

Research Article

Extralimital introductions of *Salminus brasiliensis* (Cuvier, 1816) (Teleostei, Characidae) for sport fishing purposes: a growing challenge for the conservation of biodiversity in neotropical aquatic ecosystems

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Abstract

Human-mediated translocation of species is widely considered to be a serious problem for the conservation of biodiversity. Documentation of new records is important to understand the causes of extralimital species introductions because of their potential to displace native species and interfere with ecosystem functions. In Brazil, concern about documenting the presence of non-native fishes has predominantly focused on species from other continents; a relatively minor effort has been devoted to the extralimital spread of species from other basins inside the country. Here we summarize several records of a popular sportfish, the dourado, *Salminus brasiliensis* (Characidae) outside its natural range in Brazil, and discuss the potential causes and consequences of its introduction. More empirical research is needed to quantify new extralimital spread records of this species resulting from sport fishing. Confirmation of anecdotal reports is important to provide managers and stakeholders with reliable information. We focus the discussion on this species and other apex predators frequently introduced for sport fishing purposes.

Key words: alien species, aquatic ecoregions, human commensalism, predator

Introduction

Increased facilitation of trade and transport due to globalization has led to increased translocation of species around the globe (e.g., Ricciardi 2007; Copp et al. 2007; Gozlan et al. 2010). This problem has been increasingly regarded as an issue of public interest, representing a major challenge both for ecology and future generations (Vitule et al. 2012a; b; Simberloff et al. 2013). Fishes are among the most commonly introduced vertebrates and are widely distributed through aquaculture, ornamental fish trade and sport fishing, activities that generate substantial economic profit (Cambray 2003; Moyle and Marchetti 2006; Britton and Orsi 2012). Direct human-mediated introduction of species is a major cause of extralimital range

expansion for non-native fish fauna in continental aquatic ecosystems, creating significant problems for existing natural biodiversity (Ricciardi and Simberloff 2009; Vitule et al. 2009; Paolucci et al. 2013).

Intentional and illegal exchange of species between basins within a geographical or a geopolitical unit (i.e., extralimital introductions) for sport fishing purposes is an often overlooked and undervalued problem in developing countries, where there is a continuous push for economic growth, especially in the Neotropical region (e.g., Nuñez and Pauchard 2010; Pelicice et al. 2014). Anglers buy fish from culture facilities and release them illegally at sites where they want to promote sport fishing activities, in what constitutes a global problem (Cambray 2003; Moyle and

Marchetti 2006). The introduction of species with recreational fisheries potential represents a major pathway in the Global Invasive Species Database (GISD 2005). In South Africa, sport fishing is a leading cause of introductions of non-native fishes (35% of cases). And worse, among those that have reached an invasive status, more than half (55%) have been introduced by anglers (Ellender and Weyl 2014). Furthermore, Moyle and Marchetti (2006) note that more than 60% of the established alien species in California (USA) belong to five families of typical “game fishes” (Cyprinidae, Ictaluridae, Salmonidae, Centrarchidae, and Cichlidae). In Brazil, sport fishing-motivated introductions were a result of state-supported formal stocking programs because of a perceived lack of suitable native species, cultural imperialism or illegal stocking (e.g., Vitule 2009; Vitule et al. 2009). This is an issue of concern, because the introduction of a new predator in an aquatic ecosystem may have deleterious effects, even before the establishment phase of the invasion (Blackburn et al. 2011), such as the drastic reduction in density or even local extirpation of rare native populations, or individual-level sub-lethal effects. Some aquatic invaders used in sport fishing even have major effects on adjacent terrestrial environments (e.g., Estes et al. 2011; Paolucci et al. 2013). In addition, large predators with visual feeding habits (e.g., peacock bass *Cichla* spp.), introduced from the Amazon into other river basins with the purpose of fostering recreational fisheries, resulted in significant and rapid declines in native fish diversity (e.g., Vitule 2009; Pelicice and Agostinho 2009; Britton and Orsi 2012). These game-fish are in general physiologically robust, and represent a potential threat to native fish biodiversity (Zaret and Paine 1973; Moyle and Marchetti 2006).

We reviewed all previous records and added a new extralimital record of the dourado *Salminus brasiliensis* (Cuvier 1816) (Teleostei: Characidae) in Brazil. This large-bodied long-distance potadromous characin is widely distributed in South America, in particular in Brazil, occurring naturally in Paraná, Paraguay, Uruguay and Jacuá River basins, as well as in Laguna dos Patos drainages and upper Chaparé and Mamoré River basins in Bolivia (Figure 1). It is one of the largest characins, reaching more than one meter in total length, and over 30 kg (Britski et al. 1999; Froese and Pauly 2013). Gonadal maturation in females occurs when fish attain 324-378 mm (Suzuki et al. 2004; Agostinho et al. 2007). It is an avid predator, feeding on a great variety of prey from fish to small reptiles and birds (Gubiani et al.

