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ARTICLE

Non-native freshwater fish from drainages of Rio Grande do Sul State, Brazil

Vinicius de Araújo Bertaco[1,2] & Marco Aurélio Azevedo[1,3]

[1] Secretaria do Meio Ambiente e Infraestrutura (SEMA), Museu de Ciências Naturais. Porto Alegre, RS, Brasil.
[2] ORCID: 0000-0002-3919-6042. E-mail: vbertaco@gmail.com (corresponding author)
[3] ORCID: 0000-0003-1214-0038. E-mail: marco-azevedo@sema.rs.gov.br

Abstract. The present study catalogues exotic and allochthonous fish species found in the three main freshwater river drainages of Rio Grande do Sul State using records of scientific collections and literature, and discusses the main impacts caused by their introduction in natural environments. Ten exotic species are found in the area, *i.e., Clarias gariepinus, Coptodon rendalli, Ctenopharyngodon idella, Cyprinus carpio, Hypophthalmichthys molitrix, Hypophthalmichthys nobilis, Ictalurus punctatus, Micropterus salmoides, Oncorhynchus mykiss* and *Oreochromis niloticus,* belonging to five orders, nine genera and seven families. These fishes are native from African, Asian, European and North American countries. The eight allochthonous species, *i.e., Acestrorhynchus pantaneiro, Hoplerythrinus unitaeniatus, Hoplias lacerdae, Megaleporinus macrocephalus, Piaractus mesopotamicus, Pachyurus bonariensis, Serrasalmus maculatus,* and *Trachelyopterus lucenai,* belong to three orders, eight genera, and six families, are native from the Río La Plata basin, that includes the Río Uruguay, and have been all registered in the Laguna dos Patos. Two of these species are further recorded in the Rio Tramandaí system (*A. pantaneiro* and *T. lucenai*). The study also presentes a brief history of the first records of exotic species in the state and in the country, and their main vectors of introduction. According to the records of exotic species in scientific collections, the two exotic species with the highest number of records in the country are tilapias *Coptodon rendalii* (508 records) and *Oreochromis niloticus* (376 records), and most records occurred in the last two decades. The two carps *Cyprinus carpio* and *Ctenopharyngodon idella* are the only exotic species recorded in the three main drainage basins of the state. In addition, we warn about the importance of studies about the biology and negative impacts of exotic species over native species on the understanding of management in wild environments.

Keywords. Allochthonous; Biological invasion; Ichthyofauna; Invasive alien species.

INTRODUCTION

The Convention on Biological Diversity (CDB, 2005, Decision VI-23) defines "Exotic Species" as: a species, subspecies or lower-ranking taxon occurring outside its past or present natural range; includes any part such as gametes, seeds, eggs or propagules that can survive and subsequently reproduce. The CBD also defines "Invasive exotic species" as an exotic species whose introduction and/or dispersion threatens biological diversity.

Thus, species of any group of living beings, when introduced outside their original distribution areas, that is, in places where they did not occur naturally, are called "exotic species". When these species, once introduced, spread in the environment in an uncontrolled way and cause some kind of damage to native species and/or imbalance to ecosystems, they are called "invasive exotic species". Therefore, not every species introduction results in a biological invasion, as introduced populations may not establish themselves in the new environment, remaining dormant or becoming extinct (Espínola & Júlio-Jr., 2007).

In general, species that show accelerated reproduction and growth, great ability to disperse and adapt to new environments, and a broad and flexible diet have a greater potential to become invasive (Leão *et al.,* 2011; Latini *et al.,* 2016). However, in addition to the biological attributes of the species, the characteristics of the environments can make them more susceptible to invasions. Anthropized habitats, for example, can be more easily invaded in relation to intact environments (Elton, 1958; Lodge, 1993; Bøhn *et al.,* 2004; Espínola & Júlio-Jr., 2007). The combination of these two factors – characteristics of species and environments – can determine whether an invasion will succeed or not.

The expansion of the human population and the increasing communication among continents and distant regions of the planet in recent centuries, combined with predatory development models without ecological concern, led to an increase in cases of *biological invasions,* so that this has

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become a global problem with records of invasive exotic species in virtually all ecosystems and involving almost all groups of organisms (Dechoum, 2009; Latini *et al.,* 2016, Neves *et al.,* 2019; Lima *et al.,* 2021). Specifically to fish, the main motivations for the introduction of exotic species are related to initiatives to increase fish production or repopulation of fish stocks, increase in sport fishing and use as ornamental species (Latini *et al.,* 2016).

Invasive exotic species have been identified as one of the main causes of biodiversity loss in the world and can cause several problems in ecosystems, altering ecological processes and interactions, such as predation and competition for food, spaces and breeding sites (Leão *et al.,* 2011; Latini *et al.,* 2016). In Brazil, studies have shown that the introduction of exotic fish species in some regions has caused a decrease in the richness of native ichthyofauna and the homogenization of aquatic biota (increased similarity, causing the substitution of native species for non-native ones (Mack *et al.,* 2000)). The introduction of exotic fish species, for example, can bring a series of diseases and parasites for which native species do not have defenses, and may even affect commercial crops (Latini *et al.,* 2016). In the Rio Doce basin, Souza *et al.* (2021) demonstrate that the invasion of several predatory fish, especially the two introduced piscivores tucunaré *Cichla kelberi* and piranha *Pygocentrus nattereri,* eroded the taxonomic and functional diversity of Neotropical freshwater fishes in natural lakes, including the extirpation of at least seven species.

The government agency for the environment of the state of Rio Grande do Sul, recognizing the need to manage these problems at a regional level, published an official list of invasive exotic species occurring in its territory (SEMA, 2013). This list contains 93 invasive exotic species (44 plants; two algae; 18 invertebrates, three of which are domestic; 19 terrestrial vertebrates, of which five are domestic, and 10 fish). In relation to fish, it also has a list of six species native to Rio Grande do Sul, but allochthonous in one or more watersheds in the state itself.

This study presents an updated knowledge on the number of exotic and allochthonous fish species for the state of Rio Grande do Sul, based on records of specimens in scientific collections and bibliographic information. We also provide the distribution and introduction vectors of these fish species throughout the Río Uruguay, Laguna dos Patos and Rio Tramandaí systems. The main impacts caused by the introduction into natural environments are presented and discussed.

MATERIAL AND METHODS

Study area

The Laguna dos Patos system is formed by three large lagoons: the Laguna dos Patos with 9,280 km^2, the Lagoa Mirim with 3,250 km^2 and the Lagoa Mangueira with 802 km^2 (Schwarzbold & Schäfer, 1984). Its main tributaries are the Jacuí, the Taquari-Antas, the Camaquã and the Jaguarão rivers. Most of this drainage is located in the state of Rio Grande do Sul, southern Brazil, with half of the west bank of the Lagoa Mirim and two major tributaries located in Uruguay. This area constitutes the "Laguna dos Patos Ecoregion" (334), recognized based on the distribution, composition and endemism of freshwater fish species (Abell *et al.,* 2008; Bertaco *et al.,* 2016).

The Río Uruguay is the smallest of the three main tributaries of the Río La Plata basin. The river extends for 1,838 km, with a drainage area of 365,000 km^2 (Di Persia & Neiff, 1986), originating in the Serra Geral formation in southern Brazil and flowing into the estuary of the Río de La Plata between Uruguay and Argentina. Its main tributaries are the rivers on the left bank: Negro, Quaraí, Ibicuí, Ijuí and Passo Fundo. The "Salto do Yucumã", a remarkable longitudinal waterfall that extends for 1.8 km along the Río Uruguay, in the northwest region of the state where Turvo State Park is located, divides the "lower Río Uruguay" (Ecoregion 332) and the "upper Río Uruguay" (Ecoregion 333, *sensu* Abell *et al.,* 2008; Bertaco *et al.,* 2016).

The Rio Tramandaí system is located in the northeast of the state of Rio Grande do Sul, and is divided into two subsystems of interconnected lagoons: one to the north of the Lagoa Tramandaí, formed by the Rio Tramandaí itself and the Lagoa Itapeva, the Lagoa dos Quadros, and a set of small lagoons in the Osório Municipality, and the second to the south, including a set of interconnected lagoons that reach the Lagoa da Porteira (Schwarzbold & Schäfer, 1984; Malabarba & Isaia, 1992). The Rio Tramandaí, together with the Rio Mampituba and Rio Araranguá (Santa Catarina State), constitutes the "Tramandaí-Mampituba Ecoregion" (Abell *et al.,* 2008; Bertaco *et al.,* 2016). In this study, only the occurrences for the Rio Tramandaí system are reported, since no record of exotic species was found for the Rio Mampituba basin in the Rio Grande do Sul State.

Scientific collections

Records in scientific fish collections were searched on SpeciesLink (https://specieslink.net), on the National Database of Invasive Exotic Species (https://bd.institutohorus.org.br/base-dados-nacional), and from information given by the curators of collections not available in these systems, such as MCN and MNRJ. The current nomenclature of the species was confirmed in the online "Eschmeyer's Catalog of Fishes" (Fricke *et al.,* 2022) and in the global fish biodiversity information system "FishBase" (Froese & Pauly, 2021). A brief history since the first record of exotic species from the state of Rio Grande do Sul, and comparative analysis of these records in Brazilian scientific collections by species, watershed, year and collection, are presented.

Records were taken from 15 fish collections from the following institutions: Instituto de Ciências Biológicas da Universidade Federal de Rio Grande (CIFURG); Universidade de Passo Fundo, Passo Fundo (CPUPF); Laboratório de Ictiologia de Ribeirão Preto, Faculdade de Filosofia, Letras e Ciências Humanas, Universidade de São Paulo, São Paulo (LIRP); Coleção Zoológica,

Museu de Biologia Professor Mello Leitão, Santa Teresa (MBML); Museu de Ciências Naturais, SEMA-RS, Porto Alegre (MCN); Museu de Ciências e Tecnologia, Pontifícia Universidade Católica do Rio Grande do Sul, Porto Alegre (MCP); Museu Nacional, Rio de Janeiro (MNRJ); Museu de Zoologia, Universidade Estadual de Londrina, Londrina (MZUEL); Museu de Zoologia da Universidade do Vale dos Sinos, São Leopoldo (MZUNISINOS); Museu de Zoologia da Universidade de São Paulo, São Paulo (MZUSP); Núcleo de Pesquisas em Limnologia, Ictiologia e Aquicultura, Universidade Estadual de Maringá, Maringá (NUP); Núcleo em Ecologia e Desenvolvimento Sócio-Ambiental (NUPEM), Universidade Federal do Rio de Janeiro, Macaé (NPM); Departamento de Zoologia, Universidade Federal do Rio Grande do Sul, Porto Alegre (UFRGS); and National Museum of Natural History, Smithsonian Institution, Washington D.C. (USNM).

