compared for each species in relation to host sex and collection period. Prevalence was compared using the chi-square contingency test, and abundance was compared using the Mann−Whitney test. The significance level used was 5% in all the analyses. All tests were performed using Past software, version 4.09 (Hammer et al., 2001).

The parasite importance index (I) was calculated to determine the role of a given helminth species in the helminth community as follows (Thul et al., 1985):

$$I_j = M_j\ x\ \left[\left(A_j x\ B_j\right)\right] \div \sum i\ (A_i x B_i) x\ 100$$

where A = number of individual parasites of a particular species, B = number of hosts infected with parasites of species 'x', and M is a maturity factor equal to 1.0 if at least one mature individual of species 'x' is found and equal to 0 otherwise.

Dominant species characterized by $I \geq 1.0$; codominant species contributing significantly to the community, though to a lesser degree than dominant species ($0.01 \leq I < 1.0$); subordinate species occurring infrequently and although they may develop and reproduce, they do not contribute significantly to the community ($0 < I < 0.01$); unsuccessful pioneer species that gain access to the host but do not mature or reproduce and contribute little to the community and are characteristic of another host ($I = 0$).

## 3. Results

From 1997 to 1999, 51 and 22 specimens of *N. squamipes* were captured in the localities of Pamparrão and Porteira Verde, respectively. In 2021, twenty-one specimens of *N. squamipes* were captured in the Pamparrão locality. Seven helminth species were found in each period. The estimated species richness was also seven for each period. The mean species richness was 1.9 ± 1.4, varying from one to five for the past period and 1.8 ± 1.2, varying from one to six for the present period. No significant difference was observed in mean species richness between periods (U = 680, $p = 0.422$). The beta-diversity between collection periods was 0.143.

Among the 73 rodent specimens captured in 1997–1999, 76.7% were infected with at least one helminth species (Table 1). Seven helminth species were found. Four nematode species were identified: *Physaloptera bispiculata* Vaz and Pereira, 1935 (Spirurida: Physalopteridae), found in the stomach; *Hassalstrongylus epsilon* (Travassos, 1937) (Strongylida: Heligmonellidae), found in the small intestine; *Syphacia venteli* Travassos, 1937 (Oxyurida: Oxyuridae), found in the cecum and large intestine; and *Litomosoides chagasfilhoi* Moraes Neto, Lanfredi & De Souza, 1997 (Rabditida: Onchocercidae), found in the abdominal cavity. Two trematode species were identified: *Schistosoma mansoni* Sambon, 1907 (Digenea: Schistosomatidae), which was found in the mesenteric and portal veins, and *Echinostoma paraensei* Lie and Basch, 1967 (Digenea: Echinostomatidae), which was found in the small intestine. A cestode species was found in the small intestine, *Raillietina* sp. (Cyclophyllidea: Davaineidae), which was not identified at the species level due to the absence of the scolex, which is a taxonomic characteristic necessary for species identification. The most abundant species was *S. venteli,* and the most prevalent was *H. epsilon* (Table 1).

Among the 21 rodent specimens captured in 2021, 90.5% were infected with at least one helminth species (Table 1). Five nematode species were identified: *L. chagasfilhoi,* found in the abdominal cavity; *P. bispiculata,* found in the stomach; *H. epsilon,* found in the small intestine; *S. venteli,* found in the cecum and large intestine; and *Syphacia evaginata* Hugot and Quentin, 1985 (Oxyurida: Oxyuridae), found in the cecum and large intestine. The characteristics that differentiate the two *Syphacia* species are very evident. *Syphacia venteli* does not have a pair of derids whereas *S. evaginata* does (Robles and Navone, 2010), and the latter has a very prominent vulva (Hugot and Quentin, 1985). Two trematode species were identified: *S. mansoni* which was found in the mesenteric and portal veins, and *E. paraensei* which was found in the small intestine. *Syphacia venteli* was the most abundant and prevalent species.

Significant differences in prevalence in relation to host sex were observed only for *S. mansoni* in 1997–1999 (Table 2). *Schistosoma mansoni* occurred in 17.65% of female hosts and in 53.85% of male hosts, with a sex ratio of 39 M:17 F. Regarding abundance, differences in host sex were observed only for *S. mansoni* for the same period (Table 2). In 1997–1999, *Litomosoides chagasfilhoi* occurred only in male hosts; however, in 2021, this species occurred in both sexes. *Raillietina* sp. occurred only in female hosts and only in 1997–1999.