2010; Froese and Pauly 2013). Being a large and powerful visual predator, it is extremely appreciated by sports fishermen, both where it occurs naturally, and where it has been introduced (Barbieri et al. 2000; 2001; Vieira and Pompeu 2001; Agostinho et al. 2007; Gubiani et al. 2010; Froese and Pauly 2013). A number of recent official and non-official extralimital occurrences of *S. brasiliensis* prompted us to synthesize occurrence data. We discuss the problems caused by introductions of freshwater fishes distributed through sport fishing.

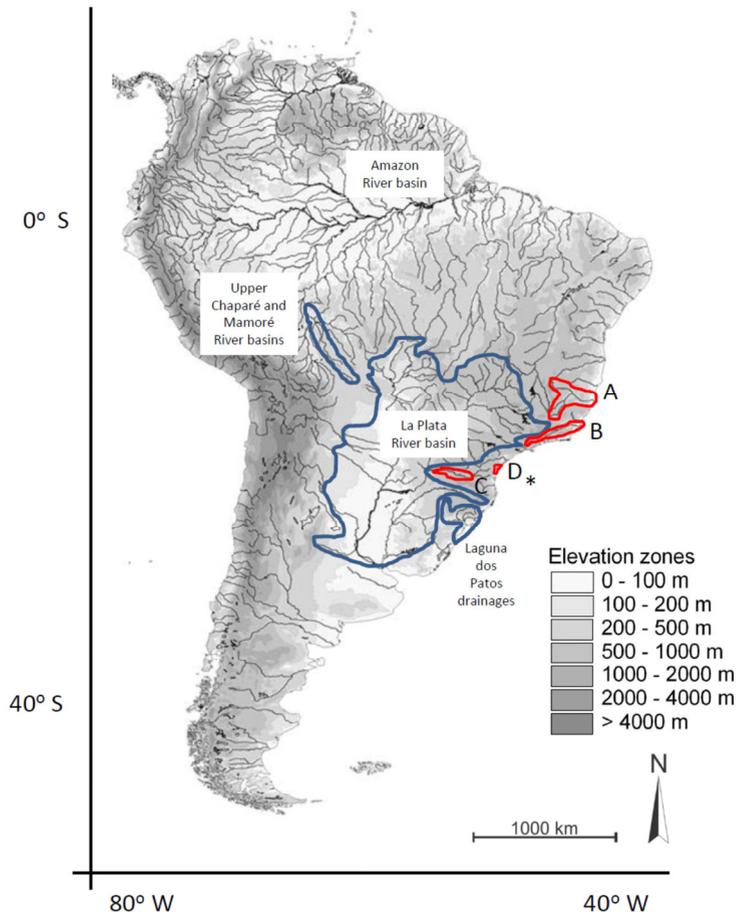
Methods

Using a combination of literature review, museum records, and personal surveys, we reviewed previous records of the dourado *S. brasiliensis* (Cuvier, 1816) (Characidae) in Brazil (see supplementary material). Our newest record is based on an individual that was sampled at Rio das Pombas, a tributary of the Guaraguaçu River basin in the Atlantic rainforest biome. This fish was captured incidentally during sampling for another introduced fish species (Vitule et al. 2006). The Guaraguaçu River basin is the largest eastern river of the sub-basin of Paranaguá Bay, Paraná coast, Brazil. Its headwaters are located in the Serra do Mar, 766 m above sea level, in the Saint-Hilaire/HugoLange National Park. It discharges into the Paranaguá Bay (Maack 1981, - 25°41'47"S, 48°31'31"W, Figure 1). The basin includes important areas for conservation of aquatic species (Vitule et al. 2006). This individual *S. brasiliensis* was caught in January 2006 by bottom gillnet, with 4 cm-mesh between adjacent knots. The specimen was identified, fixed and deposited at the Museu de História Natural Capão da Imbuia collection (MHNCI 12331).

