Metacercariae of *Austrodiplostomum compactum* (Trematoda, Diplostomidae) in non-native fish species in Brazil: a possible explanation for the high rate of parasitic infection

IGOR P. RAMOS, CIBELE D. PAGLIARINI, LIDIANE FRANCESCHINI & REINALDO J. DA SILVA

Abstract: Metacercariae of Diplostomidae are widely distributed in America and may cause diplostomiasis, an ocular disease in fishes. The aim of this study is to report the occurrence of metacercariae of *Austrodiplostomum compactum* in *Plagioscion squamosissimus* (non-native fish species) from Nova Avanhandava Reservoir, Tietê River, Brazil and an explanation for the high infection rates with this parasite in the Paraná River Basin is proposed. Eyes of 70 hosts were examined, the metacercariae were preserved and identified. The prevalence (P), mean intensity of infection (MII) ± standard deviation, mean abundance (MA) ± standard deviation, were calculated and a bibliographic review was performed. There was no difference in parasitism between male and female hosts. The values of P = 80%, MII = 21.55 ± 3.25 and MA = 17.24 ± 2.91 were high, as in most studies in areas where *P. squamosissimus* were introduced, while these values were low in areas of natural occurrence. This may be explained by the genetic susceptibility of the host to the parasite. The entire population of *P. squamosissimus* from the Upper Paraná has been founded by a few specimens, resulting in very low genetic variability. Consequently, the population may be highly susceptible to *A. compactum*.

Key words: introduced species, fish parasite, eye-fluke, corvina, Sciaenidae, Tietê River Basin.

INTRODUCTION

Metacercariae of Diplostomidae are widely distributed in the Americas (Ramos et al. 2013, García-Varela et al. 2016). Ocular diplostomiasis is a parasitic disease that affects reared and wild fish (Pinto & Melo 2013) caused by metacercariae, which at high densities may result in blindness and retarded development, as well as facilitating predation by piscivorous birds (Shariff et al. 1980, Corrêa et al. 2014). They may also infect the cranial cavity of fish and induce changes in their swimming behavior (Corrêa et al. 2014). In South America, diplostomiasis is mainly caused by species of the genus *Austrodiplostomum* Szidat & Nani, 1951.

The adults of *Austrodiplostomum compactum* (Lutz, 1928) were recorded in several countries from America (Argentina, Brazil, U.S.A., Mexico and Venezuela) inhabit the intestine of the piscivorous birds *Nannopterum auritus* (Lesson, 1831) (=*Phalacrocorax auritus*) and *Nannopterum brasilianus* (Gmelin, 1789) (=*Phalacrocorax brasilianus*) (Szidat & Nani 1951, Dubois 1968, Ostrowski de Núñez 1982, 2017, Dronen 2009, Monteiro et al. 2011, O’Hear et al. 2014, García-Varela et al. 2016, Rosser et al. 2016). Although, cercariae emerge from the...
 tegument of gastropods such as: Biomphalaria straminea (Dunker, 1848), Biomphalaria glabrata (Say, 1818) (Pinto & Melo 2013), Biomphalaria prona (Martens, 1873) (Ostrowski de Núñez 1982), Biomphalaria obstricta (Morelet, 1849) (Rosser et al. 2016) and larval forms (metacercariae) can inhabit the eyes of several species of freshwater fishes (Yamada et al. 2008, Ramos et al. 2013). According to Ramos et al. (2013, 2016) and Campos et al. (in press), metacercariae of A. compactum have been reported in 38 Brazilian fish species belonging to 13 families of four orders, highlighting the high infection rates in Plagioscion squamosissimus (Heckel, 1840).

Plagioscion squamosissimus is a native species of the Amazon, Tocantins (Merona 1986), and Parnaíba Basins (Silva & Menezes 1950), with carnivorous food habits (Hahn et al. 1997, Stefani & Rocha 2009, Neves et al. 2015). The colonization of the Paraná River by this species may have begun in the decade of 1960, through an introduction conducted by the Companhia Energética de São Paulo (CESP) (Torloni et al. 1993). Introduced specimens came from the Nazaré Lake (municipality of Nazaré, State of Piauí, Brazil) and the Feitoria Lake (municipality of Oeiras, State of Piauí, Brazil) in 1949 (Fontenele & Peixoto 1978).