**Table 1**
Number of infected hosts, prevalence rates (95% confidence intervals) and mean abundance and intensity (±SDs) for each helminth species found in *Nectomys squamipes* collected between 1997 and 1999 (n = 73) and in 2021 (n = 21) in Sumidouro, Rio de Janeiro state, Brazil.

| Past | | | | | | | |
|---|---|---|---|---|---|---|---|
| Species | | | | | | | |
| Parameters | *Hassalstrongylus epsilon* | *Physaloptera bispiculata* | *Syphacia venteli* | *Litomosoides chagasfilhoi* | *Schistosoma mansoni* | *Echinostoma paraensei* | *Raillietina* sp. |
| Number of infected hosts | 44 | 24 | 39 | 4 | 24 | 6 | 1 |
| Prevalence | 60.27 (48–71) | 32.88 (22–44) | 53.42 (41–65) | 5.48 (1–13) | 32.88 (22–44) | 8.22 (3–17) | 1.37 (0.03–7) |
| Abundance | 34.59 (±56.32) | 3.86 (±8.73) | 195.36 (±442.08) | 0.67 (±3.88) | 16.56 (±44,93) | 0.68 (±3.48) | 0.21 (±1.64) |
| Intensity | 57.39 (±63.03) | 11.75 (±11.91) | 365.67 (±553.5) | 12.25 (±13.15) | 50.38 (±66,82) | 8.33 (±9.87) | 15 (±9.19) |
| Present | | | | | | | |
| **Species** | | | | | | | |
| | *Hassalstrongylus epsilon* | *Physalopteta bispiculata* | *Syphacia evaginata* | *Syphacia venteli* | *Litomosoides chagasfilhoi* | *Schistosoma mansoni* | *Echinostoma paraensei* |
| Number of infected hosts | 8 | 3 | 4 | 9 | 4 | 6 | 5 |
| Prevalence | 38.1 (18–61) | 14.28 (3–36) | 19.05 (5–41) | 42.86 (21–65) | 19.05 (5–41) | 28.57 (11–52) | 23.81 (8–41) |
| Abundance | 17.9 (±35.85) | 0.2381 (±0.89) | 2.14 (±6.37) | 88.76 (±164.88) | 7.71 (±31.33) | 9.05 (±21.8) | 0.48 (±2) |
| Intensity | 47 (±45.73) | 1.67 (±2.12) | 11.25 (±10.82) | 207.11 (±198.16) | 40.5 (±69.1) | 31.67 (±32.26) | 2 (±1.22) |

**Table 2**
Chi-squared and Mann-Whitney tests of helminth prevalence and abundance, respectively, importance indices and their classification of each species in the helminth community found in *Nectomys squamipes* in relation to host sex collected between 1997 and 1999 (Past) (n = 73) and in 2021 (Present) (n = 21) in Sumidouro, Rio de Janeiro state, Brazil.

| | Species | χ2 | *p* | U | *p* | Importance index | Classification |
|---|---|---|---|---|---|---|---|
| Past | *Schistosoma mansoni* | 8.3321[a] | 0.004 | 425[a] | 0.004 | 4.124 | Dominant |
| | *Hassalstrongylus epsilon* | 3.3626 | 0.07 | 478.5 | 0.067 | 15.791 | Dominant |
| | *Syphacia venteli* | 0.85796 | 0.35 | 492 | 0.354 | 79.051 | Dominant |
| | *Physaloptera bispiculata* | 3.4076 | 0.06 | 506 | 0.065 | 0.962 | Codominant |
| | *Raillietina* sp. | 3.7172[a] | 0.05 | | | 0.002 | Subordinate |
| | *Echinostoma paraensei* | 1.0237 | 0.31 | 452 | 0.312 | 0.043 | Subordinate |
| Present | *Hassalstrongylus epsilon* | 1.2886 | 0.26 | 35 | 0.256 | 13.79 | Dominant |
| | *Syphacia venteli* | 0.029371 | 0.86 | 50 | 0.864 | 76.89 | Dominant |
| | *Litomosoides chagasfilhoi* | 0.01123 | 0.915 | 52 | 0.916 | 2.97 | Dominant |
| | *Schistosoma mansoni* | 0.68727 | 0.41 | 46 | 0.407 | 5.23 | Dominant |
| | *Syphacia evaginata* | 0.28636 | 0.59 | 49.5 | 0.593 | 0.83 | Codominant |
| | *Echinostoma paraensei* | 0.15273 | 0.695 | 51.5 | 0.696 | 0.23 | Codominant |
| | *Physaloptera bispiculata* | 0.005024 | 0.94 | 55 | 0.943 | 0.07 | Subordinate |

[a] Significant values ($p < 0.05$).

Significant differences in the abundance of the helminth species over time were observed only for *P. bispiculata* (U = 571.5; *p* = 0.02) (Table 3). No significant difference was observed in prevalence over time.

