

## Helminth communities of *Nectomys squamipes* naturally infected by the exotic trematode *Schistosoma mansoni* in southeastern Brazil

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### Abstract

The water rat *Nectomys squamipes* is endemic in Brazil and found naturally infected with *Schistosoma mansoni*. Helminth communities, their prevalences, intensity of infection and abundance in *N. squamipes* in an endemic area of schistosomiasis in the state of Rio de Janeiro, Brazil were studied. Four species of nematodes (*Physaloptera bispiculata*, *Syphacia venteli*, *Hassalstrongylus epsilon* and *Litomosoides chagasfilhoi*) were recovered in 85.3%, two trematodes (*Schistosoma mansoni* and *Echinostoma paraensei*) in 38.8% and one cestode species (*Raillietina* sp.) in 1.7% of rats examined. Rats were infected with up to five helminth species each, and these were highly aggregated in distribution. For *H. epsilon* and *S. venteli*, intensities and abundances were higher in adult male and subadult female hosts, respectively. *Hassalstrongylus epsilon*, *P. bispiculata*, *S. venteli* and *S. mansoni* were classified as dominant species, *L. chagasfilhoi* and *E. paraensei* as co-dominant and *Raillietina* sp. as subordinated. No significant correlation was found in the intensity of infection between each pair of helminth species. *Schistosoma mansoni* was not related to any other helminth species according to their infection rates, although *S. mansoni* was well established in the natural helminth community of the water rat.

### Introduction

Schistosomiasis caused by *Schistosoma mansoni* is considered an important and widespread human disease in Brazil. However, control programmes have largely neglected the role of wild rodents in the dynamics of *Schistosoma mansoni* transmission (WHO, 1993) and additional information on *S. mansoni* in rodents is

required, especially with regard to the epidemiology of the host–parasite relationship.

A long-term study focusing on the role of the semi-aquatic water rat *Nectomys squamipes* in the dynamic transmission of *S. mansoni* has been carried out in the municipality of Sumidouro, Rio de Janeiro state, Brazil, an endemic area of schistosomiasis. This study indicated that *N. squamipes* could maintain and potentially increase the transmission of this parasite to humans, and may spread the parasite, establishing new infection foci (D'Andrea *et al.*, 2000). The evidence accumulated from water rat collection in different Brazilian ecosystems has

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demonstrated heterogeneity in prevalence rates (Rey, 1993; Chieffi *et al.*, 1994). This variability could result from interaction between species within the helminth community in each ecosystem studied (Lello *et al.*, 2004).

The helminth community ecology of *N. squamipes* has not hitherto been evaluated, especially in regions where the exotic species *S. mansoni* is present. Studies relating to helminths of the water rat are restricted to species descriptions (Gomes & Vicente, 1984). Under laboratory conditions, substantial antagonistic and synergistic interactions between *S. mansoni* and *Echinostoma revolutum* have been described in mice (Christensen *et al.*, 1981) and between *S. mansoni* and *E. paraensei* in *N. squamipes*, the natural host of both trematodes in Brazil (Maldonado Jr *et al.*, 2001a).

The present study aims to investigate helminth communities of *N. squamipes* in an endemic area of schistosomiasis, where this rodent is found naturally infected with *S. mansoni*. The prevalence, intensity of infection and abundance of each helminth are investigated and the influence of *S. mansoni* on the helminth fauna of the water rat evaluated.

## Materials and methods

### Study site

The study was conducted in the Pamparrão and Porteira Verde valleys, Sumidouro municipality, state of Rio de Janeiro, Brazil (22°02'46"S; 42°41'21"W), every other month from April 1997 to April 1999. The landscape is composed of small rural properties with vegetable plantations, pastures and a few small Atlantic Forest fragments. The climate is humid-mesotermic (Nimer, 1979) and the rainfall seasonal. The mean temperature during the period of study was  $24.3 \pm 2.4^\circ\text{C}$  and the rainfall was  $121.7 \pm 126.1 \text{ mm}^3$  (data obtained from National Institute of Meteorology of Rio de Janeiro, Brazil).

### Collection of rats and parasites

Water rats were collected along watercourses and flooded areas by live traps set at the intervals of 13 m between traps. The age of rats was estimated according to the growth curve obtained for *N. squamipes* in the laboratory (D'Andrea *et al.*, 1996) and three age groups were categorized as described by Gentile *et al.* (2000), namely juveniles with a body mass less than 110 g in both sexes, young adults with a body mass more than 110 g and less than 190 g in males and less than 215 g in females, and adults with a body mass more than 190 g in males and 215 g in females. Rat abundances were estimated as the number of animals captured under a constant trapping regime (total number of traps per trapping period).