Since then, P. squamosissimus has colonized a wide variety of habitats in the Upper Paraná River Basin and it is considered the best example of introduced species successfully established in this basin according to Agostinho et al. (2008). Furthermore, this host presented the highest prevalence and mean intensity of infection values among fish species parasitized by A. compactum in the Upper Paraná River Basin.

The aim of the present study was to report the occurrence of metacercariae of A. compactum in P. squamosissimus from the Bonito River, in the Nova Avanhandava reservoir, Lower Tietê River, State of São Paulo, Brazil, and to propose an alternative explanation for the high rate of parasitic infection in areas where P. squamosissimus were introduced (non-natural occurrence).

**MATERIALS AND METHODS**

This study was conducted in the Bonito River (Nova Avanhandava reservoir, Lower Tietê River Basin) in the municipality of Glicério, State of São Paulo, Brazil (21°12'21.69” S 50°08’36.59” W) (Figure 1). Seventy fish specimens (31 males and 39 females) were collected by fishermen in April 2012, frozen, and transported to the laboratory, where they were weighed (total weight in grams of fish with viscera) and measured (standard length in centimeters measured from the tip of the snout to the final vertebra). Their eyes were removed and examined with the aid of a stereomicroscope. Metacercariae were collected from the aqueous humor and vitreous humor, fixed in alcohol-formalin-acetic acid solution (AFA) under slight pressure with a coverslip, preserved in 70% ethanol, and later stained with carmine and clarified with eugenol for identification (Eiras et al. 2006). Morphometric analysis of the metacercariae was carried out using a computerized system for image analysis with differential interference contrast (DIC) (Leica Application Suite, V3; Leica Microsystems, Wetzlar, Germany) and the identification of the parasite was based on Ostrowski de Núñez (2017). Specifically, for the pseudosuckers (right and left) the length and width measurements were randomly performed because they were symmetrical. Thus, the data presented for this morphological structure come from measurements of the two pseudosuckers grouped of all the samples evaluated. All measurements were described in micrometers.
and represented by mean followed by standard error, and range and number of specimens measured in parenthesis.

Prevalence (P), mean intensity of infection (MII), and mean abundance (MA) were calculated according to Bush et al. (1997), for all studies when possible (present and reviewed studies). Mean intensity of infection and mean abundance are expressed as mean, followed by standard deviation. The prevalence of males and females and the natural and non-natural areas were compared using the G-test, while the mean intensity of infection and mean abundance of male and female were compared using the Mann-Whitney test (U-test). The mean abundance among the natural and non-natural occurrence areas for *P. squamosissimus* was tested by Summary-t test. All statistical tests were performed using BioEstat version 5.3 software. The significance level used was *p*<0.05.

Parasite and host voucher specimens were deposited in the Coleção Helmintológica do Departamento de Bioestatística, Biologia Vegetal, Parasitologia e Zoologia (CHIBB 6723 and 6962) and the Coleção de Peixes do Laboratório de Biologia e Genética de Peixes (LBP 3493), respectively, both in the Instituto de Biociências of the Universidade Estadual Paulista (UNESP), located in the municipality of Botucatu, State of São Paulo, Brazil. A review of the studies on the infection of *P. squamosissimus* by *Austrodiplostomum* spp. in Brazil was carried out using Ramos et al. (2013) and a database search (SciELO, ISI, Scopus, and Google Scholar). Studies with a sample smaller than 20 animals were not considered due to the probability of
the sample size influencing the results of the parasitological attributes (P, MII, and MA).

RESULTS

The morphology of the recovered metacercariae followed the redescription proposed by Ostrowski de Núñez (2017): body bipartite; forebody spatulate, slightly concave ventrally (1253.0 ± 41.3 (941.3–1583.3; n=21) long and 456.9 ± 17.1 (310.8–624.5; n=23) wide); hindbody very short, with a small conical segment (98.1 ± 5.5 (64.0–132.4; n=16) long and 88.5 ± 5.3 (52.5–130.9; n=19) wide). Oral sucker subterminal (40.5 ± 2.5 (29.2–59.2; n=13) long, and 52.9 ± 2.1 (32.2–72.1; n=22) wide), two lateral pseudosuckers well developed and symmetric, on each side of oral sucker (pseudosuckers 94.3 ± 3.8 (52.3–137.4; n=19) long and 69.3 ± 3.3 (42.3–120.5; n=19) wide); ventral sucker absent. Small pharynx (60.2 ± 5.0 (38.5–90.2; n=12) long and 54.9 ± 4.3 (37.7–90.2; n=12) wide), esophagus short (24.6 ± 2.9 (18.2–37.8; n=6) long), ceca simple, reaching until level of genital primordia. Holdfast organ (= tribocytic organ) elliptical and bilobed (321.0 ± 18.9 (201.8–538.3; n=20) long and 179.6 ± 9.6 (104.7–257.8; n=20) wide). Glandular cells most spread in the anterior region, extending from pseudosuckers to the region before of the tribocytic organ. Genital primordia poorly developed, differentiated in two small testes, ovary not distinct.