Exotic and allochthonous species

The species presented here belong to the official list of invasive exotic species, according to SEMA (2013). The records of two species that are absent in the official list are further investigated based on recent published reports of occurrence out of their natural geographic distributions (Río La Plata basin, including the Río Uruguay). The palometa, *Serrasalmus maculatus* Kner, 1858 has been currently recorded in the Rio Jacuí basin, Laguna dos Patos system (UFRGS 28800, Bertaco *et al.,* 2022) (Tables 1 and 2); as well as the piava, *Megaleporinus macrocephalus* (Garavello & Britski, 1988) recently confirmed in the Laguna dos Patos system (Ramirez *et al.,* 2017) (Table 2). Information about ten exotic species and eight allochthonous species recorded in the main hydrographic basins of the state is presented, based on data from scientific collections and scientific articles. The species are presented in two groups identified as exotic or allochthonous, in alphabetical order of Order, Family, Genus and Species. The classification of families in Orders follows Van der Laan *et al.* (2022).

The invasive exotic species listed in the SEMA (2013), fall into two restriction categories (Table 1): **Category 1** – Refers to species that are prohibited from transport, breeding, release or translocation, cultivation, propagation (by any form of reproduction), trade, donation or intentional acquisition in any form; and **Category 2** – Refers to species that can be used under controlled conditions, with restrictions, subject to specific regulations.

RESULTS

Exotic species

According to Nomura (1977), the first introduction of exotic species in Brazil date from the end of XIX century and beginning of XX century, in the states of São Paulo and Rio de Janeiro: the carp, *Cyprinus carpio* Linnaeus, 1758, in 1882; rainbow trout, *Salmo gairdnerii* [currently a synonym of *Oncorhynchus mykiss* (Walbaum, 1792)] in 1913, 1949 and 1950; trout, *Salmo fario* [currently a synonym of *Salmo trutta* Linnaeus, 1758] in 1913; black-bass, *Micropterus salmoides* (Lacepède, 1802), in 1922; argentinian silverside, *Basilichthys bonariensis* [currently *Odontesthes bonariensis* (Valenciennes, 1835)] in 1930

Table 1. Invasive exotic species occurring in the river basins of the state of Rio Grande do Sul. BRU = Río Uruguay basin, SLP = Laguna dos Patos system, SRT = Rio Tramandaí system. * Estação Experimental de Piscicultura da Lagoa dos Quadros, Terra de Areia Municipality; ** Records based on photos and reports of fishermen according to Machado *et al.* (2015). Categories 1 and 2 according to SEMA (2013).

Ordem/Family/Species	Popular name	Origin	Basin	Categories
Centrarchiformes				
Centrarchidae				
Micropterus salmoides (Lacepède, 1802)	Black-bass	North America	SLP, BRU	1
Cypriniformes				
Cyprinidae				
Cyprinus carpio Linnaeus, 1758	Common carp	Europe and Asia	SLP, SRT**, BRU	2
Xenocyprididae				
Ctenopharyngodon idella (Valenciennes, 1844)	Grass carp	China and Russia	SLP, SRT**, BRU	2
Hypophthalmichthys molitrix (Valenciennes, 1844)	Silver carp	Asia	SLP, SRT**	2
Hypophthalmichthys nobilis (Richardson, 1845)	Big-head carp	Asia (China)	SLP, SRT**	2
Perciformes				
Cichlidae				
Coptodon rendalli (Boulenger, 1897)	Tilapia	Africa	SLP, SRT*, BRU	1
Oreochromis niloticus (Linnaeus, 1758)	Nile tilapia	Africa	SLP, SRT*, BRU	2
Salmoniformes				
Salmonidae				
Oncorhynchus mykiss (Walbaum, 1792)	Rainbow trout	North America	SLP, BRU	2
Siluriformes				
Clariidae				
Clarias gariepinus (Burchell, 1822)	African catfish	Africa and Asia	SLP	1
Ictaluridae				
Ictalurus punctatus (Rafinesque, 1818)	Channel catfish	United States	SLP	1

Table 2. Allochthonous species from river basins of the state of Rio Grande do Sul. BRU = Río Uruguay basin, SLP = Laguna dos Patos system, SRT = Rio Tramandaí system. * Records based on photos and reports of fishermen according to Machado *et al.* (2015). ** Species not included in the 2013 species list (SEMA, 2013). Categories 1 and 2 according to SEMA (2013).

Ordem/Family/Species	Popular name	Native	Allochthonous	Categories
Characiformes				
Acestrorhynchidae				
Acestrorhynchus pantaneiro Menezes, 1922	Peixe-cachorro	BRU	SLP, SRT	1
Anostomidae				
Megaleporinus macrocephalus (Garavello & Britski, 1988)	Piava	BRU	SLP	**
Erythrinidae				
Hoplerythrinus unitaeniatus (Spix & Agassiz, 1829)	Jejú	BRU	SLP	1
Hoplias lacerdae Miranda Ribeiro, 1908	Trairão	BRU	SLP	2
Serrasalmidae				
Serrasalmus maculatus Kner, 1858	Palometa	BRU	SLP	**
Piaractus mesopotamicus (Holmberg, 1887)	Pacu	BRU	SLP, SRT*	2
Perciformes				
Sciaenidae				
Pachyurus bonariensis Steindachner, 1879	Corvina-de-rio	BRU	SLP	2
Siluriformes				
Auchenipteridae				
Trachelyopterus lucenai Bertoletti, da Silva & Pereira, 1995	Porrudo	BRU	SLP, SRT	1

and 1935 (latter discovered as also native from Rio Grande do Sul coastal lagoons); blue-gill, *Lepomis macrochirus* Rafinesque, 1819, in 1922; and tilápias, *Tilapia rendalli* [currently *Coptodon rendalli* (Boulenger, 1897)] in 1953, *Tilapia hornorum* [currently a synonym of *Oreochromis urolepis* (Norman 1922)] and *Tilapia nilotica* [currently *Oreochromis niloticus* (Linnaeus, 1758)] in 1971.

In the state of Rio Grande do Sul, based on the database of scientific collections of fish, the first records of exotic freshwater species in natural environments occurred in 1965 with specimens of black bass *Micropterus salmoides* captured in the lake of Barragem do Salto, São Francisco de Paula Municipality (MCN 1685). In 1967, another specimen of black bass was recorded in a reservoir in Novo Hamburgo Municipality (MCN 2064). In the following year (1968), records of common carp and tilapia occurred in Novo Hamburgo Municipality (*Cyprinus carpio,* MCP 8770; and *Coptodon rendalli,* MCP 8659). In the 1970s, there are several records of these two species mainly in the Campos de Cima da Serra region, all cataloged in the fish collection of MCP. Until this period, all records occurred in the Laguna dos Patos system, but in the following decade (1980s), in addition to these species continuing to be recorded in this hydrographic system, *Coptodon rendalli* and the rainbow trout *Oncorhynchus mykiss* were recorded in the upper Río Uruguay basin, and Nile tilapia *Oreochromis niloticus* from the lower Río Uruguay. From 1979 onwards, with the implementation of the "Estação Experimental de Produção de Alevinos da Lagoa dos Quadros" in Terra de Areia Municipality, a lake belonging to the Rio Tramandaí system, records of *C. carpio* and *O. niloticus* from this station were cataloged in scientific fish collections of the MCN and MCP.

In the 1990s, there are few records of exotic species in scientific collections, only of *C. carpio* and *O. niloticus* from the reservoir of the Itaúba Hydroelectric Power Plant located in the Rio Jacuí, all cataloged in the MCN fish collection. In the following decades (2000 to 2020), with the formation of new masters and doctors in ichthyology and ecology (Bertaco *et al.,* 2016) and with the financial resources available to carry out scientific research, the records of exotic species in scientific collections began to increase, including species not yet captured in natural environments of the state. By that time other species of carp were recorded such as *Ctenopharyngodon idella* (Valenciennes, 1844) in 2003 and *Hypophthalmichthys nobilis* (Richardson, 1845) in 2014, the channel catfish *Ictalurus punctatus* (Rafinesque, 1818) in 2002 and the African catfish *Clarias gariepinus* (Burchell, 1822) in 2003. These ten species are distributed in five orders, nine genera and seven families (Table 1).

Considering the total number of records of exotic species in scientific collections between 1965 and 2020 (Fig. 1), *C. carpio* is the species with most records (39; corresponding to 27.5% of the total), followed by *M. salmoides* (31; 21.8%), *C. rendalli* (29; 20.4%) and *O. niloticus* (22; 15.5%). No records were found in scientific collections for the big-headed carp (*H. molitrix*). The high number of records found for black-bass and tilapia is due to several records cataloged with only one individual

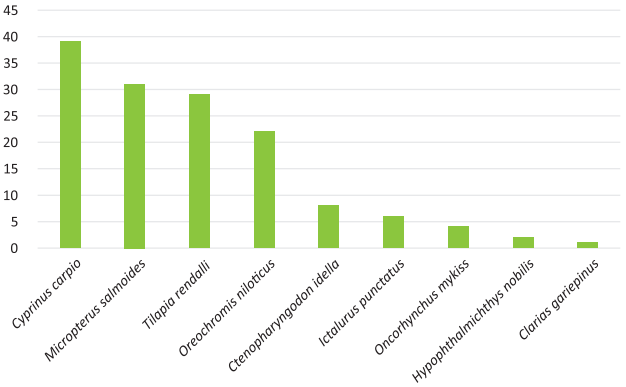

Figure 1. Total number of records of exotic species cataloged in scientific collections between 1965 and 2020. No records were found in scientific collections for the big-headed carp *Hypophthalmichthys molitrix.*