Animals were euthanized using a CO<sub>2</sub> chamber. Organs were removed and placed in Petri dishes with saline 0.9% solution and the thoracic and peritoneal cavities examined for helminths. The species recovered from each organ were counted and fixed according to Amato (1985). Nematodes were fixed with alcohol-formalin-acetic acid (AFA) at 60°C and cleared in lactophenol. Trematodes were fixed with AFA at room

temperature under the pressure of a cover slip. Ten specimens of trematode species were stained with chlorhydric carmine, dehydrated in a graded alcohol series, cleared in methylsalicylate and mounted in Canada balsam. Species were identified by comparison with paratypes deposited at the Oswaldo Cruz Collection (CHIOC). Protocol experiments were performed according to the Ethical Commission of Animal Use of the Fundação Oswaldo Cruz. The collection of rats was carried out strictly in accordance with the rules and conditions of the licence from the Brazilian Authority for Environment and Natural Resources (IBAMA).

### Data analyses

Distribution patterns of each helminth were determined by an index of dispersion calculated as the variance to mean ratio of parasite abundance (Ludwig & Reynolds, 1988).

For helminth community analysis, the prevalence, intensity and abundance of infection for each species were calculated according to Bush *et al.* (1997). These parameters were also compared in relation to host gender and age and prevalences were analysed by logistic regression. Intensities and abundance were compared in relation to host gender and age together only for *H. epsilon* and *S. venteli*. For other species only host gender was compared due to the lack of sufficient data.

The co-occurrence of helminths was investigated through Pearson correlation coefficients or Spearman coefficients when data were not normally distributed and the intensities for each helminth pair were considered only in rats infected with both species of the pair (Zar, 1999).

The helminth community structure was classified according to Thul *et al.* (1985) as follows: dominant species characterized by  $I > 1.0$ ; co-dominant species contributing significantly to the community, though to a lesser degree than dominant species ( $0.01 < I < 1.0$ ); 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 they contribute little to the community and are characteristic of another host ( $I = 0$ ).

The importance value,  $I$ , was calculated for each helminth species as follows:

$$I_j = M_j \times [(A_j \times B_j) \div \sum_i (A_i \times B_i)] \times 100$$

where  $A$  = number of individual parasites of a particular species,  $B$  = number of hosts infected with parasites of species 'x', and  $M$  is a mature factor equal to 1.0 if at least one mature individual of species 'x' is found and equal to 0 otherwise (Thul *et al.*, 1985).

Helminth richness was considered as the number of species. Diversity was calculated using the Shannon index, which represents the most abundant species (Ludwig & Reynolds, 1988). Helminth richness and diversity was calculated relative to host gender, age class and for the entire host population.

Helminth prevalences were calculated for each species for each trapping session. The prevalences of *S. mansoni*

were correlated with the prevalences of other helminths to evaluate the possible relationship between *S. mansoni* and the natural helminth fauna of *N. squamipes*.

Statistical significance levels of 0.05 were accepted in all tests and a Bonferroni correction was used for multiple comparisons.

## Results

One hundred and sixteen individuals of the wild water rat *Nectomys squamipes* were examined which produced a sex ratio biased toward males ( $\chi^2 = 6.40$ ,  $P = 0.014$ , 77M: 39F). The rats harboured from 1 to 5 concurrent helminth species and the overall infection rate was 87% (89.6% for males and 82% for females). There was no difference in the overall infection rate between sexes ( $\chi^2 = 0.09$ ,  $P = 0.76$ ).

Seven species of helminths were recovered, four species of which were nematodes with an overall prevalence of 85.3%. *Physaloptera bispiculata* (Seurat) occurred in the stomach and represented 1.8% of overall worm burdens. *Hassalstrongylus epsilon* (Travassos) occurred in the duodenum representing 13.8%, with *Syphacia venteli* (Travassos) occurring in the caecum and large intestine, representing 76.1% of worms. *Litomosoides chagasfilhoi* (Moraes Neto *et al.*) was found in the abdominal cavity and represented 1.0% of all nematodes found. This is the first occurrence of *L. chagasfilhoi* in *N. squamipes*. Two trematode species were found in 38.8% of rats, 6.9% being *Schistosoma mansoni* (Sambon) localized in the mesenteric and portal veins and 3% were *Echinostoma paraensei* (Lie & Basch) from the small intestine, mainly in the duodenum. One cestode species, *Raillietina sp.*, was found in the small

intestine of 1.7% of rats, representing 0.05% of all worms recovered.

