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New host records and a checklist of fishes infected with *Austrodiplostomum compactum* (Digenea: Diplostomidae) in Brazil

Novos registros de hospedeiros e "checklist" de peixes infectados por *Austrodiplostomum compactum* (Digenea: Diplostomidae) no Brasil

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Abstract

This study reports the infection of fishes by *Austrodiplostomum compactum* metacercariae in the Chavantes reservoir, medium Paranapanema River, municipality of Ipaussu, São Paulo State, Brazil. Twenty-three fish species were analysed, and 13 were infected with *A. compactum* metacercariae (56.5%) in their eyes. The following six fish species are new hosts for this metacercaria: *Crenicichla haroldoi* (1/1), *Eigenmannia trilineata* (11/6), *Hoplosternum littorale* (11/1), *Iheringichthys labrosus* (17/2), *Leporinus amblyrhynchus* (11/1), and *Piaractus mesopotamicus* (3/1). These new species increase the number of Brazilian fish species infected with this parasite to 36. Based on these findings, we hypothesise that the metacercariae larval stage of the parasite has a low specificity for the second intermediate host (fish). The majority of fish species infected in Brazil belong to the Loricariidae and Cichlidae families. For the fish species with higher mean abundances in Brazil, six are non-native species, and currently, *Plagioscion squamosissimus* has the highest mean abundance. The majority of fish species infected with *A. compactum* in Brazil are concentrated in the Paraná basin, although this may be related to the distribution of researchers.

Keywords: Freshwater fishes, parasite, Trematoda, metacercariae, infection, Paraná basin.

Resumo

Este estudo relata a infecção por metacercárias de *Austrodiplostomum compactum* em peixes do reservatório de Chavantes, médio Paranapanema, Ipaussu, São Paulo, Brasil. Vinte e três espécies de peixes foram analisadas, e 13 estavam infectadas com metacercárias (56,5%) em seus olhos. Seis espécies de peixes foram registradas como novos hospedeiros: *Crenicichla haroldoi* (1/1), *Eigenmannia trilineata* (11/6), *Hoplosternum littorale* (11/1), *Iheringichthys labrosus* (17/2), *Leporinus amblyrhynchus* (11/1), and *Piaractus mesopotamicus* (3/1), aumentando para 36 o número de peixes brasileiros infectados por este parasita. Assim, inferimos que este estágio larval do parasita possui baixa especificidade parasitária em relação ao seu segundo hospedeiro intermediário (peixes). No Brasil, a maioria das espécies de peixes infectadas pertence às famílias Loricariidae e Cichlidae. Quanto às espécies de peixes com as maiores abundâncias médias no Brasil, seis são espécies não-nativas, sendo *Plagioscion squamosissimus* a espécie com a maior abundância média. Ainda, a maioria das espécies de peixes infectadas por *A. compactum* no Brasil, estão concentradas na bacia do Paraná, sendo este fato possivelmente relacionado com a distribuição de pesquisadores.

Palavras-chave: Peixes de água doce, parasita, Trematoda, metacercária, infecção, bacia do Paraná.

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Introduction

Eye fluke diplostomids have complex life cycles, involving three hosts, of which two are intermediate and one is definitive (KARVONEN et al., 2006; VIOLANTE-GONZÁLEZ et al., 2009), and parasitise several fish species in the world (EIRAS, 1994). *Austrodiplostomum compactum* (Lutz, 1928) is widely distributed in the Neotropical region, and *A. compactum* metacercaria parasitise several species of Brazilian freshwater fishes.

The *A. compactum* cercariae (first larval stage) infect aquatic snails and molluscs of the genus *Biomphalaria* Preston, 1910 in Mexico (VIOLANTE-GONZÁLEZ et al., 2009) and Brazil (PINTO; MELO, 2013). *Diplostomum* and *Austrodiplostomum* metacercariae are frequently found in the eyes of freshwater fishes, which are the second intermediate hosts during the life cycle of the parasite (SEPPÄLÄ et al., 2004). The adult stage parasitises the digestive tract of piscivorous birds, and *Phalacrocorax brasilianus* (Gmelin, 1789) [=*Phalacrocorax olivaceus*] is considered definitive host of this digenean in Brazil (TRAVASSOS et al., 1969; NORONHA et al., 2009; MONTEIRO et al., 2011).