Results

We found no studies in Brazil that focused on problems caused by extralimital or inter-basin introductions of freshwater fishes for sport fishing purposes, nor on the role of the public in spreading nonnative species. We report here the record of a 42 cm individual of *S. brasiliensis* (Figure 1D, asterisk). However, we did identify many important human-mediated extralimital introductions of *S. brasiliensis*, which are depicted in Figure 1: Doce River basin (Ruschi 1965, Figure 1A), Paraíba do Sul River basin (Bizerril and Primo 2001; Buckup et al. 2007, Figure 1B), Iguacu River basin (Gubiani et al. 2010, Figure 1C), all in the Atlantic Rainforest biome. We also

Figure 1. Map of South America showing in the blue-shaded area the natural range of distribution of the dourado *S. brasiliensis*. The smaller red-shaded areas indicate the extralimital river drainages where it has been reported: Doce River basin (A, Ruschi 1965, with routine sport and commercial fishing of the dourado since then, Bizerril and Primo 2001; Buckup et al. 2007), Paraíba do Sul River basin (B, Bizerril and Primo 2001; Buckup et al. 2007 with routine sport and commercial fishing of the dourado), Iguaçu River basin (C, Gubiani et al. 2010, single occurrence reported), and now also Guaraguaçu River (D, asterisk, this study). The map also shows the elevation zones across the continent. Image modified from map provided by the Conservation Science Program, World Wildlife Fund.



found many anecdotal reports in the World Wide Web about dourado fishing and sport fishing activities, some of them in areas outside its natural range (e.g., in Ribeira do Iguape River basin, Dr João Alves Vieira, personal communication, and anecdotal images and videos – see links in the Supplementary material).

Discussion

The migratory behavior of the dourado is generally regarded as a limit to invasion success, given the difficulties invaders face when they require widely separated habitats at different life history stages, as they frequently displaying high mortality rates during migration (reviewed in Lockwood 1999). Nevertheless, there have been reports of successful invasions of other migratory fishes in South America (Agostinho et al. 2007; Vitule et al. 2012b), so the establishment of *S. brasiliensis* in the Paraíba do Sul and Doce River

basins reinforces our concerns - already “prophetically” stated by Ruschi (1965) - that the migratory behavior of the dourado will probably not prevent its establishment in other river basins. Therefore, migratory behavior in aquatic animals *per se* does not seem to represent a real barrier to invasion. In particular, once barriers are overcome, migratory fish can potentially spread even more than non-migratory fishes. Also, large body size is a characteristic of desirable game-fishes popularity which can promote invasive success (Donaldson et al. 2011).

Impacts of introduced species on freshwater communities obviously can vary to a great degree, depending on both the traits of the introduced species and those of the ecosystem. In general, large top-predators widely used in sport fishing activities seem to share similar trajectories between their introduction and the process of invasion. Propagule pressure is a correlate of establishment success (Kolar and Lodge 2001; Lockwood et al.

2005), and human preference for some species increases its propagule pressure (Lockwood et al. 2005).

Non-native invasions can contribute to fish assemblage's homogenization in the new occurrence areas for two reasons: 1) increasing similarities between basins where the species is native and the new occurrence areas, or 2) by its predation effects on rare local native species in the new occurrence areas (Rahel 2007). The Iguaçú basin and Guaraguaçu River have high native richness and high rates of endemism of native fishes (see Gubiani et al. 2010; Abilhoa et al. 2011; Daga and Gubiani 2012). This suggests that the dourado dispersion and range expansion can have negative effects on the basin's native fish fauna, which would benefit from better monitoring and protection (e.g., Vitule et al. 2006; Gubiani et al. 2010; Daga and Gubiani 2012). The dourado invasion is probably related to the occurrence of human activity and particularly sport fishing (e.g., McKinney 2006; Leprieur et al. 2008). Both watersheds are located inside the Atlantic Rain Forest biome, which is home to a large number of small-sized, endemic fish species (Abilhoa et al. 2011). The high rate of speciation and geographic endemism is an important factor that needs to be considered in the conservation policies about invasions by sport fishing, particularly since this biome is located in the most populated regions of the country, close to large urban centers, and is thus more prone to intense sport fishing-related propagule pressure. Approaches that may address this issue include education, law enforcement, and cooperation between production and conservation sectors of the society (Johnson et al. 2009; Vitule et al. 2009).

In Brazil the issue of aquatic biological invasions has just begun to be investigated (Vitule et al. 2009). New introductions are important to document, given the potential risks associated with the introduction of predators (Eby et al. 2006; Estes et al. 2011). This is a problem in Brazil, and other tropical developing countries with large size and species richness (Lövei et al. 2012), where species introductions are considered likely to lead to decreased biodiversity. Recreational sport fishing may represent a significant risk in terms of new extralimital introductions of top-predators, especially because non-native sport-fishes are often introduced intentionally by government agencies to develop or improve recreational sport fishing, as well as illegally by anglers or anonymous "eco-vandals". We urge natural resource managers to consider

the balance between the important societal role of some non-native fishes, sport fishing and conservation of biological diversity (e.g. see Cambray 2003; Pelicice et al. 2014).