The overall helminth diversity was 1.72. Males of *N. squamipes* showed a higher helminth diversity than females (2.46 and 1.85 respectively). The diversity in adults was greater than in sub-adults and young individuals, being 2.84, 1.64 and 1.42, respectively. All helminth species were highly aggregated within the *N. squamipes* population: namely *H. epsilon* 78.6; *P. bispiculata* 16.8; *S. venteli* 1563.8; *L. chagasfilhoi* 67 + 1; *S. mansoni* 215.7; *E. paraensei* 16.1; *Raillietina sp.* 13.1.

The highest prevalences, intensities and abundances of infection were observed for *S. venteli* followed by *H. epsilon* and *S. mansoni*. The lowest values were observed for *Raillietina sp.* followed by *E. paraensei* (tables 1 and 2).

The prevalence of *H. epsilon* was significantly different in relation to gender ( $P = 0.044$ ), where male hosts had higher prevalences than female hosts. *Physaloptera bispiculata* presented significant differences in prevalences relative to host age ( $P = 0.037$ ), where young hosts had higher prevalences. No other helminth species showed any significant differences in prevalence relative to host age and gender.

Significant differences between host gender and age in intensity and abundance were observed for *H. epsilon* ( $\chi^2 = 74.79$ ,  $P < 0.001$ ;  $\chi^2 = 40.9$ ,  $P < 0.001$ , respectively) and *S. venteli* ( $\chi^2 = 440.2$ ,  $P < 0.001$ ;  $\chi^2 = 59.1$ ,  $P < 0.001$ , respectively). In *H. epsilon* the intensity and abundance were larger for adult male hosts whereas in *S. venteli* these values were larger in females. No other helminth showed differences in abundances and intensities relative to host gender.

Analyses of helminth communities indicated that no species was considered an unsuccessful pioneer.

Table 1. The prevalence (P), intensity (I) and abundance (A) of nematode species in *Nectomys squamipes*, relative to host gender and age.

Host gender/age	<i>Hassalstrongylus epsilon</i>			<i>Physaloptera bispiculata</i>			<i>Syphacia venteli</i>			<i>Litomosoides chagasfilhoi</i>		
	P	I	A	P	I	A	P	I	A	P	I	A
Males	73.3	49.2	36.5	48.0	9.6	4.6	49.3	326.1	163.0	8.0	28.2	2.3
Females	48.8	22.5	27.3	30.2	12.6	3.9	44.2	488.6	217.9	11.6	20.8	2.5
Juvenile	50.0	48.4	27.0	10.0	27.0	3.0	50.0	570.0	316.7	0	0	0
Sub-adults	50.0	46.5	23.9	31.6	8.8	2.9	39.5	610.5	247.5	7.9	8.7	0.7
Adults	73.2	52.4	39.0	49.3	10.7	5.3	49.3	266.1	131.6	11.3	30.9	3.5
Total	6.3	52.0	33.2	40.5	10.8	4.4	52.6	347.8	362.7	9.5	24.8	2.3

Table 2. The prevalence (P), intensity (I) and abundance (A) of trematode and cestode species in *Nectomys squamipes*, relative to host gender and age.

Host gender/age	<i>Schistosoma mansoni</i>			<i>Echinostoma paraensei</i>			<i>Raillietina sp.</i>		
	P	I	A	P	I	A	P	I	A
Males	42.7	50.9	22.0	9.3	7.3	0.7	0	0	0
Females	20.9	33.8	7.2	4.6	13.5	0.6	4.6	7.5	0.4
Juvenile	10.0	15.0	1.7	0	0	0	0	0	0
Sub-adults	23.7	30.2	7.4	2.6	17.0	0.5	2.6	1.0	0.03
Adults	43.7	53.1	23.5	11.3	7.6	0.9	1.4	14.0	0.2
Total	34.5	48.3	16.7	7.8	8.7	0.7	1.7	7.5	0.13

*Hassalstrongylus epsilon*, *P. bispiculata*, *S. venteli* and *S. mansoni* were considered as dominants (I = 16.9, 1.4, 76.8, 4.6, respectively), with *L. chagasfilhoi* and *E. paraensei* as co-dominants (I = 0.18, 0.04, respectively) and *Railletina* sp. as subordinated (I = 0.0018).

No significant correlation was found in the overall intensities of infection between helminth species, and no interactions between each pair of helminth species were found. Due to low sample sizes, it was not possible to test the interaction between *S. mansoni* and *L. chagasfilhoi*, *S. mansoni* and *E. paraensei* and *Railletina* sp. and the other helminth species (table 3).