According to Eiras (1994) and Seppälä et al. (2005), the presence of Diplostomidae metacercariae in eyes of fishes can cause loss of vision, blindness and increases the coverage of cataracts of the lens area in fish with high rates of infection. This makes the fish more susceptible to predation and facilitates the transmission of the parasite to the definitive hosts (SEPPÄLÄ et al., 2004).

However, a few Brazilian fish species were evaluated for the presence of *A. compactum* metacercariae and their possible effects. This study reports the occurrence of *A. compactum* in fish species from the Paranapanema River and its parasitological indexes, as well as several considerations regarding ecological aspects and a checklist for fishes parasitised in Brazil.

Materials and Methods

This study was conducted in the Chavantes reservoir (medium Paranapanema River), municipality of Ipaussu, São Paulo State, Brazil (23° 07' 36" S and 49° 59.23' 10" W) (Figure 1 and Table 1). Fish samples were collected monthly from March 2009 to February 2010 using gillnets (3 to 14 cm meshes between adjacent nodes) with 14 hours of exposure (from 5:00 PM to 7:00 AM). All

Table 1. Physical and chemical characteristics (mean and standard error) of the sampling sites in the Chavantes Reservoir, municipality of Ipaussu, São Paulo State, southeast Brazil from Carvalho et al. (2012a).

Sites	Values ± SE
Water temperature (°C)	23.8±2.5
Water transparency (m)	3.1±0.8
Dissolved oxygen (mg O_2.L^{-1})	8.2±1.7
pH	7.1±0.3
Conductivity (μS.cm^{-1})	40.3±6.2
Depth (m)	11.7±0.4
Chlorophyll a (μg.L^{-1})	1.9±1.3
Total P (μg.L^{-1})	9.7±4.1
Total N (μg.L^{-1})	236.0±78.7

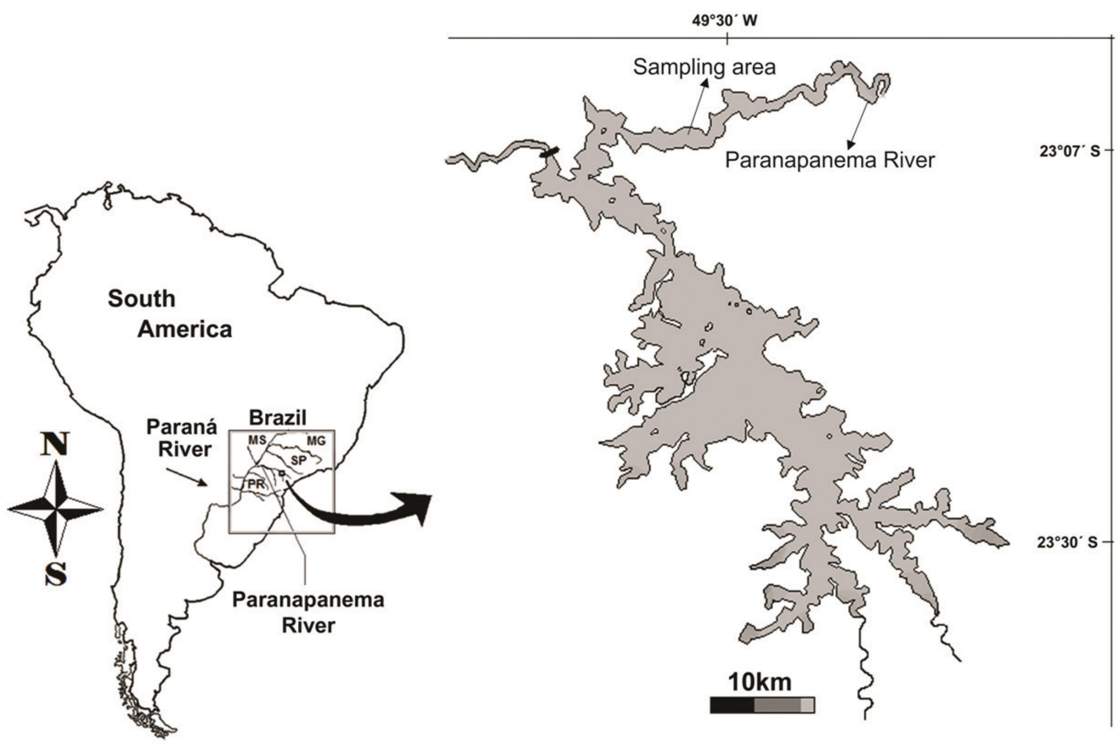

Figure 1. Map of the hydrographical network in São Paulo State highlighting the Chavantes reservoir and sampling location on the Paranapanema River in the municipality of Ipaussu, São Paulo State, southeast Brazil.