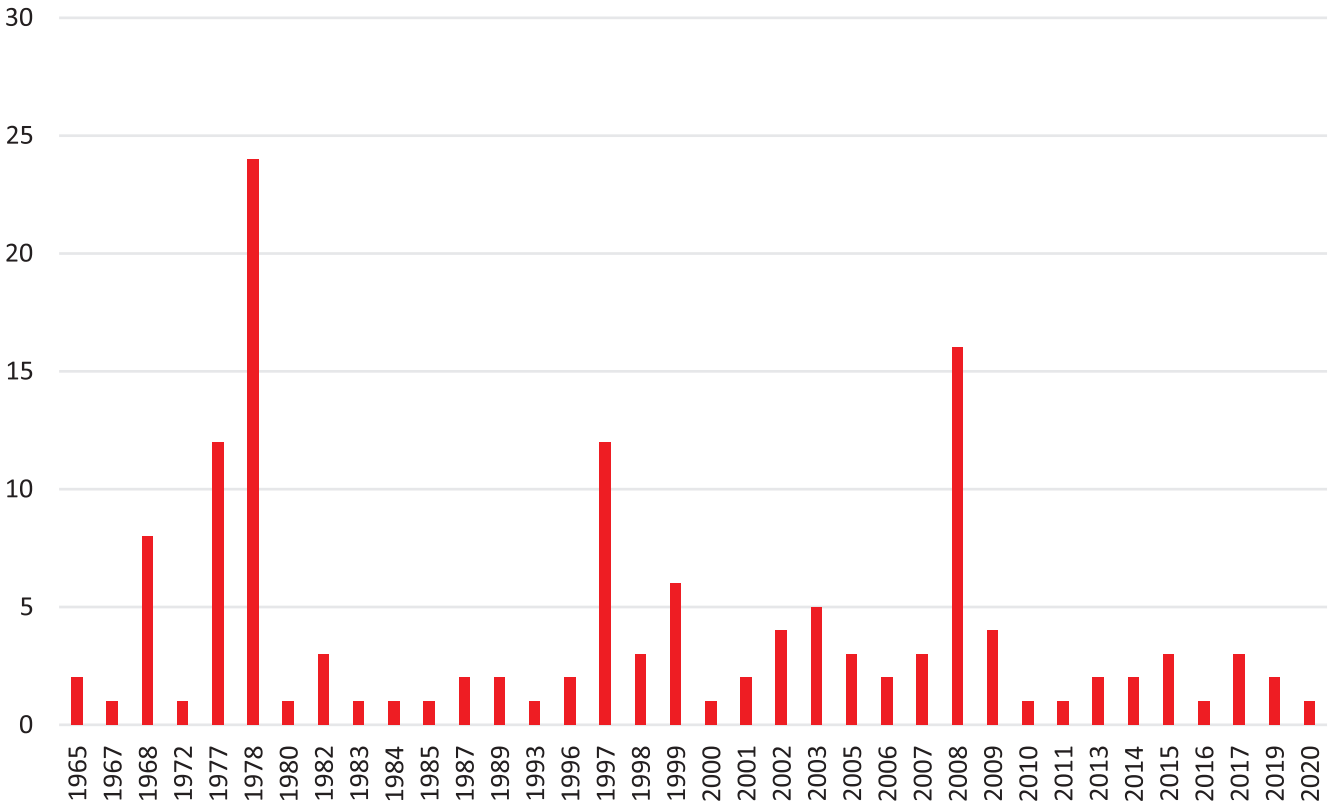

Figure 2. Total number of records of exotic species per year cataloged in scientific collections between 1965 and 2020.

from the same locality; most black-bass records are from Vacaria Municipality in 1978 and for tilapia are from Bento Gonçalves Municipality in 1977 (Fig. 1). The largest number of records presented by the common carp is possibly due to its being the first exotic species introduced in the country in 1882 (Nomura, 1977), and, consequently, one of the most cultivated species in fish farming (Baldisserotto, 2009), in together with its varieties, such as the mirror carp.

Considering the total number of records of exotic species recorded per year in scientific collections between 1965 and 2020 (Fig. 2), the years with the highest number of records were 1978 (24; corresponding to 17% of the total), 2008 (16; 11.3%), 1977 and 1997 (both with 12; 8.5%). Many of these records only make reference to the municipality where the material came from, not presenting more precise information about the location of the collection site. The high number of records found in 2008 and 1997 is directly related to the increase in ichthyofauna studies carried out in dams, hydroelectric plants and small hydroelectric plants, as these surveys and monitoring are required by the responsible environmental agencies as a means of mitigating the impacts caused by the implementation of these projects.

As well as the number of records in the collection, the number of articles that record the occurrence of non-native species (including exotic and allochthonous species) of freshwater fish in the Neotropics has increased significantly over the years, especially in the last two decades (Gubiani *et al.,* 2018). Knowledge of the fish fauna of a region or watershed is closely related to the collection effort (Bertaco *et al.,* 2016), and the availability of financial resources to develop research projects. According to Bertaco *et al.* (2016) from the 1990s to 2015 the number of freshwater species described for the state of Rio Grande do Sul increased considerably when compared to previous decades, mainly due to the increase in human and financial resources destined for this purpose.

Regarding the total number of records of exotic species per hydrographic basin, the highest number occurred in the basins of the Laguna dos Patos (89; 70.6%), the upper Río Uruguay (24; 19%), the lower Río Uruguay (7; 5.5%) and the Rio Tramandaí (4; 3.2%) (Fig. 3). Some black bass records were not accounted for, as it was not possible to locate the watershed due to incomplete source data, as the registered municipalities cover more than one watershed. The scientific collections with the highest number of records of exotic species were MCP (87; 61.3%), UFRGS (21; 14.8%) and MCN (18; 12.7%), among the nine collections analyzed and with information on exotic species in the state (Fig. 4).

Allochthonous species

The eight allochthonous species are distributed in three orders, eight genera, and six families (Table 2). The piava *Megaleporinus macrocephalus* (Anostomidae), pacu *Piaractus mesopotamicus* (Serrasalmidae, Fig. 5), peixe-cachorro *Acestrorhynchus pantaneiro* (Acestrorhynchidae), jejú *Hoplerythrinus unitaeniatus,* traírão *Hoplias lacerdae* (Erythrinidae), porrudo *Trachelyopterus lucenai* (Auchenipteridae), and corvina-de-rio *Pachyurus bonariensis* (Sciaenidae), have a natural distribution encompassing the Río Uruguay basin. Over the last two decades (except for *T. lucenai* recorded

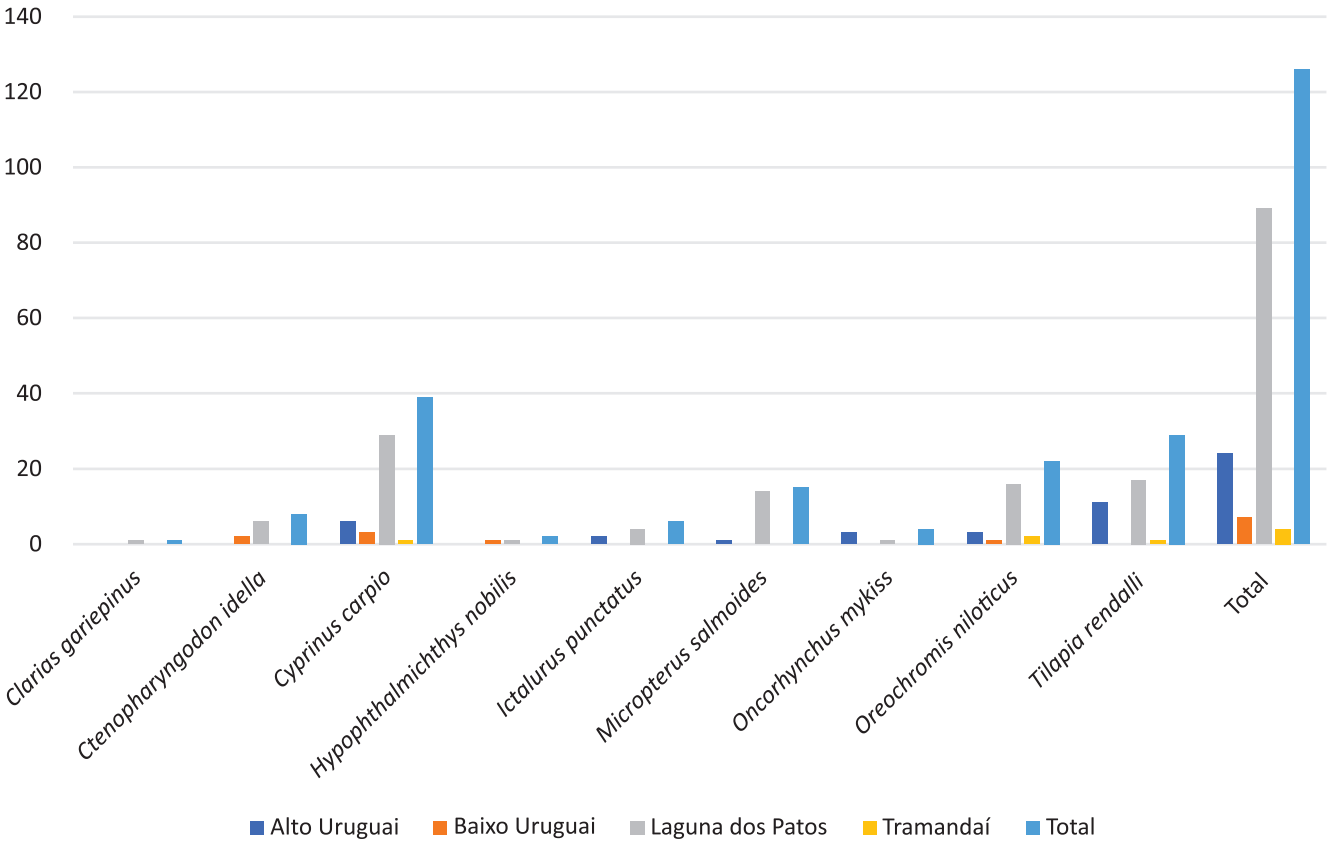

Figure 3. Total number of records of exotic species by drainage basin cataloged in scientific collections between 1965 and 2020. No records were found in scientific collections for the big-headed carp *Hypophthalmichthys molitrix.*

in the Laguna dos Patos system since 1989 by Bertoletti *et al.,* 1995), they have been captured and recorded in the Laguna dos Patos and/or Rio Tramandaí (Bertaco *et al.,* 2016), and the number of records and individuals has increased in recent years.