Considering the possible co-variation in infection rates between *S. mansoni* and other helminths in the overall *N. squamipes* population, no significant correlation was found. There was no correlation between water rat abundance and the intensity of helminths overall (table 4).

**Discussion**

Interactions between intestinal helminths may be determined by direct influences of one parasite on another through secretory products, gut physiology, interspecific competition or crowding effects. Furthermore, interactions would be mediated through the host's immune system (Lello et al., 2004).

The water rat *Nectomys squamipes*, which is widespread in Brazil (Bonvicino, 1994), was highlighted from a parasitological viewpoint when it was found to be involved in the transmission of *S. mansoni* (Rey, 1993, D'Andrea et al., 2000). Studies on the helminths of *N. squamipes* were subsequently intensified and its natural helminth fauna was identified. *Physaloptera bispiculata* was recorded in *N. squamipes* for the first time by Vaz & Pereira (1935) in Mogi das Cruzes, São Paulo, *Syphacia venteli* by Travassos (1937) in Angra dos Reis, Rio de Janeiro, *Litomosoides chagasfilhoi* from Rio Bonito by Moraes-Neto et al. (1997), *Hassalstrongylus epsilon* by Travassos (1937) in Formosa, Goiás, and *Echinostoma paraensei* in Sumidouro by Maldonado et al. (2001b). The higher helminth diversity observed in adult hosts was as expected. The heaviest and therefore the oldest rodents would have had the longest exposure and opportunity to accumulate worm burdens. As males forage more than females, and occupy larger home ranges (Gentile et al., 2000), their risk of infection would be expected to be higher than that of females.

Dispersion can be viewed as an extension of the transmission process, and is conditioned by several factors such as longevity, specificity, population density, morbidity, host migration, distribution, free living stage dispersal as well as environmental conditions (Bush et al., 2001). An aggregated distribution is the most frequent pattern observed for parasites in the wild and can indicate social interactions for the purpose of mating, feeding cooperation or defence (Bush et al., 2001). All species exhibited highly aggregated patterns, and *S. mansoni* and *L. chagasfilhoi* may follow the aggregated distribution of their intermediate hosts, *B. glabrata* (Giovannelli et al., 2001) and *Ornithonyssus bacoti* (Renz & Wenk, 1981). *Litomosoides chagasfilhoi* is transmitted by haematophagous arthropods and infection by the *Litomosoides* genus occurs when

Table 3. Correlation coefficients between helminth intensities in *Nectomys squamipes*.

	<i>Hassalstrongylus epsilon</i>	<i>Physaloptera bispiculata</i>	<i>Syphacia venteli</i>	<i>Litomosoides chagasfilhoi</i>	<i>Schistosoma mansoni</i>	<i>Echinostoma paraensei</i>
<i>P. bispiculata</i>	n = 35, P = 0.50 R = 0.116					
<i>S. venteli</i>	n = 39, P = 0.70 R = -0.062	n = 26, P = 0.59 R = 0.110				
<i>L. chagasfilhoi</i>	n = 8, P = 0.56 R = 0.243	n = 6, P = 0.82 R = -0.123	n = 5, P = 0.22 R = 0.667			
<i>S. mansoni</i>	n = 30, P = 0.007 R = -0.485	n = 18, P = 0.80 R = -0.062	n = 6, P = 0.23 R = 0.577	n = 3		
<i>E. paraensei</i>	n = 4	n = 6, P = 0.80 R = 0.137	n = 1	n = 2	n = 4	
<i>Railletina</i> sp.	n = 2	n = 0	n = 0	n = 0	n = 1	n = 0

n, sample size; P, significance; R, correlation coefficient.

Table 4. Prevalence values (%) of each helminth species, relative to the abundance of *Nectomys squamipes* and trapping periods from April 1997 to April 1999.

Month/year	Number of hosts	Helminth species						
		<i>Hassalstrongylus epsilon</i>	<i>Physaloptera bispiculata</i>	<i>Syphacia venteli</i>	<i>Litomosoides chagasfilhoi</i>	<i>Schistosoma mansoni</i>	<i>Echinostoma paraensei</i>	<i>Raillietina</i> sp.
1997								
April	16	87.5	31.2	81.2	12.5	43.8	6.7	6.2
July	14	85.7	35.7	64.3	14.3	35.7	7.1	0
September	12	91.7	58.3	66.7	8.7	25.0	16.7	8.3
November	6	83.3	66.7	66.7	0	50.0	0	0
1998								
January	8	37.5	37.5	37.5	12.5	12.5	0	0
March	4	0	50.0	100	0	50.0	50.0	0
May	6	83.3	66.7	33.3	16.7	50.0	16.7	0
July	5	100	0	40.0	0	40.0	0	0
September	2	100	50.0	50.0	0	100	50.0	0
November	7	42.8	42.8	14.3	0	42.8	0	0
1999								
January	7	57.1	71.4	14.3	0	28.7	0	0
March	8	50.0	62.5	37.5	0	50.0	0	0
May	12	25.0	8.3	16.6	0	25.0	0	0
August	8	37.5	25.0	25.0	50	0	12.5	0