The helminth species *H. epsilon*, *S. venteli* and *S. mansoni* were dominant in both periods. In 1997–1999, *P. bispiculata* was codominant, while *L. chagasfilhoi*, *E. paraensei* and *Raillietina* sp. were subordinate. In 2021, *L. chagasfilhoi* was dominant, *P. bispiculata* and *E. paraensei* were codominant, *P. bispiculata* was subordinate, and *Raillietina* sp. was an unsuccessful pioneer (Table 2).

## 4. Discussion

A comparison of the helminth community of the water rat *N. squamipes* after 22 years revealed stable species richness, with seven species in both periods, although one species in the community, *Raillietina* sp., was not found currently. The similar estimated species richness between periods and in relation to the observed values, as well as the non-significant difference in mean species richness between periods and the low value of beta-diversity, indicate a stable community structure over time.

The present study is the first to report *S. evaginata* in *N. squamipes*, which is a new host for this nematode. The three dominant species in the past period (*H. epsilon*, *S. venteli* and *S. mansoni*) remained dominant in the 2021 community, while *L. chagasfilhoi, E. paraensei* and *P. bispiculata* became dominant, codominant and subordinate, respectively, over time. These findings indicated little variation in the helminth community structure over time.

The helminth species richness of *N. squamipes* populations in Sumidouro (seven species) was much greater than that in other studies carried out in agroforestries in the state of Bahia, Brazil, which reported three species of nematodes in each locality (Kersul et al., 2016; Costa et al., 2022). The helminth communities found in those studies represent a subgroup of the helminth community of the *N. squamipes* population from Sumidouro. Kuhnen et al. (2012) found only one helminth morphospecies in *N. squamipes* in each of two preserved areas in the state of Santa Catarina. In one locality, *Hassalstrongylus* sp. was found, and in the other locality, eggs of the family Ancylostomidae were found.

**Table 3**
Chi-squared and Mann-Whitney tests of helminth prevalence and abundance, respectively, for each helminth species found in Nectomys squamipes in relation to collection periods in Sumidouro, Rio de Janeiro state, Brazil.

| Species | χ2 | *p* | U | *p* |
|---|---|---|---|---|
| *Hassalstrongylus epsilon* | 3.2456 | 0.07 | 601 | 0.12 |
| *Physaloptera bispiculata* | 2.7532 | 0.1 | 571.5 | 0.02 |
| *Syphacia venteli* | 0.72881 | 0.39 | 654 | 0.28 |
| *Litomosoides chagasfilhoi* | 3.8559 | 0.069 | 456 | 0.09 |
| *Schistosoma mansoni* | 0.13911 | 0.71 | 725 | 0.65 |
| *Echinostoma paraensei* | 3.8363 | 0.065 | 310 | 0.485 |

The nematodes *H. epsilon* and *S. venteli* were the most prevalent and abundant species in both periods. Both species have a direct life cycle, which facilitates their transmission and maintenance in the environment (Maldonado et al., 2006). As in the present study, the species *H. epsilon* and *S. venteli* were found to parasitize populations of *N. squamipes* in other localities in Brazil and Argentina, with high abundances and prevalence (Kersul et al., 2020; Panisse et al., 2017). *Hassalstrongylus epsilon* and *S. venteli* were also found in *N. squamipes* by Gomes et al. (2003). In addition, *H. epsilon* parasitizes not only *N. squamipes* but also the rodents *Akodon cursor* (Winger, 1887; Gomes et al., 2003) and *Oligoryzomys nigripes* (Olfers, 1818) (Panisse et al., 2017; Costa et al., 2022), which are the most abundant rodent species after *N. squamipes* in Sumidouro (D'Andrea et al., 2007). The direct life cycle and host generalist habit of *H. epsilon* may favor the maintenance of the life cycle of this nematode in the region and explain its high prevalence and abundance.

The two trematode species found in *N. squamipes* have not been reported in other studies of helminth communities of *N. squamipes* (Panisse et al., 2017; Kersul et al., 2020; Costa et al., 2022). However, the occurrence of *E. paraensei* has been reported in water rat populations in Sumidouro and Rio Bonito, both of which are in the state of Rio de Janeiro (present study, Maldonado et al., 2001, 2005). The rare occurrence of this trematode in small wild rodents has been attributed to the geographic distribution of its intermediate hosts and to environmental conditions (Costa et al., 2022). The snail *Biomphalaria glabrata* is an intermediate host of *Schistosoma mansoni* and *E. paraensei*; thus, the presence of this species enabled the occurrence of these parasites in Sumidouro (Lie and Basch, 1967; Maldonado et al., 2001; Giovanelli et al., 2001).