The first allochthonous species recorded in the state was *H. lacerdae* collected in 1977, in the Ernestina Dam, Rio Jacuí basin (MZUSP 25026), and its occurrence was confirmed later (Malabarba, 1989; Oyakawa & Mattox, 2009). Later, *T. lucenai* was collected in the Lago Guaíba in 1989 and its occurrence recorded by Bertoletti *et al.* (1995). Although *M. macrocephalus* had been cataloged in fish collection in 2003 (MCP 33404), the identification

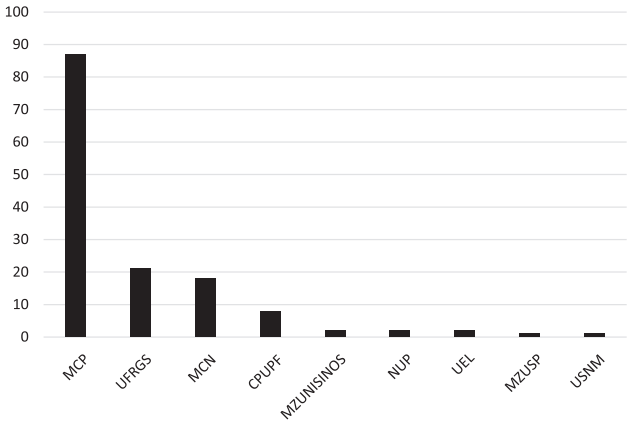

Figure 4. Total number of records of exotic fish species cataloged in scientific collections between 1965 and 2020.

of the species for the basin was only made in 2016 (Bertaco *et al.,* 2016). *Pachyurus bonariensis* was collected in the Lago Guaíba in 2002 (Dufech & Fialho, 2007), two years later *A. pantaneiro* was captured in the Delta do Jacuí in 2004 (Saccol-Pereira *et al.,* 2006). According to Dufech & Fialho (2007) *P. bonariensis* is widely distributed and adapted to the Laguna dos Patos system, and the capture of several sexually mature females suggests reproductive activity and indicates that the species is established in the system. *Hoplerythrinus unitaeniatus* and *P. mesopotamicus* had their occurrence recorded in the Rio dos Sinos basin by Leal *et al.* (2009). Although the last species had already been cataloged in fish collection in 2003 (a specimen from Rio Gravataí, MCN 17139), there were doubts about the accuracy of this record. Leal *et al.* (2009) pointed out that the reasons for the introduction of *A. pantaneiro, P. bonariensis,* and *T. lucenai* in the Rio Jacuí basin are natural, and the occurrence of *H. unitaeniatus* is accidental. We disagree with those authors, as these species invaded the Rio Jacuí basin through some artificial connection between basins (Bertaco *et al.,* 2016; 2022). In the Rio Tramandaí system, even though there were specimens already cataloged in fish collections since 1995 (Lagoa do Quintão, MCP 17596, 1 ex., collected by A.R. Cardoso) and 1997 (Rio Maquiné, MCN 14072, 1 ex.), the first published record of *T. lucenai* was in 2004 based on specimens from Lagoa Fortaleza (Schifino *et al.,* 2004). *Acestrorhynchus pantaneiro* was captured in the Lagoa Fortaleza and Lagoa das Malvas in 2008 (Artioli *et al.,* 2013) (Figs. 6-8).

Figure 5. *Piaractus mesopotamicus* (pacu) MCN 17139, 201.0 mm SL, between the mouth of the Rio Gravataí and the Ilha Humaitá, Delta of the Rio Jacuí, Laguna dos Patos system. Photo: Vinicius A. Bertaco.

After the first occurrences of *A. pantaneiro, P. bonariensis,* and *T. lucenai* in the invaded basins, these species were captured frequently and in relative high abundance, indicating that they are possibly already established in these environments (Becker, 1998, 2001; Dufech & Fialho, 2007; Artioli *et al.,* 2013; Maia *et al.,* 2013). Figures 9-11 show the number of records in fish collection over the years of these three species in the Laguna dos Patos and Rio Tramandaí systems. *Trachelyopterus lucenai* was the first species to invade the Laguna dos Patos system (in

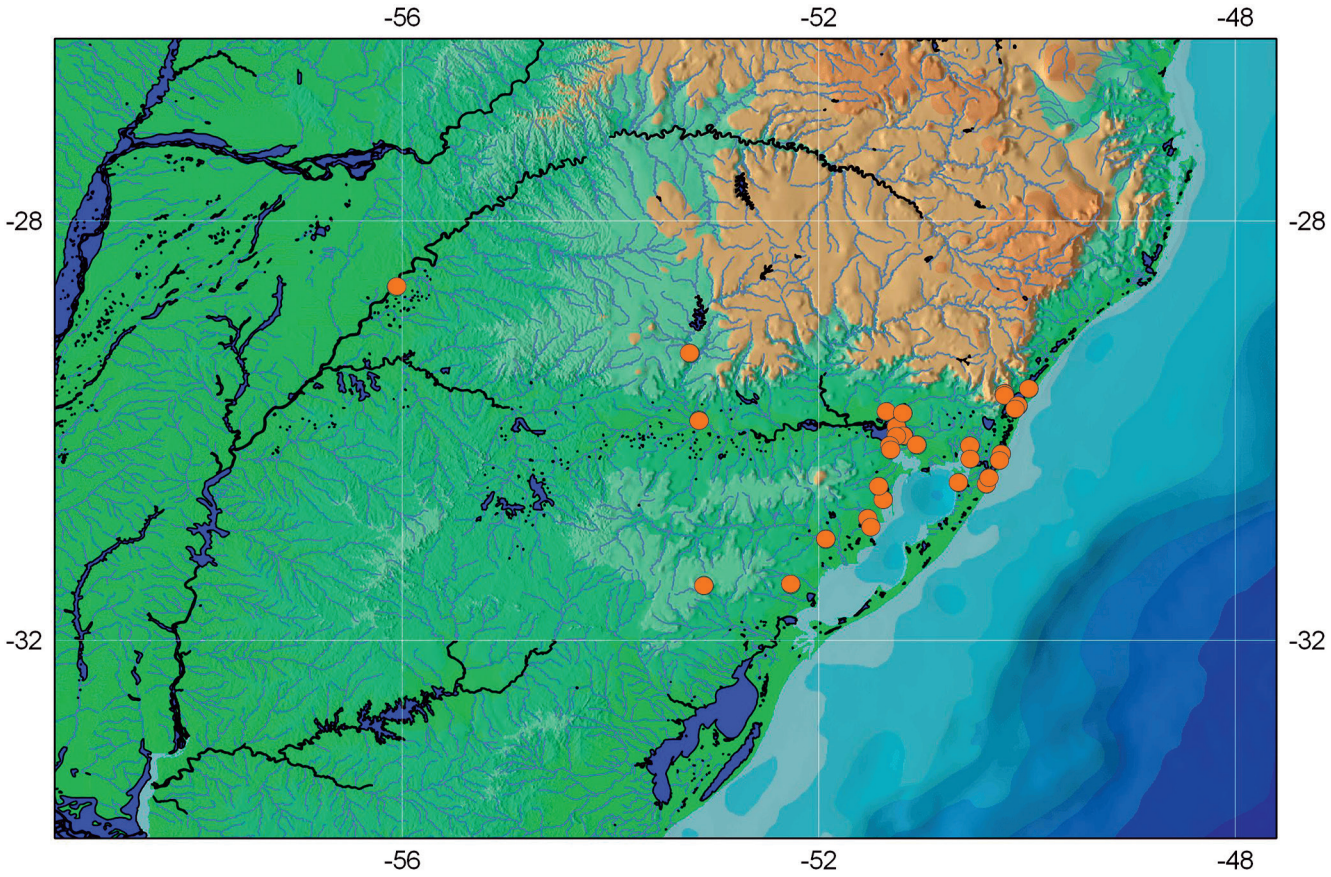

Figure 6. Distribution of records of *Trachelyopterus lucenai* in Río Uruguay, Laguna dos Patos and Rio Tramandaí basins.

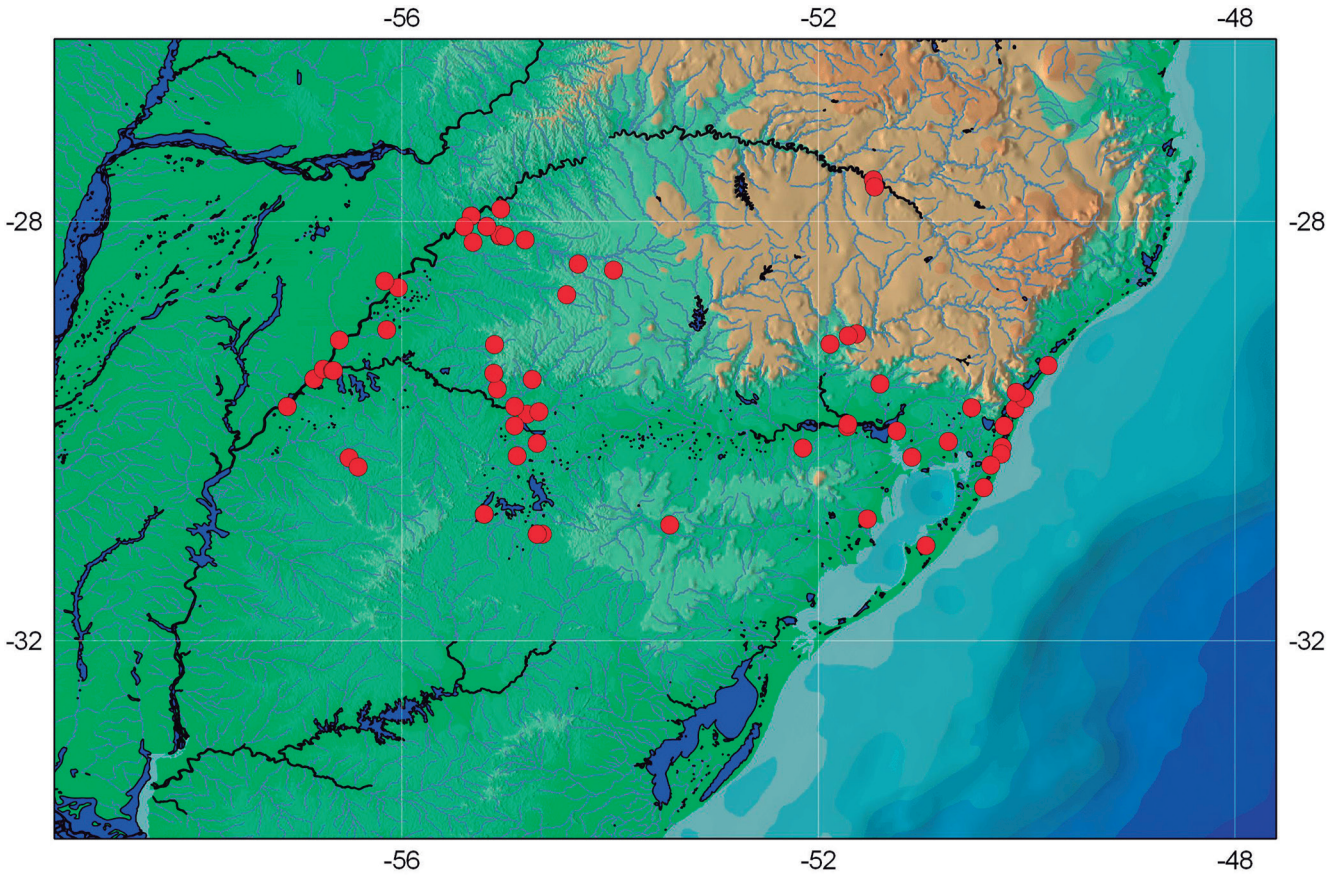

Figure 7. Distribution of records of *Acestrorhynchus pantaneiro* in Río Uruguay, Laguna dos Patos and Rio Tramandaí basins.