captured fishes were frozen and transported to the laboratory where their eyes were removed and examined with a stereomicroscope. The metacercariae were collected from the vitreous humour, fixed in 70% alcohol under cover slip pressure and preserved in 70% alcohol (EIRAS et al., 2006). The metacercariae were stained with carmine and cleared with eugenol for identification. Morphological analyses were performed with a computerised system for image analysis (Qwin Lite 3.2 – Leica Microsystems, Wetzlar, Germany).

Twenty-three fish species were analysed: 'peixe-cachorro', *Acestrorhynchus lacustris* n=33 (Lütken, 1875), 'canivete', *Apareiodon affinis* n=41 (Steindachner, 1879), 'lambari-do-rabo-amarelo', *Astyanax altiparanae* n=37 Garutti & Britski, 2000, 'lambari-do-rabo-vermelho', *Astyanax fasciatus* n=30 (Cuvier, 1819), 'saguiru-do-rabo-vermelho', *Cyphocharax modestus* n=1 (Fernández-Yépez, 1948), 'peixe-cadela', *Galeocharax knerii* n=32 (Steindachner, 1879), 'traíra', *Hoplias malabaricus* n=9 (Bloch, 1794), 'piava', *Leporinus amblyrhynchus* n=11 Garavello & Britski, 1987, 'ferreirinha', *Leporinus octofasciatus* n=1 Steindachner, 1915, 'pacu', *Piaractus mesopotamicus* n=3 (Holmberg, 1887), 'ximborê', *Schizodon nasutus* n=17 Kner, 1858, 'piranha', *Serrasalmus maculatus* n=21 Kner, 1858, 'sardela', *Triportheus nematurus* n=6 (Kner, 1858), 'caborja', *Hoplosternum littorale* n=11 (Hancock, 1828), 'cascudo', *Hypostomus regani* n=4 (Ihering,1905), 'mandiuva', *Iheringichthys labrosus* n=17 (Lütken, 1874), 'mandi-guaçu', *Pimelodus maculatus* n=34 Lacépède, 1803, 'bagre', *Rhamdia quelen* n=1 (Quoy & Gaimard, 1824), 'tucunaré', *Cichla kelberi* n=42 Kullander & Ferreira, 2006, 'joaninha', *Crenicichla haroldoi* n=1 Luengo & Britski, 1974, 'acará', *Geophagus brasiliensis* n=2 (Quoy & Gaimard, 1824), 'corvina', *Plagioscion squamosissimus* n=30 (Heckel, 1840), and 'tuvira', *Eigenmannia trilineata* n=11 López & Castello, 1966.

The prevalence, mean intensity of infection and mean abundance were calculated according to Bush et al. (1997) for fish species with at least nine specimens collected. Parasite voucher specimens were deposited in the Coleção Helmintológica do Departamento de Parasitologia (CHIBB 6723, 6974-6985) at the Instituto de Biociências, Universidade Estadual Paulista (IB/UNESP), municipality of Botucatu, São Paulo State, Brazil. Fish voucher specimens were identified and deposited by Dr. Cláudio de Oliveira in the Coleção do Laboratório de Biologia e Genética de Peixes (LBP 4797, 9192, 9174, 9179, 9181, 9183, 9184, 9185, 9186, 9191, 9194) at IB/UNESP and the Coleção Ictiológica do Nupélia (NUP 6117), Universidade Estadual de Maringá, municipality of Maringá, Paraná State, Brazil.

A review of the fishes infected with *A. compactum* in Brazil was performed using books (EIRAS et al., 2010) and by searching databases (SciELO, ISI, Scopus and Google Scholar). When available, data regarding the prevalence, mean intensity of infection and mean abundance along with their errors or standard deviations were added to the Table. In cases where these data do not exist but data does exist that enable their calculations, we performed the calculations according to the method described by Bush et al. (1997).