Seventy fish (standard length 14.1 ± 0.1 (11.4–16.3) cm; total weight 57.9 ± 1.6 (29.1–84.3) g), of which 39 males (standard length 13.8 ± 0.2 (11.4–16.0) cm, total weight of 54.6 ± 2.6 (33.7–81.9) g), and 31 females (standard length of 14.3 ± 0.1 (12.0–16.3) cm, total weight of 60.7 ± 2.0 (29.0–84.3) g) were examined. The length and weight of the males and females were similar (U-test p>0.05).

The overall prevalence was 80% (male 77.4% and female 82.1%), mean intensity of infection 21.6 ± 3.3 (male 16.8 ± 2.8 and female 25.2 ± 5.2), and mean abundance 17.2 ± 2.8 (male 13.0 ± 2.51 and female 20.6 ± 4.6). A total of 1207 (1–151 per host) parasites were collected from the eyes of 56 P. squamosissimus specimens, of which 402 (1–51 per host) were from males and 805 (1–151 per host) from females. No significant differences in prevalence (G-test p>0.05), mean intensity of infection, and mean abundance (U-test p>0.05) were observed between male and female hosts.

The prevalence, mean abundance and mean intensity of infection with metacercariae of A. compactum in the aqueous humor and vitreous humor of P. squamosissimus observed in the present study and others studies in non-natural occurrence area were higher than in the natural occurrence area (p<0.05) (Table I).
Table I. List of studies recording *Austrodiplostomum compactum* metacercariae in the eyes of *Plagioscion squamosissimus* in Brazil. Number of specimens examined (N), prevalence (P), mean intensity of infection (MII) and mean abundance (MA). Mean values followed by standard deviation when available; different small letter = significative difference (p<0.05) between the natural (Solimões River) and non-natural occurrence area; different capital letters = significative difference (p<0.05) between the natural (Tocantins River) and non-natural occurrence area. CF = area close to cage fish farm; CT = area not influenced by cage fish farms.