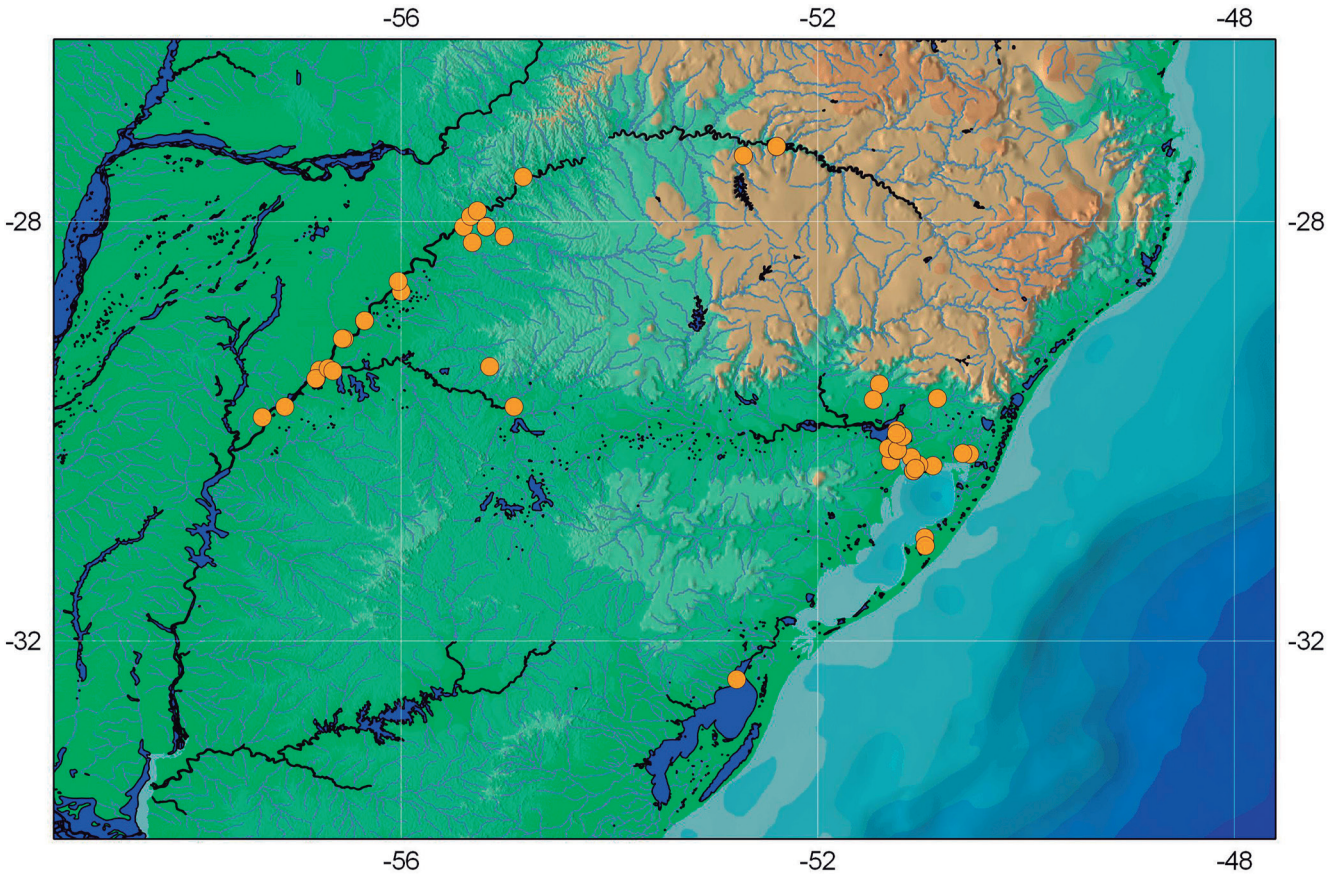

Figure 8. Distribution of records of *Pachyurus bonariensis* in Río Uruguay and Laguna dos Patos basins.

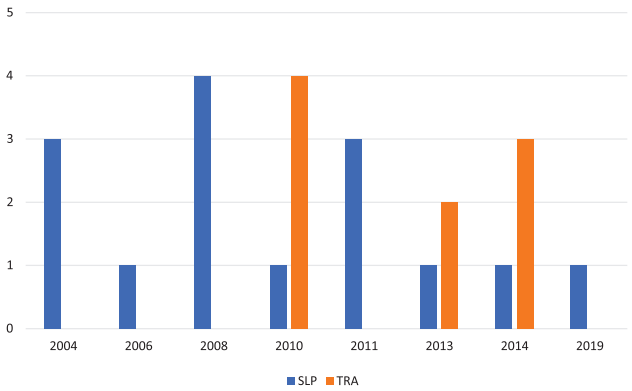

Figure 9. Number of records of allochthonous species *Acestrorhynchus pantaneiro* recorded over the years in the Laguna dos Patos (SLP) and Rio Tramandaí (TRA) systems according to scientific collections databases.

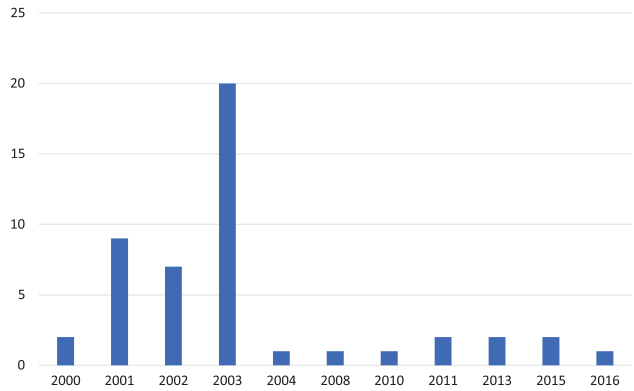

Figure 10. Number of records of allochthonous species *Pachyurus bonariensis* recorded over the years in the Laguna dos Patos (SLP) system according to scientific collections databases. No record of this species was found in the fish collections.

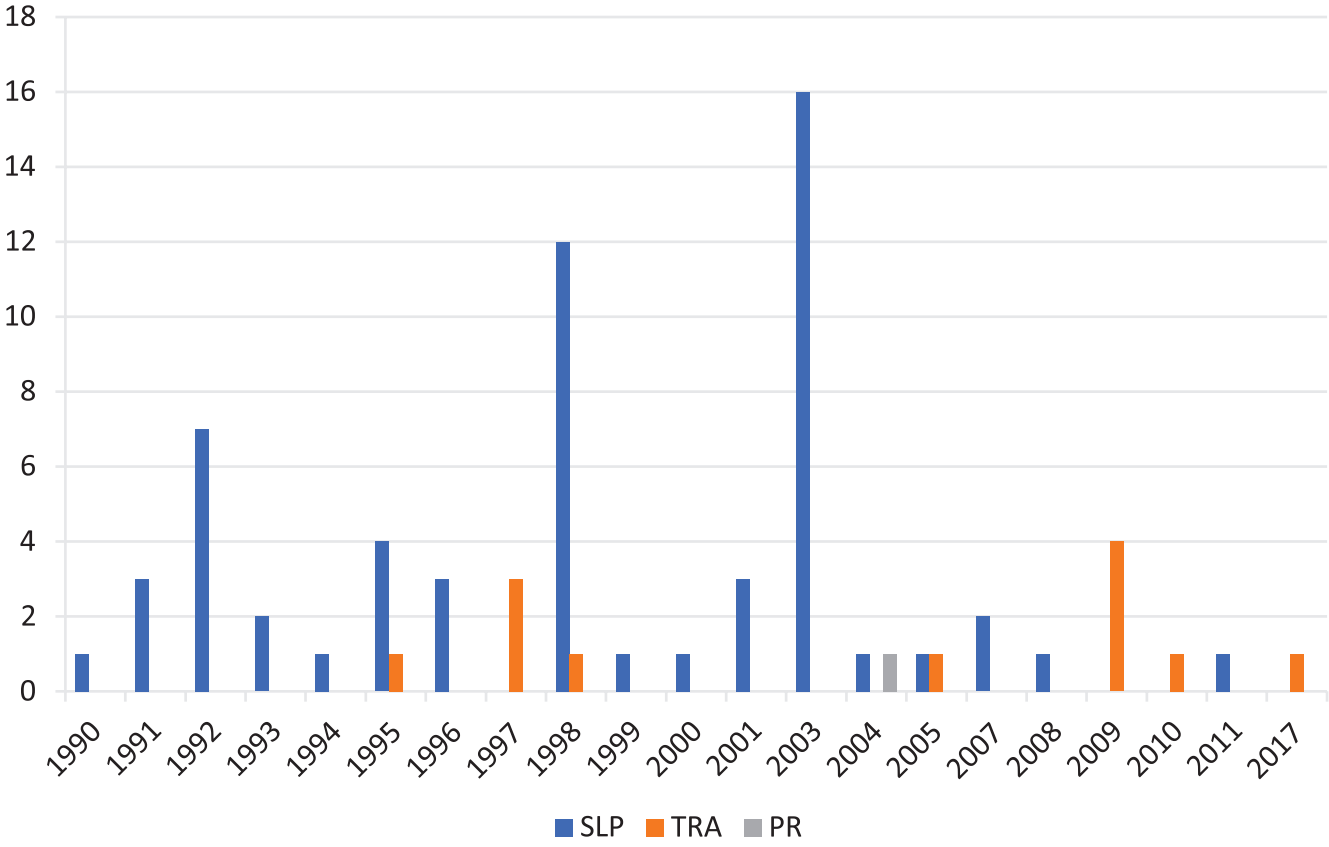

Figure 11. Number of records of allochthonous species *Trachelyopterus lucenai* recorded over the years in the Laguna dos Patos (SLP) and Rio Tramandaí (TRA) systems according to scientific collections databases. PR = First published record for the Rio Tramandaí system (Schifino *et al.,* 2004).

1990) and 10 years before the other species, and was also the first to reach the Rio Tramandaí system, 15 years before *A. pantaneiro*. No record of *P. bonariensis* in the Rio Tramandaí system was found in the fish collections. It is important to note that all the first records of these three species in the Laguna dos Patos system were in the Delta do Jacuí region, where the confluences of the Rio Jacuí, Rio Caí, Rio dos Sinos, and Rio Gravataí are located, which flow into Lago Guaíba. The first records of *T. lucenai* in the Rio Tramandaí system was in the Rio Maquiné in 1997 (MCN 14072) and in the Lagoa Fortaleza in 1998 (MCN 17084), and of *A. pantaneiro* in the Lagoa Fortaleza in 2008 (UFRGS 12066, Artioli *et al.,* 2013). On the other hand, all these records can make it easier to find the main access routes for allochthonous species in the invaded basins, especially records in the Lagoa Fortaleza.