Results

In the present study, the fish collected in the Paranapanema River showed a total of 357 *A. compactum* metacercariae, recovered from 43 fish specimens. Thirteen fish species were infected by at least one parasite (56.5% of the fish species analysed), *C. kelberi, C. haroldoi, E. trilineata, G. brasiliensis, H. regani, H. littorale, H. malabaricus, I. labrosus, L. amblyrhynchus, P. mesopotamicus, P. maculatus*, *P. squamosissimus,* and *S. nasutus*, of which, two were non-native species, *C. kelberi* and *P. squamosissimus*.

Of the thirteen species of fish parasitised (192 specimens), the prevalence was 22.3% (43 fishes). Six freshwater fish species were identified as new hosts for *A. compactum* metacercariae, *C. haroldoi, E. trilineata, H. littorale, I. labrosus, L. amblyrhynchus,* and *P. mesopotamicus,* totalling 46.2% of the infected fish species and 26.1% for all the fish species analysed. Three fish orders, Characiformes, Perciformes, and Siluriformes had four parasitised fish species, and Gymnotiformes had one infected fish species. The Cichlidae family had three infected species (23.1%), followed by Pimelodidae and Anostomidae, with two infected species each (15.4%) (Table 2).

The overall prevalence was 10.9%, and the highest prevalence was observed in *P. squamosissimus* (66.6%), followed by *E. trilineata* (54.5%) and *I. labrosus* (11.8%). The mean intensity of infection and mean abundance were low for all fish species, with *P. squamosissimus* having the highest values (13.1±6.1 and 8.7±4.2, respectively). All other fish species had values less than or equal to 2.0 for the mean intensity of infection and less than 1.0 for the mean abundance (Table 2).

Austrodiplostomum compactum metacercariae parasitised 36 Brazilian fish species and two taxa not identified (*Cichla* sp. and *Hypostomus* sp.) belonging to 13 families and four orders. The reports identified the fish species as follows: Characiformes (families: Anostomidae, three species; Curimatidae, one species; Erythrinidae, one species; and Serrasalmidae, four species); Siluriformes (families: Auchenipteridae, two species; Callichthyidae, one species; Loricariidae, eight species; and Pimelodidae, three species); Gymnotiformes (families: Gymnotidae, one species; and Sternopygidae, one species); and Perciformes (families: Centropomidae, one species; Cichlidae, 10 species; and Sciaenidae, one species). Eight infected fish species are non-native according to Langeani et al. (2007): *Cichla* sp., *C. kelberi*, *C. ocellaris*, *G. proximus*, *G. surinamensis*, *Metynnis maculatus*, *P. squamosissimus* and *Satanoperca pappaterra* (Table 2).

Of the 36 fish species parasitised, only eight showed a mean abundance higher than five metacercariae. Of these fishes, six are non-native species of the order Perciformes. The non-native species, *P. squamosissimus* had the highest mean abundance of all the parasitised species (Table 2). The Paranapanema River showed the highest number of parasitised fish species (21), followed by the Paraná River (nine species), Tietê and Guandu Rivers (seven species each) and Grande River (two species). The other rivers had one fish infected species each (Table 2).

Discussion

Austrodiplostomum compactum metacercariae have been recorded in a wide variety of Brazilian fishes (Table 2). This study demonstrated that 56.5% of all fish species collected were infected. These fish species belong to four orders, Characiformes,

Table 2. List of fish species reported as an intermediate host of *Austrodiplostomum compactum* metacercariae in Brazil. Number of specimens examined (N), prevalence (P), mean intensity of infection (MII), mean abundance (MA) and site of infection (SI).