| Studies                      | N   | P (%)  | MII  | MA      | State/River       | Coordinates                                    |
|------------------------------|-----|--------|------|---------|-------------------|-----------------------------------------------|
| Natural occurrence area      |     |        |      |         |                   |                                               |
| Lacerda et al. (2012)        | 35  | 40.0a  | 10.8 | 4.3±7.8a| AM/Solimões       | 4°20'0"S, 63°15'16"W                          |
| Lacerda et al. (2012)        | 35  | 8.3A   | 2.9  | 0.1±0.5A| TO/Tocantins      | 10°66'55"S, 48°42'36"W                        |
| Non-natural occurrence area  |     |        |      |         |                   |                                               |
| Martins et al. (1999)        | 68  | 45.6aB | 7.1  | 3.2     | MG/Grande         | Volta Grande reservoir (uninformed)           |
| Martins et al. (2002)        | 70  | 52.8aB | 5.3  | 2.8     | MG/Grande         | Volta Grande reservoir (uninformed)           |
| Souza-Santos et al. (2002)   | 61  | 91.8bB | 42.0 | 38.5    | SP/Paranã         | NUPELIA Base (uninformed)                     |
| Machado et al. (2005)        | 81  | 95.1bB | 38.9±64.3 | 37.0±63.2bB | PR/Paranã       | 33 different sites (uninformed)               |
| Paes et al. (2010a)          | 378 | 94.2bB | 21.7 | 20.4    | SP/Tietê          | 21°07'S, 50°17'W                               |
| Paes et al. (2010b)          | 213 | 90.1bB | 20.8 | 18.7    | SP/Tietê          | 21°07'S, 50°17'W                               |
| Kohn et al. (2011)           | 61  | 36.1aB | -    | -       | PR/Paranã         | 25°32'52"S, 54°35'17"W                       |
| Lacerda et al. (2012)        | 35  | 88.6bB | 98.8 | 87.5±153.3bB | PR/Paranã      | 22°46'11"S, 53°17'6"W                      |
| Souza-Santos et al. (2012)   | 57  | 98.0bB | 42.7 | 41.9    | PR/Paranã         | 21°45'48"S, 52°06'56"W                       |
| Ramos et al. (2013)          | 30  | 66.6bB | 13.1±6.1 | 8.7±23.0bB | SP/Paranapanema  | 23°07'36"S, 49°59.23'10"W                    |
| Ramos et al. (2014) CF       | 37  | 86.4bB | 20.3±1.1 | 17.7±38.3bB | SP/Paranapanema  | 23°07'37"S, 49°30.71'37.31"W                |
| Ramos et al. (2014) CT       | 28  | 57.1aB | 4.3±7.1 | 2.3±4.2  | SP/Paranapanema  | 23°07'36"S, 49°59.23'10"W                    |
| Present study                | 70  | 80.0bB | 21.55±3.2 | 17.24±23.4* | SP/Tietê        | 21°12'21.69"S, 50°08'36.59"W                |
However, the mean intensity of infection of the fish analyzed in the present study (21.5 ± 3.2) was similar to that observed by Karvonen et al. (2004) for Diplostomum spathaceum (Rudolphi, 1819). Karvonen et al. (2004) reported that the fish harbored more than 20 metacercariae per eye, had cataracts coverage of 100%, causing vision problems. Hahn et al. (1997) affirmed that P. squamosissimus is a visual predator, has large eyes arranged laterally to the skull, and carnivorous. Therefore, it is possible to infer that infection with metacercariae of A. compactum can affect food intake, as described by Owen et al. (1993) for Gasterosteus aculeatus Linnaeus 1758, and Crowden & Broom (1980) for Leuciscus leuciscus (Linnaeus, 1758). These infections also alter fish behavior when metacercariae are found in the cranial cavity, as reported by Seppälä et al. (2004) for Oncorhynchus mykiss (Walbaum, 1792) and Corrêa et al. (2014) for Hoplias malabaricus (Bloch, 1794), with consequences for susceptibility to predation.

Another important fact observed is the maintenance of high rates of infection over time. In a previous study with P. squamosissimus in the Nova Avanhandava reservoir, Paes et al. (2010b) recorded a mean abundance of metacercariae of A. compactum in the aqueous humor of 18.7 and a mean intensity of infection of 20.8 parasites per host, similar to the results observed in the present study (mean abundance 17.2 ± 2.9 and mean intensity of infection 21.5 ± 3.2). Thus, local environmental conditions may not have changed over this period or did not influence the infection rates of metacercariae of A. compactum in P. squamosissimus.

Lacerda et al. (2012) suggested that P. squamosissimus in Upper Paraná River Basin may be acting as a new and very suitable host for a local Austrodiplostomum sp., i.e., a reservoir for native parasites from which infections flow back to native hosts, which firstly could be explained by the spillback. Parasite spillback process second Kelly et al. (2009), could occur when a non-native species is a competent host for a native parasite, with the presence of the additional host increasing disease impacts in native species. However, there is no data available for the incidence of Austrodiplostomum metacercariae in native fish species, anterior to the introduction of P. squamosissimus in non-natural occurrence area (Upper Paraná Basin).

The prevalence of metacercariae of Austrodiplostomum exceeds 20% in native fish species such as Crenicichla britskii Kullander, 1982, Eigenmannia trilineata López & Castello, 1966, Hoplias malabaricus, Hypostomus iheringii (Regan, 1908), Hypostomus regani (Ihering, 1905), Hypostomus strigaticeps (Regan, 1908), Loricariichthys castaneus (Castelnau, 1855) and Pimelodus maculatus Lacôpêde, 1803 (Ramos et al. 2013).

Additionally, to the hypothesis proposed by Lacerda et al. (2012), we present another fact that could also contribute to the high infection rates observed in P. squamosissimus in the Upper Paraná River Basin. We infer that non-native hosts with high prevalences such as Cichla kelberi Kullander & Ferreira, 2006, Geophagus sveni Lucinda, Lucena & Assis, 2010 (= Geophagus proximus), Satanoperca pappaterra (Heckel, 1840) and P. squamosissimus (Ramos et al. 2013) may be acting as parasitic amplifiers, and possibly contributing to increase the population of A. compactum metacercariae in the Upper Paraná River Basin. Moreover, the high infection rates and prevalence observed in P. squamosissimus may be related to the low genetic variability of non-native populations.