The trematode *S. mansoni* was first recorded in *N. squamipes* in Brazil in 1953 (Amorim, 1953). Due to its importance for the epidemiology of intestinal schistosomiasis in Brazil, several other records of water rat populations naturally infected by the trematode were observed in the states of Minas Gerais (Martins et al., 1955), Sergipe (Piva and Barros, 1966), São Paulo (Rodrigues and Ferreira, 1969) and Rio de Janeiro (Carvalho, 1982), where rodents presented a high prevalence of the parasite (Rey, 1993).

During the long-term study of *S. mansoni* infection in *N. squamipes* in Sumidouro conducted by D'Andréa et al. (2000), the mean prevalence between 1991 and 1995 in Pamparrão and Porteira Verde was 26%, varying from zero to 57%. In our study, in both periods, the prevalence rates were quite similar to those in D'Andréa et al.'s (2000) study. In November 2005, 75% of the rodents analyzed for the presence of *S. mansoni* were positive (Gentile et al., 2006). While the prevalence of

*S. mansoni* is always high in rodents, the prevalence in humans in Pamparrão does not follow the same pattern. A survey carried out in Pamparrão over 10 years (1990–2000) showed that the mean prevalence of *S. mansoni* in humans was 12.76% (M.S. Soares, personal communication). In the 2000s, the prevalence in humans was 13.4% (Gentile et al., 2006). Between 2005 and 2006, in another locality of Sumidouro, the prevalence decreased from 28.6 to 6.7% after chemotherapy treatment with praziquantel (Igreja et al., 2018). In Pamparrão, the prevalence in humans in 2019 was 11% (Brito, 2021).

The significant difference found in the abundance and prevalence of *S. mansoni* in relation to host sex in the 1997–1999 period may be due to the larger home ranges of males compared to females of the water-rat (Bergallo and Magnusson, 2004). The greater movements of male hosts may result in greater exposure to *S. mansoni* infection than those of female hosts (Maldonado et al., 2006).

A comparison of the parasitological parameters over time revealed that *P. bispiculata* was significantly less abundant in 2021 than in 1997–1999, similar to the findings of Kersul et al. (2020) and Costa et al. (2022), who reported low abundances of this genus. This parasite has an indirect life cycle, and its possible intermediate hosts are insects (Hobmaier, 1941; Maldonado et al., 2006). Considering that it is an agricultural area impacted by the use of pesticides (Stotz, 2005), this could reduce insect populations with a consequent reduction in the transmission of *P. bispiculata*.

In conclusion, despite the 22-year interval at which the helminth communities were separated from the *N. squamipes* communities studied in Sumidouro, an area impacted by agriculture, these communities remained stable, with very similar species richness and similar prevalence and abundance. This study highlights the importance of the water rat as a natural host of *S. mansoni* in the locality of Pamparrão, where the prevalence of this trematode in *N. squamipes* has remained stable for decades in the region, which is a complicating factor for schistosomiasis elimination in the area, requiring permanent investigation and control programs.

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## Ethics in publishing

The euthanasia of rodents followed the guidelines of the Animal Care and Use Committee of the American Society of Mammalogists (Sikes et al., 2016) and the Brazilian Guide to Good Practices for Euthanasia in Animals by the Ethics, Bioethics, and Animal Welfare Committee of Brazil's Federal Council of Veterinary Medicine (CFMV, 2013). Permits for rodent capture and handling were issued by the Chico Mendes Institute for Biodiversity Conservation (ICMBio/SISBIO, license numbers 13373-1, 45839-1, and 63023-4); the State Environmental Institute of Rio de Janeiro (INEA, license number 020/2011); Procedures were approved by the ethics committees on animal use of the Oswaldo Cruz Foundation and the Oswaldo Cruz Institute (CEUA--FIOCRUZ, license number LW-39/14, and CEUA-IOC, license number L-036/2018).

## CRediT authorship contribution statement

**Karina Varella:** Conceptualization, Formal analysis, Investigation, Methodology, Project administration, Writing – original draft, Writing – review & editing. **Beatriz Elise de Andrade-Silva:** Formal analysis, Methodology, Writing – review & editing. **Sócrates Fraga da Costa-Neto:** Formal analysis, Writing – review & editing. **Brena Aparecida de Oliveira Cruz:** Formal analysis. **Arnaldo Maldonado Junior:** Conceptualization, Formal analysis, Investigation, Methodology, Project administration, Resources, Supervision, Writing – original draft, Writing – review & editing. **Rosana Gentile:** Conceptualization, Formal analysis, Investigation, Methodology, Resources, Supervision, Writing – original draft, Writing – review & editing.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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