Taxa	N	P(%)	MII	MA	SI	State/River	References
Order Characiformes							
Family Erythrinidae							
Hoplias malabaricus (Bloch, 1794)*	9	11.1	1.0	0.1±0.1	E	SP/Paranapanema	present study
*Hoplias malabaricus***	198	11.1	1.4±1.3	0.2±0.6	E/CC	PR/Paraná	Machado et al. (2005)
Hoplias malabaricus	7	14.3	9.0	1.3	E	SP/Tietê	Paes et al. (2010b)
Hoplias malabaricus	28	60.7	32.6	19.8	E	PR/Paraná	Santos et al. (2012)
Hoplias malabaricus	10	57.1	2.5	1.4	E	MG/Doce	Belei et al. (2013)
Family Serrasalmidae							
Metynnis maculatus (Kner, 1858)£	298	0.3	1	0.003	E	SP/Tietê	Paes et al. (2010b)
Piaractus mesopotamicus (Holmberg, 1887)*§	3	33.3	6.0	2.0±2.0	E	SP/Paranapanema	present study
Pygocentrus nattereri Kner, 1858*	40	15.0	1.6±0.7	0.1±0.7	M	AM/Solimões	Morais et al. (2011)
Serrasalmus maculatus Kner, 1858	3	33.3	1.0	0.3	E	PR/Paranapanema	Yamada et al. (2008)
Family Anostomidae							
Leporinus amblyrhynchus Garavello & Britski, 1987*§	11	9.1	2.0	0.2±0.2	E	SP/Paranapanema	present study
Schizodon borellii (Boulenger, 1900) †	-	-	-	-	-	PR/Paraná	Pavanelli et al. (1997)
Schizodon borellii	15	6.6	2.0	0.1	E	PR/Paranapanema	Yamada et al. (2008)
Schizodon nasutus Kner, 1858*	17	5.9	2.0	0.1±0.1	E	SP/Paranapanema	present study
Schizodon nasutus	84	4.8	1.2	0.05	E	SP/Tietê	Paes et al. (2010b)
Family Curimatidae							
Cyphocharax gilbert (Quoy & Gaimard, 1824)	60	1.6	1.0	0.01	E	RJ/Guandu	Abdallah et al. (2005)
Order Siluriformes							
Family Auchenipteridae							
Auchenipterus osteomystax (Miranda Ribeiro, 1918)	2	50.0	1.0	0.5	E	PR/Paranapanema	Yamada et al. (2008)
Trachelyopterus striatulus (Steindachner, 1877)*	60	1.6	1.0±0.5	0.02±0.3	E	RJ/Guandu	Mesquita et al. (2011)
Family Callichthyidae							
Hoplosternum littorale (Hancock, 1828)*§	11	9.1	1.0	0.1±0.1	E	SP/Paranapanema	present study
Family Loricariidae							
Hypostomus sp.*	5	40.0	17.5±16.5	7.0±6.8	E	SP/Paranapanema	Zica et al. (2011)
Hypostomus affinis (Steindachner, 1877)	31	-	-	-	-	RJ/Guandu	Azevedo et al. (2010)
Hypostomus hermanni (Ihering, 1905)	1	100	27.0	27.0	E	SP/Paranapanema	Zica et al. (2011)
Hypostomus iheringii (Regan, 1908)*	28	64.3	13.1±3.2	8.4±2.4	E	SP/Paranapanema	Zica et al. (2011)
Hypostomus margaritifer (Regan, 1908)	1	100	35.0	35.0	E	SP/Paranapanema	Zica et al. (2011)
Hypostomus regani (Ihering, 1905)*	4	50.0	21.0±18.0	10.5±9.5	E	SP/Paranapanema	present study
Hypostomus regani	8	25.0	0.5	0.1	E	PR/Paranapanema	Yamada et al. (2008)
Hypostomus regani	1	100	1.0	1.0	E	SP/Paranapanema	Zica et al. (2009)
Hypostomus regani	3	33.3	10.0	3.3±3.3	E	SP/Paranapanema	Zica et al. (2011)
Hypostomus strigaticeps (Regan, 1908)*	45	24.4	10.3±2.4	2.7±0.9	E	SP/Paranapanema	Zica et al. (2011)
Loricariichthys castaneus (Castelnau, 1855)*	30	30	13.6	4.1±10.4	E	RJ/Paraiba do Sul	Paraguassú and Luque (2007)
Family Pimelodidae							
Conorhynchos conirostris (Valenciennes, 1840)*	24	8.3	7.5±9.2	0.6±0.4	G/E	MG/S. Francisco	Brasil-Sato and Santos (2005)
Iheringichthys labrosus (Lütken, 1874)*§	17	11.8	1.0±0.0	0.1±0.08	E	SP/Paranapanema	present study
Pimelodus maculatus Lacepède, 1803*	34	5.9	2.0±1.0	0.1±0.1	E	SP/Paranapanema	present study
Pimelodus maculatus†	239	20.5	4.0	0.8	SB/K/G	MG/São Francisco	Brasil-Sato and Pavanelli (2004)
Pimelodus maculatus†	229	1.3	1.0	0.01	SB/K/G	PR/Paraná	Brasil-Sato and Pavanelli (2004)
*Pimelodus maculatus***†	28	17.0	1	0.2±0.4	E	SC/Itajaí-Açu	Bachmann et al. (2007)
Pimelodus maculatus	60	16.6	1.1	0.2	E	RJ/Guandu	Santos et al. (2007)
Pimelodus maculatus	40	-	-	-	-	RJ/Guandu	Azevedo et al. (2010)