According to Lively (2010), the high genetic diversity of hosts is important to reduce the spread of disease in natural populations and would, therefore, reduce infection. This
hypothesis is supported by studies from the plant (Zhu et al. 2000) and animal hosts for several diseases/parasites (Dwyer et al. 1997, Baer & Schmid-Hempel 1999, Altermatt & Ebert 2008), in which the possibility of infection was related to the genetic variability of the host. The possible influence of the host genetic susceptibility to the parasite (P. squamosissimus x A. compactum) was previously proposed by Souza-Santos (2002) to explain the high infection rates, but without considering the genetic data of the hosts.

*Plagioscion squamosissimus* from the Upper Paraná River Basin shares a single haplotype with populations from the Parnaíba River, revealing that *P. squamosissimus* offspring from the Parnaíba River Basin occur only in the Paraná River Basin and have low kinship with the populations of the Amazon River Basin (Panarari-Antunes et al. 2012). According to Panarari-Antunes et al. (2012, 2015) and Diamante et al. (2017), the non-native populations of *P. squamosissimus* from the Upper Paraná River Basin and the native population of the Parnaíba River, have low polymorphism and high genetic similarity. These populations of *P. squamosissimus*, however, differ genetically from the Araguaia-Tocantins native population, which is the most basal and polymorphic population.

The high rate of prevalence and intensity of infection with *A. compactum* metacercariae in *P. squamosissimus* could be explained by the fact that the colonization in the Upper Paraná River Basin occurred with a small founding population, which was highly susceptible to this parasite. As the entire population of *P. squamosissimus* from the Upper Paraná River Basin was founded by few specimens, causing very low genetic dissimilarity and consequently high kinship, the entire population could be highly susceptible to infection with *A. compactum* metacercariae.

This fact could also be applied to other non-native invasive species that have high rates of infection with *A. compactum* metacercariae and large populations in the Upper Paraná River Basin.

Other natural mechanisms not linked to genetic diversity could explain the higher rates of prevalence and infection in non-native species in the Upper Paraná River Basin. Larger populations of intermediate hosts, such as gastropods (specifically belonging to the genus *Biomphalaria*), and piscivorous birds, coupled to high temperatures and favorable hydrological conditions, could contribute to an increase in the rates of infection with *A. compactum* metacercariae. This fact was observed between *P. squamosissimus* and *A. compactum* metacercariae by Ramos et al. (2014) in areas close to cage fish farms when compared to areas without the influence of this type of aquaculture activity in the Upper Paraná River Basin. However, there are no population size data available for gastropods and piscivorous birds in natural and non-natural occurrence areas of *P. squamosissimus*.

It is possible to infer that the high infection rate observed in the Upper Paraná River Basin, may be related to the life and introduction history of *P. squamosissimus* in this basin, which has resulted in very low genetic variability contributing to the amplifier host process.

**Acknowledgments**

We are grateful to Jair Munhoz Ramos for the collection of hosts. We also thank Universidade Estadual Paulista (UNESP), Instituto de Biociências, Botucatu and Universidade Estadual do Oeste do Paraná (UNIOESTE) for the use of laboratory facilities and logistics. CAPES (Coordenação de Aperfeiçoamento de Pessoal de Nível Superior) for post-graduate scholarships granted to L.F. (CAPES/PNPD 17/2016); C.D.P. grant: 2016/23468-6, Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP). R.J.S. and I.P.R. are supported by Conselho Nacional de Desenvolvimento Científico e Tecnológico.
(CNPq) (process 309125/2017-0 and 303311/2018-5 respectively). R.J.S. is also supported by FAPESP (2016/50377-1).

REFERENCES

AGOSTINHO AA, PELICICE FM & GOMES LC. 2008. Dams and the fish fauna of the Neotropical region: impacts and management related to diversity and fisheries. Braz J Biol 68(4): 1119-1132.

ALTERMATT F & EBERT D. 2008. Genetic diversity of Daphnia magna populations enhances resistance to parasites. Ecol Lett 11(9): 918-928.

BAER B & SCHMID-HEMPEL P. 1999. Experimental variation in polyandry affects parasite loads and fitness in a bumble-bee. Nature 397: 151-154.

BUSH AO, LAFFERTY KD, LOTZ JM & SHOSTAK AW. 1997. Parasitology meets ecology on its own terms: Margolis et al. revisited. J Parasitol 83(4): 575-583.