More recently, the palometa *Serrasalmus maculatus* (Serrasalmidae, Fig. 12) has been captured by riverine fishermen in several places in the Rio Jacuí, in the Laguna dos Patos system, and publicized in digital media since the end of 2020 (Bertaco *et al.,* 2022). This species occurs naturally in Rio Amazon and Rio Paraná-Paraguay basins, including Río Uruguay basin (Bertaco *et al.,* 2016; Fricke *et al.,* 2022). It is not known for sure how these species are transposing the Río Uruguay basin to the adjacent basins, but it is suspected that there are one or more artificial connections built for the irrigation of crops and/or water catchment for consumption in the central region of the state, possibly

Figure 12. *Serrasalmus maculatus* (Palometa), UFRGS 28800, 75.1 mm SL, arroio dos Lourenços, tributary of the Rio Vacacaí, Laguna dos Patos system. Photo: Juliano Ferrer.

between the basins of the Rio Vacacaí (Laguna dos Patos system) and the Rio Ibicuí (Río Uruguay basin). In this region, the tributaries of these basins are very close to each other and, also, there are several areas with irrigated rice plantations where the use of artificial irrigation is necessary for the development of the plants, mainly in the summer months, the driest period in the state of Rio Grande do Sul. This proximity to tributaries of different basins and possible connections had already been pointed out since 1978 by Bertoletti & Bertoletti (1978).

So far, there are no specific studies about these species and their impacts on the invaded environment and native fauna, but as most of them are omnivorous, carnivorous and/or ichthyophagous, we can infer that the most significant impacts will be on competition for food and on predation of native species, in addition to occupying spaces for shelter and reproduction that used to belong to native species. Also, we cannot ignore the risk of extinction of endemic species with restricted distribution (*e.g.,* endemic species of Campos de Cima da Serra) by invasive species.

In addition to these species, the *Aphyocharax anisitsi* Eigenmann & Kennedy, 1903 and the *Serrapinnus calliurus* (Boulenger, 1900) (Characidae), both naturally distributed in the Río Uruguay basin, are possibly allochthonous in the Laguna dos Patos and Rio Tramandaí systems (in the latter only *A. anisitsi*). Another possible species introduced into the Laguna dos Patos system is the spotted surubim *Pseudoplatystoma corruscans* (Spix & Agassiz, 1829), with a natural distribution in the Rio São Francisco, Rio Paraná and Río Uruguay basins (Bertaco *et al.,* 2016; Fricke *et al.,* 2022), but with only one record of a fish in collection from the Laguna dos Patos in 2004 (MCP 35075). It is suspected that it could be escaped from fish farming facilities or intentional release.

Records of exotic freshwater fish species in Brazil

Based on SpeciesLink queries to obtain records of the 10 exotic species presented here, 1,255 records were found in 22 Brazilian and foreign collections. It should be noted that not all databases of Brazilian collections are available on this platform. Of these, 1,070 records had complete information including year and status of origin. These records come from 21 states plus the Distrito Federal, and no records were found for the states of Acre, Amapá, Maranhão, Sergipe and Tocantins in this database, but this does not mean that these exotic species did not occur in these states. The states with the most records in collections are: Paraná (335; 26.7%), São Paulo (298; 23.7%), Bahia (146; 11.6%), Rio Grande do Sul (97; 7.7%), Espírito Santo (91; 7.2%), and Minas Gerais (81; 6.4%) (Fig. 13). Most records for the states of Paraná and São Paulo are for tilapias *O. niloticus* and *C. rendalli.* Although there are few records available in collections for Minas Gerais (or these collections are not available in websites), however, in this state 44 non-native fish species (25 are exotic) are found only in the Rio Paraíba do Sul basin, and all of them come from the largest ornamental aquaculture center in the country (Magalhães *et al.,* 2021). According to the study by Gubiani *et al.* (2018), the Alto Rio Paraná ecoregion has the highest number of non-native fish species (105 species), followed by the Iguaçu (27), Paraíba do Sul (22) and Northeast Atlantic Forest (21) ecoregions.

Records of exotic species in scientific collections began in 1900 with a record of *Coptodon rendalli* (DZSJRP 3011) and another in 1949 of *Cyprinus carpio* (MZUSP 22182). In the 1950s no records were found, with only a few in the following decade of these species plus *Micropterus salmoides* (MCP 3809) and *Oncorhynchus*

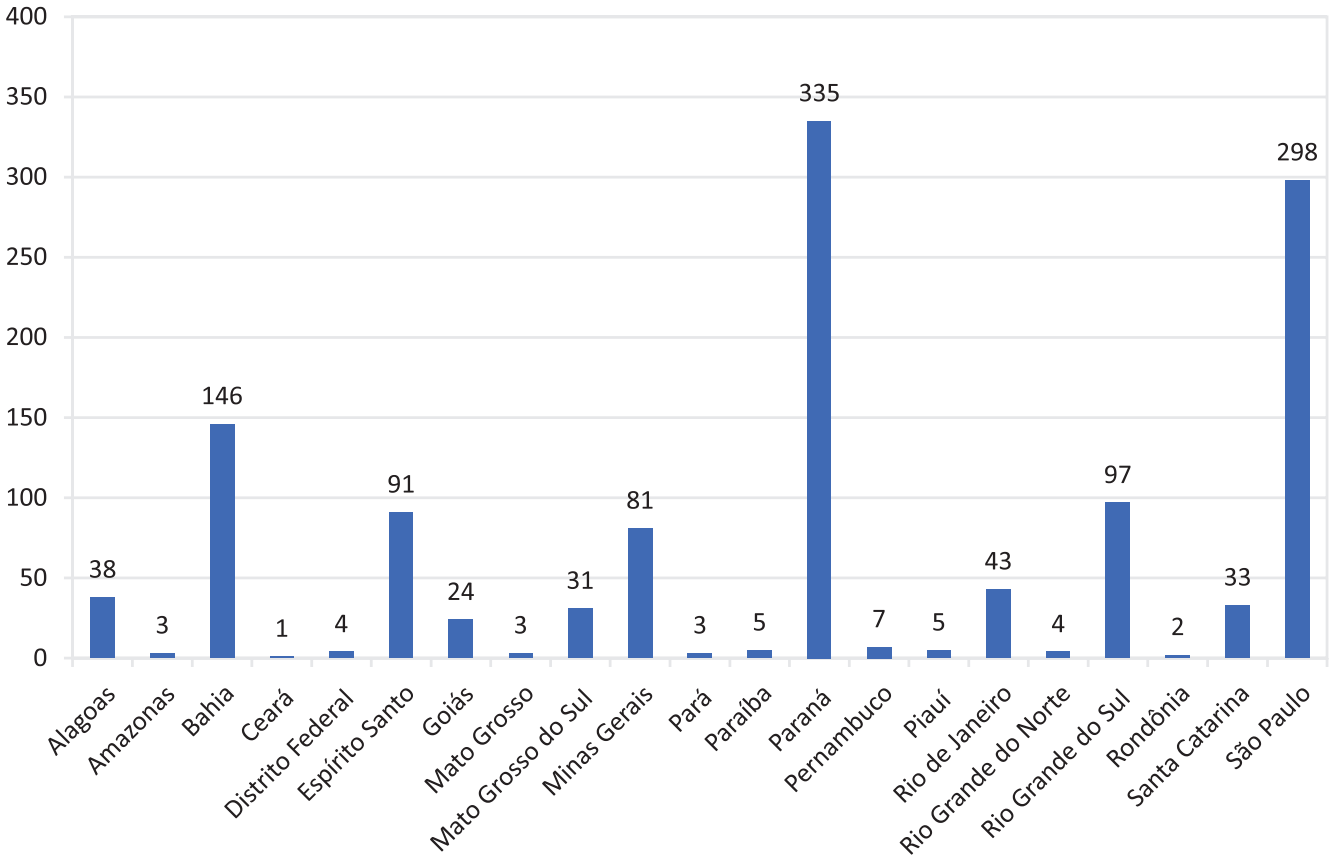

Figure 13. Number of records of exotic species by Brazilian states according to scientific collections databases.

mykiss (MZUSP 85379). It was only between 1971 and 1980 that the number of records increased, including *Oreochromis niloticus* with its first record in 1976 (MBML 2910). In the following decades there was a large increase in records and other exotic species in collections, the last two decades with the highest number, between 2001-2010 (414 records) and 2011-2020 (345 records) (Fig. 14). During this period, especially after 1970, there was an improvement and development of fish farming in the country, mainly driven by government agencies, and most of these records come from leaks from facilities such as tanks and ponds used in this activity, in addition to intentional releases in natural environments (*e.g.,* rainbow trout). Of the total records, 508 (47.4%) are from *Coptodon rendalli* (including *Tilapia rendalli* and *Tilapia* sp.) and 376 (35.1%) are from *Oreochromis niloticus* (Figs. 15-16). Tilapia represents more than 82% of the total records in collections. The other species with much less records, such as *Cyprinus carpio* (5.7%), *Clarias gariepinus* (3.5%), *Micropterus salmoides* (3.4%), and the rest with 1.4% or less (Fig. 16).

Also, in addition to these species, four more exotic species with records in the country were found in the searches on SpeciesLink and Base de Dados Nacional de Espécies Exóticas Invasoras: the Congo tilapia *Tilapia melanopleura* (currently valid name is *Coptodon zilli* (Gervais, 1848)) in the MHNCI collection with several records from the Instituto Agronômico do Paraná (IAPAR), located in Ponta Grossa, but all without date of collection; the zebra tilapia *Heterotilapia buettikoferi* (Hubrecht,

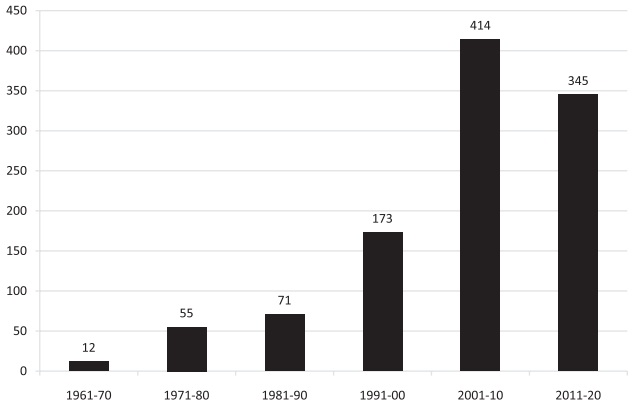

Figure 14. Number of records of the ten exotic species found in Brazil by decades between 1960 and 2020 according to scientific collections databases.

