NOTE

About the biodiversity of parasites of freshwater fish from Brazil

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Abstract
The authors analyze the biodiversity of parasites of freshwater fish from Brazil. It is concluded that the number of parasites described so far is low compared to the biodiversity of host species in the country, and that the number of parasites of the different taxa is very variable. An interpretation of these data is suggested, and several recommendations are suggested for the study of fish parasites in Brazil.

Brazil is one of the largest countries in the world. It has a large number of rivers and some of them are very long - the rivers Madeira, 3,250 km long, São Francisco (3,160 km), Paraná (2,940 km), Tocantins (2,640 km), Uruguai (1,770 km) and Paraguai (1,500) km) are some examples. Besides, Brazil has the longest and largest river in the world, the Amazon River - the Amazon River basin consists of the most extensive river system on Earth, occupying a total area of about 6,110,000 km2 and represents the largest amount of liquid freshwater of the planet (Agência Nacional de Águas, 2011).

Within this large amount of freshwater ecosystems a great fish biodiversity can be found: about 4,035 fish species representing approximately 31% of the world freshwater fish species (Levêque et al., 2008) distributed among 39 different families (Buckup et al., 2007).

Due to the high biodiversity of freshwater fish in Brazil (as in other South-American countries) a large number of species are economically very important for several reasons.

In general, a significant number of species are highly regarded as food source and reach very

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high prices in the market - the number of inland fishermen is of several thousands of people. A great number of native species, as *Piaractus mesopotamicus*, *Colossoma macropomum*, *Pseudoplatystoma* spp., *Leporinus* spp. and *Brycon* spp., among others, and some introduced ones, as *Oreochromis niloticus*, are farmed. The production of farmed freshwater fish in Brazil in 2009 was about 337.353 tons (Estatística MPA, 2008/2009), and the potential of new species for farming is being studied (Feijó et al., 2009). In the last few years a large number of "fish and pay" farms to allow recreational fishing to take place have been developed near small and large cities with good exploitation results. Finally, an important resource is represented by the ornamental fish, especially the small sized aquarium fish, whose capture is the main economic activity of several small cities mainly in the Amazonian region.

For these reasons the freshwater fish represent a valuable resource and has justified, principally in the last years, the increasing interest of the scientific community. As a result, the majority of scientific meetings have focused mainly on aspects of the biology of these species, and the number of publications concerning fish biology in general increased significantly in the past two decades. However, the corresponding number of papers on the diseases and parasites of these hosts is generally low.

The parasites of the freshwater fish from Brazil were studied by several researchers, and different checklists of parasites were produced for several taxa: trematodes (Viana, 1924; Travassos et al., 1969; Thatcher 1993; Kohn et al., 2007); myxozoans (Gióia and Cordeiro, 1996; Eiras et al. 2008, 2010); monogeneans (Kohn and Cohen, 1998; Cohen and Kohn, 2008); nematodes (Moravec, 1998); copepods (Luque and Tavares, 2007); cestodes (Rego, 2000) and acanthocephalans (Santos et al., 2008). Thatcher (2006) reported the parasites of fish from the Amazonian region, and Takemoto et al. (2009) described the diversity of fish parasites from the floodplain of the Upper Paraná River.

Recently, Eiras et al. (2010a) produced a book listing the parasites of all the taxa (and their respective hosts) infecting the freshwater fish from the country. According to the results of these authors a total of 1,034 nominal species of parasites were reported from freshwater fish of Brazil (Table 1). The parasites were collected from a total of 451 different host species. It is interesting to note that these hosts represent only 11.1 % of the species reported for the country, but at the same time represents a considerable amount of different host species from a parasitological point of view.

These results, which have not been updated since July 2010 despite the description of a small number of new species since then pose a number of interesting problems which deserve some attention:

Why is there such a low number of fish parasites described in so many fish species (an average number of 2.3 parasites species per host)? Why only 451 fish species were studied? How do we explain the differences in the number of species of the different taxa? Is the number of parasitic species "real" or are there more or less abundant synonyms?

These are interesting questions which we try to answer. We consider three main factors that

might explain, at least partially, these figures: 1) factors related to the research effort; 2) factors related to the facility of detection of the parasites, and 3) factors related to the type of the host.

Table 1. Number of parasites species, per taxon, described for freshwater fish from Brazil (data reported to July, 2010).

Parasites taxon	Number of species
Amoebae	1
Flagellata (*sensu latum*)	66
Apicomplexa	10
Ciliophora	15
Myxozoa	79
Monogenea	312
Digenea	148
Cestoda	116
Nematoda	124
Acanthocephala	133
Hirudinea	12
Crustacea	118

Research effort

In relation to some groups of parasites (Amoebae, Apicomplexa, Hirudinea) there is practically no research being conducted and the number of people studying these groups is very small.