CAMPOS DWJ, MANOEL LO, FRANCESCHINI L, VERÍSSIMO-SILVEIRA R, DELARIVA RL, RIBEIRO CS & RAMOS, IP. IN PRESS. Occurrence of Austrodiplostomum compactum in Pimelodus platicirris in the Ilha Solteira Reservoir, São Paulo, Brazil. An Acad Bras Ciênc.

CORRÊA LL, SOUZA GTR, TAKEMOTO RM, CECCARELLI PS & ADRIANO EA. 2014. Behavioral changes caused by Austrodiplostomum spp. in Hoplias malabaricus from the São Francisco River, Brazil. Parasitol Res 113(2): 499-503.

CROWDEN AE & BROOM DM. 1980. Effects of the eyefluke, Diplostomum spathaceum, on the behaviour of dace (Leuciscus leuciscus). Anim Behav 28(1): 287-294.

DIAMANTE NA, PRIOLI SMAP, OLIVEIRA AV, FABRIN TMC, PRIOLI LM & PRIOLI AJ. 2017. Genetic relationships of Plagioscion squamosissimus (Perciformes, Sciaenidae) from five Neotropical river basins evaluated using mitochondrial atpase 6/8 gene sequences. J Fish Biol 91(1): 375-384.

DRONEN NO. 2009. Austrodiplostomum ostrowskiae n. sp. (Digenea: Diplostomidae: Diplostominae) from the Double-crested Cormorant, Phalacrocorax auritus (Phalacrocoracidae) from the Galveston, Texas Area of the Gulf of Mexico, U.S.A. Comp Parasitol 76(1): 34-39.

DUBOIS G. 1968. Synopsis des Strigeidae et des Diplostomatidae (Trematoda). Mem Soc Sci Nat Neuchatel 10(1): 1-258.

Dwyer G, Elkinton JS & Buonaccorsi JP. 1997. Host heterogeneity in susceptibility and disease dynamics: tests of a mathematical model. Am Nat 150(6): 685-707.

Eiras JC, Takemoto RM & Pavanelli GC. 2006. Métodos de estudo e técnicas laboratoriais em parasitologia de peixes. 2ª ed., Maringá, 199 p.

Fontenele O & Peixoto JT. 1978. Análise dos resultados de introdução da pescada do Piauí, Plagioscion squamosissimus (Heckel, 1840), nos açudes do Nordeste. Bol Téc DNOC 36(1): 85-112.

García-Varela M, Sereno-Uribe AL, Pinacho-Pinacho CD & Domínguez-Domínguez O. 2016. Molecular and morphological characterization of Austrodiplostomum ostrowskiae Dronen, 2009 (Digenea: Diplostomatidae), a parasite of cormorants in the Americas. J Helminthol 90(2): 174-185.

Hahn NS, Agostinho AA & Goitein R. 1997. Feeding ecology of curvina Plagioscion squamosissimus (Heckel, 1840) (Osteichthyes, Perciformes) in the Itaipu reservoir and Porto Rico floodplain. Acta Limnol Bras 9(1): 11-22.

Karvonien A, Seppälä O & Valtonen ET. 2004. Eye fluke-induced cataract formation in fish: quantitative analysis using an ophthalmological microscope. Parasitology 129(4): 473-478.

Kelly DW, Paterson RA, Townsend CR, Poulin R & Tompkins DM. 2009. Parasite spillback: A neglected concept in invasion ecology? Ecology 90(8): 2047-2056.

Kohn A, Moravec F, Cohen SC, Canzi C, Takemoto RM & Fernandes BMM. 2011. Helminths of freshwater fishes in the reservoir of the Hydroelectric Power Station of Itaipu, Paraná, Brazil. Check List 7(5): 681-690.

Lacerda ACF, Takemoto RM, Tavares-Dias M, Poulin R & Pavanelli GC. 2012. Comparative parasitism of the fish Plagioscion squamosissimus in native and invaded river basins. J Parasitol 98(4): 713-717.

Lively CM. 2010. The effect of host genetic diversity on disease spread. Amer Naturalist 175(6): E149-E152.

Machado PM, Takemoto RM & Pavanelli GC. 2005. Diplostomum (Austrodiplostomum) compactum (Lutz, 1928) (Platyhelminthes, Diplostomidae) metacercariae in fish from the floodplain of the Upper Paraná River, Brazil. Parasitol Res 97(6): 436-444.