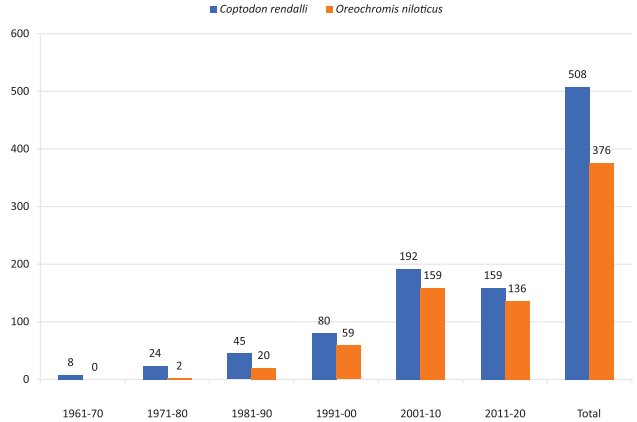

Figure 15. Number of records per decade between 1960 and 2020 of the two exotic species with the highest number of records in scientific collections.

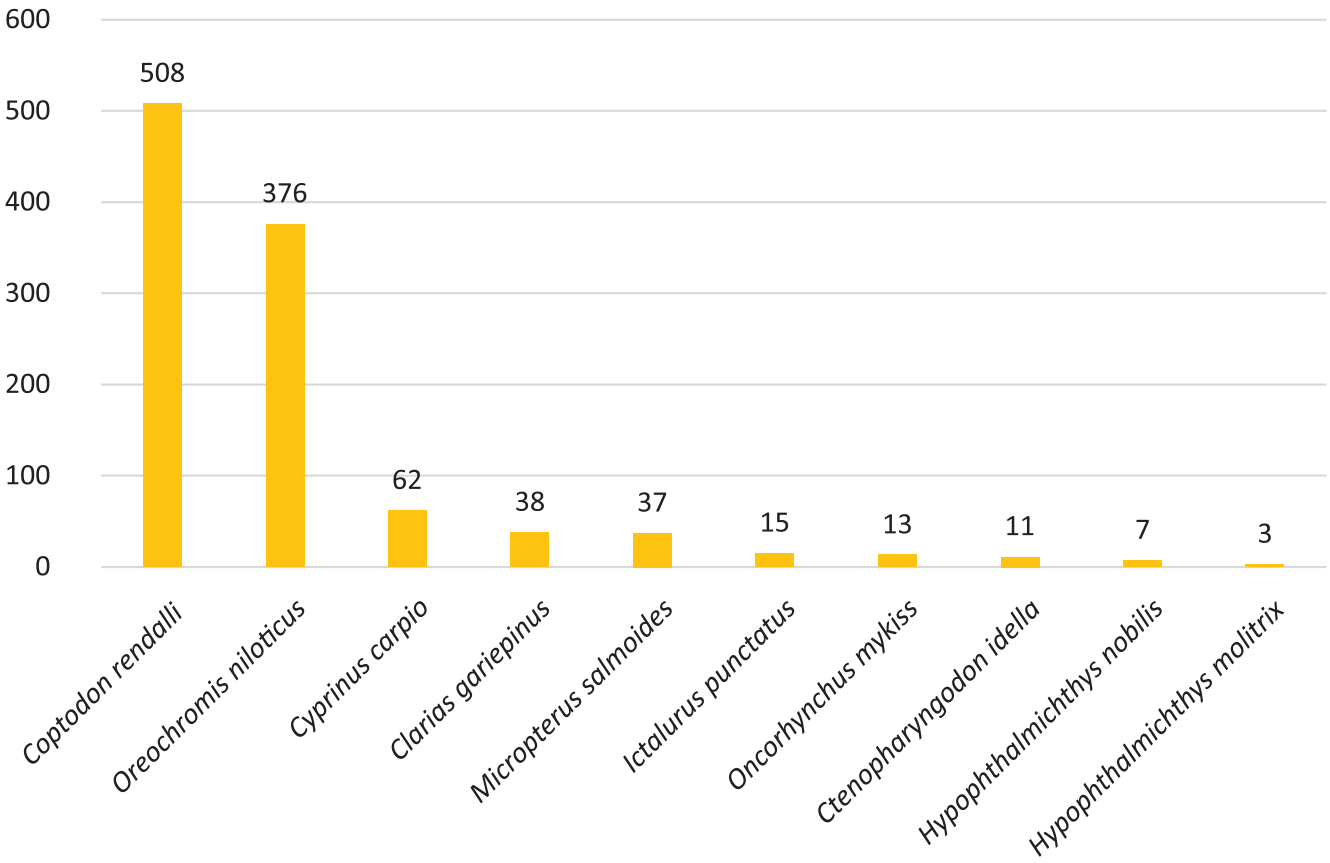

Figure 16. Number of records of exotic fish species introduced in Brazil according to scientific collections databases.

1881) from the Rio Uberabinha, Uberlândia, Minas Gerais, in 2017; the long-finned tilapia *Oreochromis macrochir* (Boulenger, 1912) from rivers and reservoirs in the states of Bahia and Paraíba; and Mozambican tilapia *Oreochromis mossambicus* (Peters, 1852) from reservoirs in Paraíba. All these species are exotic from the African continent and were introduced in artificial and natural environments in the country. The introduction of more of these species only increases our concern with natural environments and native species, as the impacts are imminent, and we do not know if other impacts may arise with these introductions, such as the introduction of parasites and diseases still unknown in the country.

DISCUSSION

Exotic species were first introduced in Brazil for the purpose of sport fishing, food and ornamentation. In 1882, the first import of carp (*Cyprinus carpio*) was made (Nomura, 1977). In 1900, the black bass, *Micropterus salmoides,* and in 1913 the rainbow trout, *Oncorhynchus mykiss,* were imported, and later, other exotic species were bred in fish farming that we know today (Baldisserotto & Gomes, 2005).

In Rio Grande do Sul State, the first fingerling fish production station was the Estação Experimental de Piscicultura da Lagoa dos Quadros, in Terra de Areia Municipality. It started in 1942 the reproduction and distribution of the peixe-rei *Odontesthes bonariensis* (Valenciennes, 1835), followed in the next years with the reproduction of other native (*Rhamdia* sp., *Geophagus brasiliensis* (= *G. iporangensis*), and *Hoplias lacerdae*) and exotic species (*Cyprinus carpio* and *Oreochromis niloticus*) (Mardini & Mardini, 2000). Fish farming in the state took off in the 1970s (Mardini *et al.,* 1997), and was disseminated to small rural properties with dams as a supplementary activity to the farmer's income and leisure. However, the information disclosed was related to the production of fish for subsistence and regional trade, but little was disclosed about the care of probable escapes from the dams to the natural environment, such as rivers, streams and lagoons.

Most of these dams and reservoirs are built with mud rammed earth from the property itself without using waterproof material and no system to prevent possible escapes of exotic species into the natural environment; and sometimes there is only one net to prevent escape at the outlet of the dam's outflow point. In Rio Grande do Sul State there are periods with heavy rains in certain years, and due to this, escapes are inevitable, as occurred in the municipality of Cristal in September 2007, where fish from eight artificial ponds were carried by the flood to the Rio Camaquã, Laguna dos Patos system (Troca, 2009). It was unclear which species were being bred in these artificial ponds, but they were likely exotic.

It should be noted that little has been done to measure and mitigate the impacts on native fauna caused by the intentional or accidental introduction of exotic fish into natural environments in the state. In recent years, however, this concern has increased in the scientific community, as shown by published studies on the

deleterious effects of exotic species on native fauna (Latini & Petrere-Jr., 2004; Canonico *et al.,* 2005; Pereira & Vitule, 2019) and also by the increase in records of exotic species in the natural environment in Rio Grande do Sul State (Braun *et al.,* 2003; Wincler-Sosinski, 2004; Garcia *et al.,* 2004; Becker *et al.,* 2013; Machado *et al.,* 2015; Fontoura *et al.,* 2016; Bertaco *et al.,* 2016, 2022).

Although the collections and studies of freshwater fish in the state of Rio Grande do Sul began in the 19th century (in 1863) with the arrival of the German naturalist Reinhold F. Hensel (Malabarba, 1989; Bertaco *et al.,* 2016) and continued with the arrival of other naturalists in the following century, the registration of exotic species in scientific collections began only in 1965. That is more than 100 years after the first expeditions in the state. This period coincides with the beginning of the development of fish farming in the state with the creation of exotic species in fish farming stations and also with the beginning of biological collections in the state. Currently, it can be considered that the main hydrographic basins of the state are relatively well sampled, except for a few areas where there is a lack of sampling, such as, for example, a small part of the northwest and southwest regions of the state. Also, the freshwater ichthyofauna is almost fully known and described, with at least 430 species recorded (Bertaco *et al.,* 2016, fig. 2; Fricke *et al.,* 2022). Despite this, the number of records of exotic species is very low in the main scientific collections of fish in the state of Rio Grande do Sul (MCN, MCP, and UFRGS, 125 records, most with only one fish per record, which may be related to the absence effort directed at capturing these species, which are often not collected by more traditional methods and, mainly, because exotic species are not so well established in natural environments.

In a study on the ichthyofauna of the Rio das Antas basin, six exotic species were captured (*Cyprinus carpio, Ctenopharyngodon idella, Hypophthalmichthys nobilis, Micropterus salmoides, Ictalurus punctatus,* and *Oreochromis niloticus*), and the low captures of these species would indicate that most of them are not established in the middle section of this basin, resulting from cultivation escapees and deliberate releases (in the case of black bass) according to Agostinho *et al.* (2010). In addition, those authors suggested that the common carp *C. carpio* could be the only one to reproduce in the system, due to its greater distribution and abundance compared to other exotic species, although this hypothesis needs to be proven.

Frequent captures of *Cyprinus carpio* and *Oreochromis niloticus,* as well as the existence of self-sustaining populations of the latter species around the islands that form the Delta do Jacuí, Laguna dos Patos system, were reported by commercial fishermen in the region, although recognition of these exotic species as established is still controversial, since escapees from aquaculture facilities are common and reproduction in the natural environment is not yet documented by scientific research (Fontoura *et al.,* 2016).

The records of exotic species in the region of the upper Río Uruguay and upper Rio Taquari-Antas (a tributary of the Rio Jacuí, Laguna dos Patos system) are problematic because they have the potential to impact upon the native species through competition, predation and diseases. These drainages are located in the northeast regions of the Rio Grande do Sul and southeast of Santa Catarina states recognized as Campos do Planalto das Araucárias, where the ichthyofauna is highly endemic, with several species restricted to high-altitude rivers and streams (Malabarba *et al.,* 2009; Ferrer & Malabarba, 2013). The endemic species of fish occurring in the area began to be described just over 30 years ago, with several species or genera recently described and little studied (Malabarba *et al.,* 2009; Bertaco *et al.,* 2016; Fricke *et al.,* 2022). Remarkable endemism was observed among the species from the tributaries of the Río Uruguay, with about 46% of the species showing some degree of endemism (Malabarba *et al.,* 2009). Also, in the same region, a high diversity and endemism of species of eglids (crustaceans of the genus *Aegla*) was observed, with 13 species recorded, three of which are new to science and 11 species endemic to the region, and five of them occurring in only one river or sub-basin (Bond-Buckup *et al.,* 2009).