* The values are presented as the mean and standard error; ** the values are presented as the mean and standard deviation; £ non-native fish species; § new host; † parasite identified as *Austrodiplostomum* sp. or *Diplostomum* sp.; E eye; CC cranial cavity; G gills; M muscle; SB swimming bladder; K kidney; CF cage farm; CT control.

Table 2. Continued...

Taxa	N	P(%)	MII	MA	SI	State/River	References
Order Gymnotiformes							
Family Gymnotidae							
Gymnotus carapo Linnaeus, 1758	30	-	-	-	-	RJ/Guandu	Azevedo et al. (2010)
Family Sternopygidae							
Eigenmannia trilineata López & Castello, 1966*§	11	54.5	1.3±0.2	0.7±0.2	E	SP/Paranapanema	present study
Order Perciformes							
Family Centropomidae							
Centropomus undecimalis (Bloch, 1792)	31	-	-	-	-	RJ/Guandu	Azevedo et al. (2010)
Family Cichlidae							
Cichla sp.£	23	52.2	5.9	3.1	E	PR/Paraná	Santos et al. (2012)
Cichla kelberi Kullander & Ferreira, 2006*£	42	7.1	2.0±0.6	0.1±0.1	E	SP/Paranapanema	present study
Cichla kelberi (=*C. monoculus*)£	136	5.2	2.7	0.1	E	PR/Paraná	Machado et al. (2000)
Cichla kelberi (=*C. monoculus*)**£	40	65.0	7.8±13.0	5.1±11.1	E/CC	PR/Paraná	Machado et al. (2005)
Cichla ocellaris Bloch & Schneider, 1801£	66	10.6	6.3	0.6	E	MG/Grande	Martins et al. (2002)
Cichla ocellaris£	81	55.5	9.3	5.2	E	SP/Paraná	Santos et al. (2002)
Cichla piquiti£†	27	0.3	13.4	3.5	E	PR/Paraná	Lacerda et al. (2013)
Cichla piquiti†	24	0.1	1.0	0.1	E	TO/Tocantins	Lacerda et al. (2013)
Cichlasoma paranaense Kullander, 1983**	25	12.0	1.0±0.0	0.1±0.3	E	PR/Paraná	Machado et al. (2005)
Crenicichla britskii Kullander, 1982**	44	22.7	6.2±9.0	1.4±4.9	E/CC	PR/Paraná	Machado et al. (2005)
Crenicichla haroldoi Luengo & Britski, 1974§	1	100	6.0	6.0	E	SP/Paranapanema	present study
Geophagus brasiliensis (Quoy & Gaimard, 1824)*	2	100	8.0±5.0	8.0±5.0	E	SP/Paranapanema	present study
*Geophagus brasiliensis**	50	14.0	1.6±1.1	0.2±0.2	E	RJ/Guandu	Azevedo et al. (2006)
Geophagus brasiliensis	1	100	1.0	1.0	E	SP/Tietê	Novaes et al. (2006)
*Geophagus brasiliensis**	200	18.0	2.1±1.4	0.4±1.0	E/SB	RJ/Guandu	Carvalho et al. (2010)