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Supplementary material

Databases and search terms used

The literature review on the ISI Web of Science database and Google Scholar was conducted to identify studies that showed the combination of the keywords “*sport fishing*”, “*game fish*”, “*alien*”, “*nonnative*”, and/or “*Salminus*”. Title and abstracts were carefully examined in order to exclude papers from the survey when necessary. In addition, an intensive unsystematic review of literature reporting the introduction of *Salminus* for sport fishing purposes was performed, including technical and academic reports.

Fish collection database

In Brazil, Natural History Museums, herbaria and several biological collections are integrated through networks openly and freely available on the Internet:

- SpeciesLink: An information system that integrates primary data from biological collections of Brazil (smlink.cria.org.br)
- The Biological Collection Network of Parana - TAXon-line. The primary goal of this grand project is to pass information contained within the museums to the scientific community by means the network. Among the developmental stages of this project are included the organization of the material and the support infrastructure as well as making the information available on the Internet (www.taxonline.ufpr.br).
- Neodat (www.neodat.org): the on-line databases of MNRJ, MCT, MZUSP and INPA is an international cooperative effort to make available systematic and geographic data on neotropical freshwater fish specimens deposited in natural history collections.

Institutions

Ichthyological Collection of the Nupélia (NUP)

The fish collection of the Núcleo de Pesquisas em Limnologia, Ictiologia e Aquicultura (Nupélia) was established in the early 1990's. The collection's geographic representation is Neotropical, with emphasis on the La Plata basin ichthyofauna, including the Brazilian states of Goiás, Mato Grosso, Mato Grosso do Sul, São Paulo and Paraná. More than 10,000 samples of fishes are in the database. The complete catalogue of the fish collection is searchable using the tool available at <http://peixe.nupelia.uem.br/en/>

The MNRJ Fish Collection

The Fish Collection of the Museu Nacional is one of the largest and oldest fish collections in Brazil, dating back to the late XIX Century. The Collection holds about 40,000 samples, amounting to an estimated 500,000 specimens. The collection is a participant in the NEODAT project. The catalogue of the fish collection is searchable using the tool available at <http://www.mnrj.ufRJ.br/>

The MCP Fish Collection

The collection has over 47,100 samples (estimated at more than 500,000 specimens), and is constituted by 85% of freshwater fish from South America and 15% of the marine coast of the states of Rio Grande do Sul and Santa Catarina. It comprises, along with two other large collections (MZUSP and MNRJ) the most comprehensive set of large-scale faunal surveys currently available for Brazilian freshwater fishes. There is also material collected from most Brazilian coastal rivers, and the São Francisco and Paraná River basins. Lots from the Amazon basin refer mainly to the Amazon, Tocantins, Tapajós, Xingu, Purus and Madeira systems, in Brazil, and Ucayali River basin in Peru. The catalogue of the fish collection is searchable using the tool available at <http://www.mnrj.ufRJ.br/search1p.htm> and <http://www.smlink.org.br/index?lang=en&group=all>

The MZUSP Fish Collection

The fish collection of the Museu de Zoologia holds about 84,000 lots and 1,300,000 specimens of fish. It is the most comprehensive fish collection of the Amazon region. The catalogue of the fish collection is searchable using the tool available at <http://www.mnrj.ufRJ.br/search1p.htm> and <http://www.smlink.org.br/index?lang=en&group=all>

The MHNCI Fish Collection

The Capão da Imbuia Natural History Museum is a branch of the Municipal Environment Secretariat of Curitiba. In addition to scientific research, its missions include environmental education and maintenance of the zoological database. The museum is used for consulting, taxonomic revisions and of course, the increasing of the collection to document Brazilian biodiversity. Most of the collections started in 1935 with preserved objects and animals that professors and collectors sporadically gather over the years. The fish collection holds about 13,000 lots and 30,000 specimens of Neotropical fishes, with emphasis on the Iguçu River, Upper Paraná Aquatic Ecoregion, and Atlantic Forest drainages. The catalogue of the fish collection is searchable using the tool available at <http://www.smlink.org.br/index?lang=en&group=all>

Links to anecdotal images and videos from youtube:

<http://www.youtube.com/watch?v=BiUVF4V0AZo>

<https://www.youtube.com/watch?v=vT0YjnaPcyg>

https://www.youtube.com/watch?v=sBFMS_QG0KI