As previously mentioned, the presence of invasive exotic species has been identified as one of the main causes of biodiversity loss worldwide (Leão *et al.,* 2011; Latini *et al.,* 2016). Consequently, the presence of trout *(Oncorhynchus mykiss)* in the upper Rio das Antas was also considered a threat to *Cambeva tropeiro* (Ferrer & Malabarba, 2011), a species with high endemism for the headwaters of this basin and categorized as Critically Endangered (CR) (ICMBio, 2018). Also, the presence of exotic fish farms in the region of occurrence area of *Characidium vestigipinne* Buckup & Hahn, 2000, with restricted distribution to only one locality in the upper Río Uruguay basin, was considered a possible threat for this species, so it was categorized as Critically Endangered (CR).

Using the "Fish Invasiveness Screening Kit" – FISK protocol, a risk pre-selection tool that categorizes non-native species according to their invasive potential and helps to create lists of prohibited species for cultivation. Troca & Vieira (2012) measured the invasive potential of non-native fish cultivated around the Laguna dos Patos and found out that *Cyprinus carpio, Ctenopharyngodon idella, Hypophthalmichthys molitrix, H. nobilis, Ictalurus punctatus,* and *Oreochromis niloticus* present high invasive potential (score between 22 and 38). Concluding that these species have their use prohibited.

Tilapia species are very tolerant to variations in environmental conditions, tolerating water with low oxygenation and polluted with domestic sewage. Recently, several schools and sometimes with the presence of nests and care of the young by the parents were observed during the summer months at Arroio Dilúvio, Porto Alegre Municipality (authors' observation; and publicity in digital media). The Arroio Dilúvio has 17.6 km between its source (eastern region) and its mouth located in the central region of the city, covering areas with high population densities, receiving a high load of domestic sewage. On the other hand, tilapia can even tolerate

brackish water in certain situations. The African catfish is another species that tolerates wide variations in environmental conditions, resisting low water oxygenation and diseases, in addition, has a voracious predator behavior, with a diversified omnivorous feeding habit (Roininen *et al.,* 1996). It reproduces successfully in invaded environments and has an accessory organ for air breathing, resistant fins and high mucus production, which allows it to transit out of water for some time until reaching a new aquatic environment (Donnelly, 1973; Burgess, 1989; Hee, 1999; Latini *et al.,* 2016). African and American catfish species have characteristics that facilitate their adaptation to the invaded environment, mainly due to tolerance to environmental variations and feeding habits (Burgess, 1989), representing an enormous threat to native species of aquatic fauna.

According to Stauffer *et al.* (2022) *Oreochromis niloticus* is being cultured in the Lake Malawi basin in Tanzania, Africa. This species, where introduced, has produced devastating impacts through competition or hybridization with native congenerics. Lake Malawi harbors more species of fishes than any other freshwater lake in the world, and if this species invades the lake, the loss of species diversity would be catastrophic. Those authors also claim that the *O. niloticus* is a significant threat to the native fishes of Lake Malawi.

As already mentioned, the activities of aquaculture, fish farming and the intentional release to increase leisure fishing are recognized as the main causes of the introduction of exotic fish species in natural environments (Agostinho *et al.,* 2007; Vitule *et al.,* 2009; Latini *et al.,* 2016; Casimiro *et al.,* 2018), and consequently, loss of native biodiversity in the Neotropics (Magalhães *et al.,* 2021). According to Gubiani *et al.* (2018), the origins of non-native fish species in wild environments are linked to their introduction vectors, as several fish species arrive from areas close to where they are introduced, mainly by dams, sport fishing and aquaculture. In a study carried out in the lower and middle Rio Paranapanema basin, southern Brazil, to assess the impact of flooding due to El Niño rains in 2015/2016, was investigated by evaluating fish escapes from 12 fish farms (Casimiro *et al.,* 2018). Those authors reported that the flooding resulted in the escape of more than 1.14 million fishes into the river, and including 21 non-native and native species, being the *O. niloticus* and *C. rendalli* the most abundant in the escapees (96% of all fish).

In addition to the introduction of species from other regions, cases of intentional translocations of species between river basins are known, such as, for example, the peacocks bass from the Rio Tocantins basin (*Cichla kelberi* Kullander & Ferreira, 2006 and *Cichla piquiti* Kullander & Ferreira, 2006) and the Rio Amazon basin pirarucu (*Arapaima gigas* (Schinz, 1822)), carnivorous/piscivorous species introduced into the upper Rio Paraná basin (Gasques *et al.,* 2014; Carvalho *et al.,* 2015) that can be so harmful to the native fauna and other invasive exotics, so this activity must be avoided under any circumstances.

The northwest region of the state of Rio Grande do Sul borders Argentina, separated by the middle section of the Río Uruguay basin, and in the southwest region with the country Uruguay, both separated by the Rio Quaraí basin, a tributary of the left bank of the Río Uruguay. Some exotic species already recorded in Rio Grande do Sul were also captured in natural river environments in Uruguay, such as *Cyprinus carpio* in the lower Río Uruguay and Río Negro basins, and *Oreochromis niloticus* in the lower Río Uruguay (Mello *et al.,* 2011; Serra *et al.,* 2014), and in Argentina, as well as all species of carp and tilapia presented here (Mirande & Koerber, 2020).

The Río Negro basin begins in the southeastern region of Rio Grande do Sul State (between the municipalities of Bagé and Aceguá) and runs through the entire central region of Uruguay until it flows into the Río Uruguay. In the middle section of this basin, three species of *Acipenser* sturgeon have already been recorded, *A. baerii* Brandt, 1869, *A. gueldenstaedtii* Brandt & Ratzeburg, 1833, and *A. ruthenus* Linnaeus, 1758 (Mello *et al.,* 2011; Serra *et al.,* 2014). These species were introduced in that country in the 1990s for the production of eggs and meat in fish farms and some fish escaped into the Río Negro basin (Mello *et al.,* 2011). The first two species of *Acipenser* have also been recorded in Argentina (Mirande & Koerber, 2015, 2020). Therefore, records of sturgeon species in the headwaters of the Río Negro basin located in the state of Rio Grande do Sul are not impossible to occur in the future.

Prevention and control

In order to avoid new intentional or accidental introductions and the consequent irreversible impacts on the native fauna of fish and other aquatic organisms, many of which are endemic to the state's waterways, we reinforce that fish stockings or repopulations, even with native species, should be avoided. According to Agostinho *et al.* (2000) there are no studies proving the success of this activity, which, in addition, may represent another source of impact on the local fauna. Management considering biosecurity techniques in breeding systems to prevent escapes and caution in their use in biological control techniques seem to be the most important measures (Latini *et al.,* 2016), although it is necessary to emphasize that there are no breeding systems leak proof (Becker & Grosser, 2003).

Information, environmental education and dissemination actions aimed at the community in general, clarifying the negative impacts of the introduction of exotic species on the native fauna of the region or basin, are fundamental to reduce or prevent new voluntary introductions and to value the native species of fish, among local populations, producers, managers and policymakers (Latini *et al.,* 2016).

The formulation of legislation and other regulatory instruments suitable for the management of the problem represented by the introduction of exotic species should be considered a priority. As an example, the state has established that the cultivation of the channel catfish (*Ictalurus punctatus*), cannot be licensed in the state, as

it is a species whose impacts of introduction are already well known (Becker & Grosser, 2003). This species was included in category 1 (its use is prohibited in any condition by SEMA, 2013). In addition, it is necessary to comply with the recommendations of decrees, norms, federal and state laws regarding the care necessary for environmental preservation and making inspections of fish farming activities and facilities more effective and rigorous. On the other hand, contrary to scientific recommendations and in response to sectors of the economy, sometimes the legislation disregards all the accumulated knowledge about the impacts of invasive exotic species.

The main recommendations suggested here serve as a warning to society to avoid new intentional and accidental introductions and, consequently, irreversible impacts on the native fauna of fish and other aquatic organisms, many endemics to the state of Rio Grande do Sul or to some region or watershed, as it is one of the states with the greatest diversity of freshwater fish in the country (Bertaco *et al.,* 2016).

It is extremely important to establish and comply with containment measures in fish farming, as well as to analyze their use in fish stocks, even in reservoirs. Management considering biosafety techniques in cropping systems to prevent escapes and caution in their use in biological control techniques seem to be the most important measures (Latini *et al.,* 2016). Here, we emphasize that fish stockings or repopulations (even with native species) should be avoided, as there are no studies that prove that this activity has given satisfactory results, and many times they can have another impact on the local fauna (Agostinho *et al.,* 2000). It is recommended when exotic and allochthonous fish species when captured or collected or fished in natural environments, other than their watersheds of origin, that the specimen is not released again. This may seem insignificant, but if several people have this attitude, it can make a difference in the preservation of native species.

According to Casimiro *et al.* (2018) solutions to prevent fish escapes from fish farms include: application of the precautionary principle or 'polluter pays' principle to minimize the risk of escapee fish entering the wider environment; increase of pond embankment height to prevent escape of the species during periods of flooding; and construction of containment structures that provide some biosecurity during inundation events. The results of the study carried by Magalhães *et al.* (2021) in the Rio Paraíba do Sul basin confirm that escapes from aquaculture facilities are common, and could bring severe consequences to local fish populations including endemic, rare, and threatened species. Those authors suggest that reducing the rates of introduction of exotic species and their impacts requires management strategies that promote sustainable aquaculture with protection of native fauna; and a sustainable development plan should be guided by three critical principles: environmental protection, social development, and economic viability.

In the Neotropical region it was observed that there is a general pattern of environmental degradation, as human stressors tend to be the same, such as river damming, changes in land use (*e.g.,* agriculture), aquaculture, mining, and overfishing according to Pelicice *et al.* (2021). Those authors pointed out that some activities caused by humans, such as biological invasion, are still poorly investigated and need further specific studies, and suggest that ichthyologists must continue to focus on the topic, to quantify the magnitude of each impact, identify main stressors, test, and propose causal links, build a framework that allows wide generalization and predictions, and propose management and restoration actions.

In recent years there has been an increasing concern about the introduction of exotic species into wild environments, and with that, several articles are being published mainly by the scientific community, as well as the increase in publications of legal norms by the responsible government agencies, as observed by Zenni *et al.* (2016). Several of these publications only report the occurrence of biological invasions in some place or drainage, but studies about their negative impacts on native species are necessary for the understanding of management in wild environments. Also, we agree with Zenni *et al.* (2016) when pointed that a better integration of the theoretical and applied aspects of biological invasions as support for public management is highly desirable and depends on the inclusion of the topic in more professional courses, on more opportunities for postgraduate studies in the area, counting on interactions with professionals and researchers from other countries and also the inclusion of the problem in basic and secondary education levels.

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