In other groups of parasites, an analysis of the species descriptions in the last decades show that the majority or a significant proportion of the species were described quite recently. For instance, from a total of 79 species of myxozoans, 44 (55%) were described in the last 15 years. Similarly, 109 out of 312 monogenean species (35%) were described also in the same period. However, this does not necessarily mean an increase of researchers working in the area. Concerning myxozoans, for instance, the number of people working in the field remained stable. However, the recent developments in the knowledge of these parasites and the utilization of new tools, like molecular characterization of the species, lead to a renewing of interest in the group, thus generating more studies and publications.

Considering the total number of fish species, known fish parasites, and the number of host species, it has to be concluded that the number of parasitic species is very low as indicated above. The explanation for these pictures can be related to the fact that, most of the time, the necropsy of the fish is done by researchers interested only in a particular kind of parasites. For instance, a parasitologist interested in trypanosomes takes a blood sample only; a researcher studying ectoparasites examines the body surface of the hosts; a myxozoan researcher only pays attention to those parasites. In any case, even if other parasites are present and observed, they are usually not sampled, and, as a consequence, many parasites remain unreported.

However, given the great diversity of fish found in the country, the very low number of researchers studying fish parasites in Brazil seems to be the most decisive factor responsible for the low knowledge of the fish parasites fauna in the country.

A search on the Lattes Platform (Cnpq) (Government produced list of scientists curricula including all the science subjects within the country)

using the descriptors "fish parasites" indicates about 200 different researchers. However, the individual examination of the curricula shows that in fact only about 45 researchers work on fish parasitology exclusively, including both marine and freshwater fish. This means that the number of researchers working in this field is clearly very low considering not only the population of the country (almost 200 million of people) but also the extremely high fish diversity.

Facility of detection of the parasites

The facility of detecting the parasites obviously plays a role in the number of species described. Ectoparasites, and parasites which have a monoxenous life cycle, are easier to detect and this may explain why the most "abundant" parasites are monogeneans (we are not taking into account the number of persons dedicated to the study of each group of parasites).

However, the high number of species of a certain group does not necessarily imply that the group has more species than other groups with a lower number of species reported. This may simply occur because some taxa are more intensively studied than others. On the other hand, we think that in some cases a great number of synonyms may occur. This is the case particularly for *Trypanosoma* spp. Most descriptions were done assuming that a form described in a new host represented a new species. This incorrect way of thinking most likely caused an artificial multiplication of species, and it is highly probable that the 62 trypanosome species actually described should be reduced to a much smaller number of forms. Clearly a revision of the group is needed, similarly to the work done by Baker (1960) for the trypanosomes of African fishes.

Host species

The total number of different hosts examined so far is about 451 species. Surprisingly, a detailed analysis of the hosts demonstrates that most of the parasitological studies are divided into three groups of fish: farmed species (*Colossoma macropomum*, *Piaractus mesopotamicus*, *Arapaima gigas*, *Pseudoplatystoma fasciatum*, *Oreochromis niloticus*, *Tilapia rendalli*, etc.); high economic valuable species from natural environments (all the species cited above, plus a great number of species as *Prochilodus lineatus*, *Brycon* spp., *Hoplias malabaricus, Cichla* spp., *Plagyoscion squamosissimus, Salminus maxillosus, Pimelodus maculatus, Zungaro jahu, Leporinus* spp., etc.); ornamental fish species, mainly aquarium fish (*Xiphophorus maculatus*, *X. helerii*, *Beta splendens*, *Poecilia reticulata*, *Macropodon opercularis*, *Trichogaster trichopterus*, *Paracheirodon axelrodi, Puntius conchonius*, etc.).

It is easy to understand the reasons for these figures. In the vast majority of the cases the study of fish parasites is done integrated in research projects financed by the Government or supported by State Research Institutions. Those projects are submitted for approval in a highly competitive basis and it is expected that the chances of approval are higher if the fish to be studied are economically important, namely if they are farmed or are intensively fished for human consumption. In other words, probably a kind of "applied" project is easier to approve, than a pure research aiming the study of not so "interesting" species. Therefore the fish parasitologists "invest" more in a somewhat reduced number of species, and this explains why there is a huge number of freshwater fish species which were never studied under a parasitological point of view.