Martins ML, Fujimoto RY, Nascimento AA & Moraes FR. 1999. Ocorrência de Diplostomum sp. Nordmann, 1832 (Digenea Diplostomatidae) em Plagioscion squamosissimus Heckel, 1840, proveniente do Reservatório de Volta Grande, MG, Brasil. Acta Sci 21(2): 263-266.
spp., affects the vision of three-spined sticklebacks, Gasterosteus aculeatus. J Fish Biol 42(5): 803-806.

PAES JVK, CARVALHO ED & SILVA RJ. 2010a. Infection levels of Austrodiplostomum compactum (Digenea: Diplostomidae) metacercariae in Plagioscion squamosissimus (Perciformes, Sciaenidae) from the Nova Avanhandava reservoir, São Paulo State, Brazil. J Helminthol 84(3): 284-291.

PAES JVK, CARVALHO ED & SILVA RJ. 2010b. Infection by Austrodiplostomum compactum metacercariae in fish from the Nova Avanhandava reservoir, Tietê river, São Paulo State, Brazil. Acta Sci Biol Sci 32(3): 273-278.

PANARARI-ANTUNES RS ET AL. 2012. Genetic divergence among invasive and native populations of Plagioscion squamosissimus (Perciformes, Sciaenidae) in Neotropical regions. J Fish Biol 80(7): 2434-2447.

PANARARI-ANTUNES RS, PRIOLI AJ, PRIOLI SMAP, JUNIOR JÚLIO HF, OLIVEIRA A V, AGOSTINHO CS, SILVA FILHO JP & PRIOLI LM. 2015. Genetic characterization of native and invasive Plagioscion squamosissimus (Perciformes, Sciaenidae) populations in Brazilian hydrographic basins. Genet Mol Res 14(4): 14314-14324.

PINTO HA & MELO AL. 2013. Biomphalaria straminea and Biomphalaria glabrata (Mollusca: Planorbidae) as New Intermediate Hosts of the Fish Eyefluke Austrodiplostomum compactum (Trematoda: Diplostomidae) in Brazil. Rev Bras Parasitol Vet 22(4): 511-518.

RAMOS IP, FRANCESCHINI L, ZAGO AC, ZICA EOP, WUNDERLICH AC, CARVALHO ED & SILVA RJ. 2013. New host records and a checklist of fishes infected with Austrodiplostomum compactum (Digenea: Diplostomidae) in Brazil. Rev Bras Parasitol Vet 25(2): 240-243.

RAMOS IP, FRANCESCHINI L, ZAGO AC, ZICA EOP, WUNDERLICH AC, LIMA FP & SILVA RJ. 2016. Austrodiplostomum compactum metacercariae (Digenea: Diplostomidae) in Schizodon intermedius (Characiformes: Anostomidae) from Jurumirim reservoir, Brazil. Rev Bras Parasitol Vet 25(2): 342-348.

ROSSER TG, ALBERSION NR, KHOO LH, WOODWARD ET, POTE LM & GRIFFIN MJ. 2016. Characterization of the life cycle of a fish eye fluke, Austrodiplostomum ostrowskiae (Digenea: Diplostomatidae), with notes on two other diplostomid infecting Biomphalaria obstricta (Mollusca: Planorbidae) from catfish aquaculture ponds in Mississippi, USA. J Parasitol 102(2): 260-274.

SEPPÄLÄ O, KARVONEN A & TELLervo-VAlTONEN E. 2004. Parasite-induced change in host behaviour and susceptibility to predation in an eye fluke-fish interaction. Anim Behav 68(2): 257-263.

SHARIFF M, RICHARDS RH & SOMMERVILLE C. 1980. The histopathology of acute and chronic infections of rainbow trout Salmo gairdneri Richardson with eye flukes, Diplostomum spp. J Fish Dis 3(6):455-465.

SILVA SLO & MENEZES RS. 1950. Alimentação de curvina, Plagioscion squamosissimus (Heckel, 1840) da lagoa de
Nazaré, Piauí (Actinopterygii, Sciaenidae). Rev Bras Biol 10(2): 257-264.

SOUZA-SANTOS R, MARCHIORI N, SANTAREM VA, TAKAHASHI HK, MOURINO JLP & MATINS ML. 2012. *Austrodiplostomum compactum* (Lutz, 1928) (Digenea, Diplostomidae) em olhos de peixes do rio Paraná, Brasil. Acta Sci Biol Sci 34(2): 225-231.