Geophagus brasiliensis	64	3.1	4.0	0.1	E	PR/several rivers	Bellay et al. (2012)
*Geophagus brasiliensis**	200	18.0	2.1±1.4	0.4±1.0	E/SB	RJ/Guandu	Carvalho et al. (2012b)
Geophagus proximus (Castelnau, 1855)* £	41	92.7	12.8±5.1	11.8±4.7	E	SP/Tietê	Zica et al. (2010)
*Geophagus proximus**£	116	58.6	3.6±0.5	2.1±0.3	E	SP/S. J. Dourados	Zago et al. (2013)
Geophagus surinamensis (Bloch, 1791)£	40	45.0	13.8	6.2	E	PR/Paraná	Santos et al. (2012)
Satanoperca pappaterra (Heckel, 1840)£ †	-	-	-	-	-	PR/Paraná	Pavanelli et al. (1997)
Satanoperca pappaterra (Heckel, 1840)** £	89	71.9	8.0±8.6	5.8±8.1	E/CC	PR/Paraná	Machado et al. (2005)
Satanoperca pappaterra£	25	60.0	6.4	3.8	E	SP/Tietê	Paes et al. (2010b)
Family Sciaenidae							
Plagioscion squamosissimus (Heckel, 1840)* £	30	66.7	13.1±6.1	8.7±4.2	E	SP/Paranapanema	present study
Plagioscion squamosissimus£	17	100.0	2-100/eye		E	PR/Paraná	Kohn et al. (1995)
Plagioscion squamosissimus£	-	-	-	-	-	PR/Paraná	Pavanelli et al. (1997)
Plagioscion squamosissimus£	68	45.6	7.1	3.2	E	MG/Grande	Martins et al. (1999)
Plagioscion squamosissimus£	70	52.8	5.3	2.8	E	MG/Grande	Martins et al. (2002)
Plagioscion squamosissimus£	61	91.8	42.0	38.5	E	SP/Paraná	Santos et al. (2002)
*Plagioscion squamosissimus***£	81	95.1	38.9±64.3	37.0±63.2	E/CC	PR/Paraná	Machado et al. (2005)
Plagioscion squamosissimus£	378	94.2	21.7	20.4	E	SP/Tietê	Paes et al. (2010a)
Plagioscion squamosissimus£	213	90.1	20.8	18.7	E	SP/Tietê	Paes et al. (2010b)
Plagioscion squamosissimus£	61	36.1	-	-	E	PR/Paraná	Kohn et al. (2011)
*Plagioscion squamosissimus***£†	35	88.6	98.8	87.5±153.3	E	PR/Paraná	Lacerda et al. (2012)
*Plagioscion squamosissimus***†	35	40.0	10.8	4.3±7.8	E	AM/Solimões	Lacerda et al. (2012)
*Plagioscion squamosissimus***†	35	8.3	2.9	0.1±0.5	E	TO/Tocantins	Lacerda et al. (2012)
Plagioscion squamosissimus£	57	98.0	42.7	41.9	E	PR/Paraná	Santos et al. (2012)
Plagioscion squamosissimus CF*£	37	86.4	20.3±1.1	17.7±6.3	E	SP/Paranapanema	Ramos et al. (2013)
Plagioscion squamosissimus CT*£	28	57.1	4.3±7.1	2.3±0.8	E	SP/Paranapanema	Ramos et al. (2013)