This hypothesis can be easily corroborated by a fast evaluation of the literature concerning some groups of parasites. For instance, concerning Myxozoa, it can be verified that, in the last three years, three new species were described infecting the Pintado (*Pseudoplatystoma corruscans*) an important commercial fish: *Henneguya corruscans* (Eiras et al., 2009), *H. pseudoplatystoma* (Naldoni et al., 2009) and *H. eirasi* (Naldoni et al., 2011). Similar pictures were observed in other host species as *Prochilodus lineatus* with two species described (Adriano et al., 2002, 2005a), *Piaractus mesopotamicus* with three species (Martins et al., 1997, Adriano et al., 2005b, 2006), *Brycon hilarii* with two species described (Milanin et al., 2010; Azevedo et al., 2011), and *Salminus brasiliensis* also with two species reported (Molnar et al., 1998; Adriano et al., 2009). All these five fish species are important native freshwater fish farmed and intensively fished from natural environments, and in this way, are among those whose parasitic fauna have been more intensively studied. It is interesting to note that altogether these fish species harbor 12 myxozoan species which corresponds to around 14% of the Myxozoa known to South American freshwater fish. In this way, considering the 4,035 fish species proposed to Brazil by Levêque et al. (2008), and considering the existence of an average of 2 Myxozoan species to each host species, we can estimate the existence of about 8,000 species in the Brazilian freshwater fishes (actually there are about 2,000 species described worldwide in both marine and freshwater fish), while Naldoni et al. (2011) estimate the existence of about 16,000 Myxozoan species for all the Neotropical area.

A similar picture can be observed in the Monogenea fauna where it is possible to observe several species infecting the same host fish: *Brachyplatystoma filamentosum*, a very important commercial Amazon pimelodid harbors three species of dactylogyrids (Cepeda and Luque, 2010); *Prochilodus lineatus* is infected by two species (Lizama et al., 2004; Cuglianna et al., 2009); *Leporinus lacustris* and *L. friderici* are infected by six species (Guidelli et al., 2006); *Prochilodus lineatus* is also infected by six different species of Monogenea (Lizama et al., 2005). On the other hand, it is interesting to state that, considering all the neotropical region, there are reports of 87 parasitic species for *Astyanax fasciatus*, 81 for *Cichlasoma urophtalmus* and 67 for *Hoplias malabaricus* (Luque and Poulin, 2007).

A literature survey shows that a similar situation is verified for other groups of parasites as digeneans, crustaceans or nematodes.

There are no biological reasons for a different pattern of parasitization of hosts of lesser economic importance. Therefore it is concluded that the parasitological study of other fish species may lead to a dramatic increase of the knowledge on the biodiversity of the parasites of freshwater fish from Brazil.

Conclusions

The number of species of parasites of freshwater fish from Brazil is relatively low when compared with the biodiversity of the fish; the real number of parasitic species is difficult to estimate but should be very high in all the parasites taxa;

Probably in some taxa a revision of the species would lead to a more or less important reduction of the number of valid species;

It is suggested that the study of fish parasites

should be focused not only in the "traditional" fish species but extended also to other species not so important under an economical point of view;

It is suggested that there needs to be an increase in the number of researchers working on fish parasites - the actual number of researchers is clearly not enough for the work necessary to be done.

References

Adriano EA, Arana S, Ceccarelli PS and Cordeiro NS (2002). Light and scanning electronmicroscopy of *Myxobolus porofilus* sp. n. (Myxosporea: Myxobolidae) infecting the visceral cavity of *Prochilodus lineatus* (Pisces: Characiformes: Prochilodontidae) cultivated in Brazil. *Folia Parasitologica* **49**, 259–262.

Adriano EA, Arana S and Cordeiro NS (2005a). Histopathology and ultrastructure of *Henneguya caudalongula* n. sp. infecting *Prochilodus lineatus* (Pisces: Prochilodontidade) cultivated in the state of São Paulo, Brazil. *Memórias do Instituto Oswaldo Cruz* **100**, 177–181.

Adriano EA, Arana S and Cordeiro NS (2005b). An ultrastructural and histopathological study of *Henneguya pellucida* n. sp. (Myxosporea: Myxobolidae) infecting *Piaractus mesopotamicus* (Characidae) cultivated in Brazil. *Parasite* **12**, 221–227.

Adriano EA, Arana S and Cordeiro NS (2006). *Myxobolus cuneus* n. sp. (Myxosporea) infecting the connective tissue of *Piaractus mesopotamicus* (Pisces: Characidae) in Brazil: histopathology and ultrastructure. *Parasite* **13**, 137-142.

Adriano EA, Arana S, Carriero MM, Naldoni J, Ceccarelli PS, and Maia AA (2009). Light, electron microscopy and histopathology of *Myxobolus salminus* n. sp., a parasite of *Salminus brasiliensis* from the Brazilian Pantanal. *Veterinary Parasitology* **165**, 25-29.