SOUZA-SANTOS R, PIMENTA FDA, MARTINS ML, TAKAHASHI HK & MARENGONI NG. 2002. Metacercárias de *Diplostomum* (*Austrodiplostomum*) *compactum* Lutz, 1928 (Digenea, Diplostomidae) em peixes do rio Paraná, Brasil. Prevalência, sazonalidade e intensidade de infecção. Acta Sci Biol Sci 24(2): 475-480.

STEFANI PM & ROCHA O. 2009. Diet composition of *Plagioscion squamosissimus* (Heckel, 1840), a fish introduced into the Tietê River system. Braz J Biol 69(3): 805-812.

SZIDAT L & NANI A. 1951. Diplostomiasis cerebralis del pejerrey: una grave epizootia que afecta a la economia nacional producida por larvas de trematodes que destruyen el cerebro de los pejerreyes. Rev Mus Argent Cienc Nat Bernardino Rivadavia Zool 1(8): 323-384.

TORLONI CEC, SANTOS JJ, CARVALHO-JÚNIOR AA & CORRÊA ARAA. 1993. A pescada-do-Piauí *Plagioscion squamosissimus* (Heckel, 1840) (Osteichthyes, Perciformes) nos reservatórios da CESP - Companhia Energética de São Paulo. Ser Pesqui Desenvol 1(84): 1-23.

YAMADA FH, MOREIRA LHA, CESCHINI TL, TAKEMOTO RM & PAVANELLI GC. 2008. Novas ocorrências de metacercária de *Austrodiplostomum compactum* (Lutz, 1928) (Plathyhelminthes: Diplostomidae) parasito de olhos de peixes da Bacia do Rio Paraná. Rev Bras Parasitol Vet 17(3): 163-166.

ZHU Y ET AL. 2000. Genetic diversity and disease control in rice. Nature 406: 718-722.

**SUPPLEMENTARY MATERIAL**

**Table SI.**

**How to cite**

RAMOS IP, PAGLIARINI CD, FRANCESCHINI L & SILVA RJ. 2020. Metacercarieae of *Austrodiplostomum compactum* (Trematoda, Diplostomidae) in non-native fish species in Brazil: a possible explanation for the high rate of parasitic infection. An Acad Bras Cienc 92: e20180984, DOI 10.1590/0001-3765202020180984.

**Manuscript received on September 24, 2018; accepted for publication on April 12, 2019**

**IGOR P. RAMOS**
https://orcid.org/0000-0003-4525-6491

**CIBELE D. PAGLIARINI**
https://orcid.org/0000-0002-1978-9481

**LIDIANE FRANCESCHINI**
https://orcid.org/0000-0002-4733-4820

**REINALDO J. DA SILVA**
https://orcid.org/0000-0002-3426-6873

1Universidade Estadual Paulista/UNESP, Departamento de Biologia e Zootecnia, Faculdade de Engenharia, Laboratório de Ecologia de Peixes, Campus de Ilha Solteira, Ilha Solteira, Rua Monção, 226, Zona Norte, 15385-000 Ilha Solteira, SP, Brazil

2Programa de Pós-graduação em Ciências Biológicas/Zoologia, Universidade Estadual Paulista/UNESP, Instituto de Biociências, Rua Prof. Dr. Antônio Celso Wagner Zanin, Campus Botucatu, 250, Distrito de Rubião Junior, 18618-689 Botucatu, SP, Brazil

3Universidade Estadual Paulista/UNESP, Departamento de Parasitologia, Instituto de Biociências, Rua Prof. Dr. Antônio Celso Wagner Zanin, 250, Campus Botucatu, Distrito de Rubião Junior, 18618-689 Botucatu, SP, Brazil

Correspondence to: Igor Paiva Ramos
E-mail: igor.paiva.ramos@gmail.com

**Author contributions**

Igor Paiva Ramos, as the main author, contributed to the laboratorial analysis, general structure of the manuscript, discussion of the results and interpretations contained in this manuscript. Cibele Diogo Pagliarini took part in the scientific discussions and interpretation contained in this manuscript. Lidiane Franceschini contributed to parasite identification and laboratorial analysis, and took part in the structuration, scientific discussions and interpretation contained in this manuscript. Reinaldo José da Silva took part in the scientific discussions and interpretation contained in this manuscript.