infected mites bite the rodent, transmitting the third stage larvae (Renz & Wenk, 1981). *Nectomys squamipes* hosts at least four species of mites, all potential vectors of *L. chagasfilhoi* (Guitton *et al.*, 1986). *Syphacia venteli*, the most aggregated species, has a direct life cycle without an intermediate host, and its distribution is related to the host.

*Nectomys squamipes* has also been shown to be aggregated in its distribution (Almeida *et al.*, 2000). Females of *S. venteli* usually deposit their eggs in the perianal region of the rat which facilitates direct transmission and constant reinfection. *Echinostoma paraensei* can be potentially transmitted by at least three species of snails found in abundance and clumped in their distribution in the water rat habitat in Sumidouro (Maldonado Jr. *et al.*, 2001c). In addition, this helminth can reproduce by self-fertilization (Nollen, 1996). *Physaloptera bispiculata* may have followed the distribution of its intermediate host, probably an insect (Hobmaier, 1941), whereas *Raillietina* sp. is transmitted to birds and reptiles by ingestion of insect intermediate hosts, which are probably aggregated. *Hassalstrongylus epsilon* is a geohelminth and does not have an intermediate host. Eggs of *H. epsilon* are deposited in specific areas in the soil and the host becomes infected when it has contact with infective larvae. Some of these characteristics of the transmission cycles of those helminths are related to the food web of the host *N. squamipes*, thus contributing to the helminth community structure.

The structure of the helminth community may in part be determined by host–parasite and parasite–parasite interactions within the host (Poulin, 2001) or environmental factors (Abu-Madi *et al.*, 2000). The dominant status of *S. mansoni* in the community, and a similar status for *H. epsilon*, *P. bispiculata* and *S. venteli*, could be determined by the peculiarities of its interaction with the highly susceptible *N. squamipes* or interspecific interactions between the parasite species. The single cestode species

*Raillietina* sp. from *N. squamipes* was found on only two occasions, probably as a result of accidental infections but, as fully mature worms were recovered, this species was classified as subordinate.

No direct interaction could be observed in the intensities and prevalences of these helminth species. This might suggest that helminth communities of the water rat are well established, even in the presence of the exotic species *S. mansoni* conferring the dominant status of four of the seven helminth species found. In the UK, Behnke *et al.* (2005) also found no interactions between the helminth community of the wood mouse, *Apodemus sylvaticus*. On the other hand, Maldonado *et al.* (2001a) showed a synergistic interaction between *S. mansoni* and *E. paraensei* under laboratory conditions. Infection of *N. squamipes* by *S. mansoni* facilitated the establishment of *E. paraensei* and prolonged the life span in the infected vertebrate host. Maldonado *et al.* (2001a) showed experimentally that a primary infection with *E. paraensei* in *N. squamipes* declined following a *S. mansoni* challenge infection.

Maldonado *et al.* (1994) also showed that *N. squamipes* can be reinfected by *S. mansoni* without causing any significant pathology to the rat other than peri-ovular modulation and low tissue damage (Silva *et al.*, 2002). The population dynamics of the rat are also unaffected (D'Andrea *et al.*, 2000). Previous studies by D'Andrea *et al.* (2000, 2002) have demonstrated a high susceptibility of *N. squamipes* to *S. mansoni* infections, without influencing longevity nor fecundity in the rat. *Nectomys squamipes* deposits viable eggs of *S. mansoni* in the faeces with a high infectivity potential during its entire life, confirming its role as a reservoir for schistosomiasis. Thus, this exotic species is completely established in the natural helminth community of the water rat and has adapted to the host, influencing neither host abundance nor the occurrence of other helminth species.

The fact that *S. mansoni* is a parasite of the blood system of the host, a habitat not occupied by other helminth species other than the microfilariae of *L. chagasfilhoi*, may have determined low levels of interspecific interactions. Further studies on helminth communities of the water rat without *S. mansoni* may clarify the importance of interspecific relationships between helminths in natural populations of this rodent host.

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