* The values are presented as the mean and standard error; ** the values are presented as the mean and standard deviation; £ non-native fish species; § new host; † parasite identified as *Austrodiplostomum* sp. or *Diplostomum* sp.; E eye; CC cranial cavity; G gills; M muscle; SB swimming bladder; K kidney; CF cage farm; CT control.

Perciformes, Siluriformes and Gymnotiformes, and six new records of hosts to these metacercariae. Thus, the number of Brazilian fish species infected by *A. compactum* increased to 36, and the number of families parasitised for 13. Based on these observations, we hypothesise that this larval stage of the parasite has a low specificity for the second intermediate host (fish), similar to that reported by Yamada et al. (2008). In addition, the six new hosts identified in the present study demonstrates that parasitological studies with fish communities should significantly expand the list of fish identified as second intermediate hosts for *A. compactum*.

The mean intensity of infection for the analysed fish species was lower than Höglund and Thulin (1990), who reports that fish harbouring more than 40 *Diplostomum* metacercariae on their eyes are largely parasitized. According to several authors, the high infection rate with diplostomid metacercariae in fish can cause blindness or visual impairment (EIRAS, 1994), cataracts (SHARIFF et al., 1980; KARVONEN et al., 2004), problems with a food intake and growth (OWEN et al., 1993) and increased susceptibility to predation (CROWDEN; BROOM, 1980; SEPPÄLÄ et al., 2004). However, Karvonen et al. (2004) and Owen et al. (1993) report effects in fish with less than 10 *Diplostomum spathaceum* metacercariae (Rudolphi, 1819) and correlations between the number of metacercariae and the intensity of the effect. Another study reported that fish heavily infected with *D. spathaceum* occupied surface waters with more frequency, exposing them to higher levels of predation by birds. Therefore, fish with high infection rates would be subject to the effects of parasitism by *A. compactum* metacercariae, and fish with low infection show less intense effects of parasitism. Among these effects is the difficulty to detect prey, which results in fitness consequences for the individual (OWEN et al., 1993).

The prevalence of *A. compactum* in the present study is low, with exception of the prevalence in *E. trilineata* and *P. squamosissimus*. Studies of the infection of *A. compactum* in *P. squamosissimus* showed a prevalence greater than 90% and a mean intensity of infection greater than 20 (KOHN et al., 1995; SANTOS et al., 2002, 2012; MACHADO et al., 2005; PAES et al., 2010a, b), whereas in the current study, the prevalence was 66.6% and the mean intensity of infection was 13.1±6.1. According to Karvonen et al. (2006), the infection dynamics of *D. spathaceum* in fish is related to the snail population variance. Voutilainen et al. (2009) found a positive correlation between *Lymnaea stagnalis* (Linnaeus, 1758) density (an intermediate host for *Diplostomum* spp. in Finland) and *Diplostomum* sp. prevalence in lakes and ponds in Finland. Additionally, Martins et al. (2002) and Santos et al. (2002, 2012) suggested that high infection rates of *A. compactum* are dependent on high temperatures. According to Berrie (1960), *Diplostomum* cercariae emerge in waters only at temperatures greater than 10 °C. Despite the high water temperature observed in the current study location (CARVALHO et al., 2012a), which may lead to a high intensity of infection, the values of water transparency, conductivity and chlorophyll *a* (Table 1), suggest a small quantity of available nutrients in the local aquatic ecosystem. This can limit the size of the snail populations (first intermediate hosts), leading to the low values observed for the prevalence, mean intensity of infection and mean abundance for the majority fish species analysed.

The majority of fish species infected with *A. compactum* metacercariae in Brazil belong to the Perciformes (12 species), Siluriformes (13 species), and Characiformes (nine species), and the Cichlidae (10 species) and Loricariidae (eight species) families were the most infected. However, the other fish species analysed in this study also live in this habitat and were not infected. Therefore, the absence of *A. compactum* metacercariae infection in these fish species may be related to species-specific characteristics, which remain unknown.

For the fish species with higher mean abundances in Brazil, six are non-native species, and currently, *P. squamosissimus* has the highest mean abundance. This was also demonstrated by Pojmanska and Chabros (1993), who showed that the prevalence of diplostomids was significantly lower in native fishes than non-native fishes. However, Lacerda et al. (2012) demonstrated an inverse situation in which the native fish *H. malabaricus* showed a higher abundance of *Austrodiplostomum* sp. than the introduced *P. squamosissimus*. Lacerda et al. (2012) also demonstrated that *P. squamosissimus* in native regions showed a prevalence and abundance of diplostomids that was significantly lower than *P. squamosissimus* in the region where they were introduced. According to Lacerda et al. (2012), migratory birds, such as *P. brasilianus* are the final hosts for *Austrodiplostomum*; therefore, geographic barriers for the parasite may be reduced or eliminated. Rather than introducing a new parasite, *P. squamosissimus* may be acting as a new and suitable host for a local parasite. This may also occur with other species of fish, such as the six non-native Brazilian fish species, which had higher abundances.

The majority of infected fish species are in the Paranapanema River. Specifically, the Paraná basin is the most studied region for *A. compactum* in Brazil, and this is possibly related to the distribution of researchers in Brazil. Despite the large number of studies, further investigations are necessary to understand the relationship between environmental aspects and life strategies because diplostomiasis causes large aquaculture losses each year worldwide (PAPERNA; DZIKOWSKI, 1995; OVERSTREET; CURRAN, 2004).

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