Azevedo C, Casal G, Marques D, Silva E and Matos E (2011). Ultrastructure of *Myxobolus brycon* n. sp. (Phylum Myxozoa), parasite of the Piraputanga fish *Brycon hilarii* (Teleostei) from Pantanal (Brazil). *Journal of Eukaryotic Microbiology* **58**, 88-93.

Agência Nacional de Águas (2011) Região Hidrográfica Amazônica: A maior do mundo em disponibilidade de água http://www2.ana.gov.br/Paginas/portais/bacias/amazonica.aspx. Accessed on 18/03/2011.

Backer JR (1960). Trypanosomes and dactylosomes from the blood of freshwater fish in East Africa. *Parasitology* **50**, 515-526.

Buckup PA, Menezes NA and Ghazzi MS (eds.) (2007)**. "Catálogo das Espécies de Peixes de Água Doce do Brasil."** Museu Nacional Publisher, Rio de Janeiro. ISBN 9788574270180.

Cepeda PB and Luque JL (2010). Three new species of *Demidospermus* (Monogenea: Dactylogyridae) parasitic on *Brachyplatystoma filamentosum* (Siluriformes: Pimelodidae) from the Araguaia River, Brazil. *Journal of Parasitolology* **96**, 869-873.

Cohen SC and Kohn A (2008). South American Monogenea – list of species, hosts and geographical distribution from 1997 to 2008. *Zootaxa* **1924,** 1-42.

Cnpq (2011) Conselho Nacional de Desenvolvimento Científico e Tecnológico. http://lattes.cnpq.br/. Accessed on 18/03/2011.

Cuglianna AM, Cordeiro NS and Luque J L (2009). *Apedunculata discoidea* gen. n., sp. n. (Monogenea: Dactylogyridae) parasitic on *Prochilodus lineatus* (Valenciennes, 1837) (Characiformes: Prochilodontidae) from southeastern Brazil. *Brazilian Journal of Biology* **69**, 895-898.

Eiras JC, Takemoto RM and Pavanelli GC (2010a). **"Diversidade dos Parasitas de**

Peixes de Água Doce do Brasil." Clichtec Publishers, Maringá. ISBN 978 85 87435 55 2.

Eiras JC, Monteiro CM and Brasil-Sato MC (2010). *Myxobolus franciscoi* sp. nov. (Myxozoa, Myxosporea, Myxobolidae), a parasite of *Prochilodus argenteus* (Actinopterygii, Prochilodontidae) from the Upper São Francisco River, with a revision of *Myxobolus* spp. from South America. *Zoologia* **27**, 131-137.

Eiras JC, Takemoto RM and Pavanelli GC (2008). *Henneguya caudicula* n. sp. (Myxozoa, Myxobolidae) a parasite of *Leporinus lacustris* (Osteichthyes, Anostomidae) from the high Paraná River, Brazil, with a revision of *Henneguya* spp. infecting South American fish. *Acta Protozoologica* **47**, 149-154.

Eiras JC, Takemoto RM and Pavanelli GC (2009). *Henneguya corruscans* n. sp. (Myxozoa, Myxosporea, Myxobolidae), a parasite of *Pseudoplatystoma corruscans* (Osteichthyes, Pimelodidae) from the Paraná River, Brazil: a morphological and morphometric study. *Veterinary Parasitolology* **159**, 154–158.

Estatística MPA, 2008/2009. http://www.mpa.gov.br/#publicidade/publicações (assessed in March, 2011).

Feijó MM, Arana S, Ceccarelli PS and Adriano EA (2008). Light and scanning electron microscopy of *Henneguya arapaima* n. sp. (Myxozoa: Myxobolidae) and histology of infected sites in pirarucu (*Arapaima gigas*: Pisces: Arapaimidae) from the Araguaia River, Brazil. *Veterinary Parasitology* **157**, 59-64.

Gióia I and Cordeiro NS (1996). Brazilian's myxosporidians checklist (Myxozoa). *Acta Protozoologica* **35**, 137-249.

Guidelli G, Tavechio WLG, Takemoto RM and Pavannelli GC (2006). Fauna parasitária de *Leporinus lacustris* e *Leporinus friderici* (Characiformes, Anastomidae) da planície de inundação do alto rio Paraná, Brasil. *Acta Scientiarum Biological Sciences* **28**, 281-290.

Kohn A and Cohen SC (1998). South American Monogenea – list of species, hosts and geographical distribution. *International Journal for Parasitology* **28**, 1517-1554.

Kohn A, Fernandes BMM and Cohen SC (2007). **"South American Nematodes Parasites of Fishes"**. Editors Imprinta Publishers, Rio de Janeiro.

Levêque C, Oberdorff T, Paugy D, Stiassny MLJ and Tedesco PA (2008). Global diversity of fish (Pisces) in freshwater. *Hydrobiologia* **595**, 545-567.

Lizama ML, Takemoto RM and Pavanelli GC (2004). New species of *Tereancistrum* Kritsky, Thatcher & Kayton, 1980 (Monogenea: Dactylogyridae: Ancyrocephalinae) from the gills of *Prochilodus lineatus* (Osteichthyes: Prochilodontidae) from the upper Paraná River floodplain, Brazil. *Systematic Parasitology* **57**, 45-49.

Lizama ML, Takemoto RM and Pavanelli GC (2005). Influence of host sex and age on infracomunities of metazoan parasites of *Prochilodus lineatus* (Valenciennes, 1836) (Prochilodontidae) of the Upper Paraná River floodplain, Brazil. *Parasite* **12**, 299-304.

Luque JL and Poulin R (2007). Metazoan parasite species richness in Neotropical fishes: hotpspots and the geography of biodiversity. *Parasitology* **134**, 865-878.

Luque JL and Tavares LER (2007). Checklist of Copepoda associated with fishes from Brazil. *Zootaxa* **1579**, 1-39.

Milanin T, Eiras JC, Arana S, Maia AAM, Alves AL, Silva, MRM, Carriero MM, Ceccarelli PS and Adriano EA (2010). Phylogeny, ultrastructure, histopathology and prevalence of *Myxobolus oliveirai* sp. nov., a parasite of *Brycon hilarii* (Characidae) in the Pantanal wetland, Brazil. *Memórias do Instituto Oswaldo Cruz* **105**, 762-769.

Molnár K, Ranzani-Paiva MJ, Eiras JC and Rodrigues EL (1998). *Myxobolus macroplasmodialis* sp. n. (Myxozoa: Myxosporea), a parasite of the abdominal cavity of the characid teleost, *Salminus*

maxillosus, in Brazil. *Acta Protozoologica* **37**, 241–245.

Moravec F (1998). **"Nematodes of Freshwater Fishes of the Neotropical Region"** Academia Publishers, Praha. ISBN 80 200 075 9.

Naldoni J, Arana S, Maia AAM, Ceccarelli PS, Tavares LER, Borges FA, Pozo CF and Adriano EA (2009). *Henneguya pseudoplatystoma* n. sp. causing reduction in epithelial area of gills in the farmed pintado, a South American catfish: histopathology and ultrastructure. *Veterinary Parasitolology* **166**, 52–59.

Naldoni J, Arana S, Maia AAM, Silva MRM, Carriero MM, Ceccarelli PS, Tavares LER and Adriano EA (2011). Host–parasite–environment relationship, morphology and molecular analyses of *Henneguya eirasi* n. sp. parasite of two wild *Pseudoplatystoma* spp. in Pantanal Wetland, Brazil. *Veterinary Parasitology* in press.

Rego AA (2000). Cestode parasites of neotropical teleost freshwater fishes. *In* (Ed.). In **"Metazoan Parasites in the Neotropics: a Systematic and Ecological Perspective"** (G Salgado Maldonado, AN García Aldrete, VM Vidal-Martínez, Ed.), pp 135-144. Institute of Biology Publishers, UNAM, Mexico City. ISBN 978-9683688279.

Santos CP, Gibson DI, Tavares LER and Luque JL (2008) Checklist of Acanthocephala associated with the fishes of Brazil. *Zootaxa* **1928**, 1-22.

Takemoto RM, Pavanelli GC, Lizama MAP, Lacerda CCF, Yamada FH, Moreira LHA, Ceschini TL and Bellay S (2009). Diversity of parasites of fish from the Upper Paraná River floodplain, Brazil. *Brazilian Journal of Biology* **69**, 691-705.

Thatcher VE (1993). **"Trematódeos Neotropicais."** INPA Publishers, Manaus. Thatcher VE (2006). "Amazon Fish Parasites. Aquatic Biodiversity in Latin America." Pensoft Publishers, Sofia-Moscow. ISBN 954 642 258 4.

Travassos L, Freitas JFT and Kohn A (1969). Trematódeos do Brasil. *Memórias do Instituto Oswaldo Cruz* **67**, 1-886.

Viana L (1924). Tentativa de catalogação das espécies brasileiras de trematódeos. *Memórias do Instituto Oswaldo Cruz*, **17**, 95-227.