

Viewpoint**Is there a future for artisanal fishing in the Amazon? The case of *Arapaima gigas***

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Abstract

In the last ten years *Arapaima gigas*, commonly known as pirarucu, expanded its distribution upstream into the Madeira River rapids where it is not a native species. The invasion was favored by escapes from Peruvian fish farms upstream in the Madeira River Basin, where they have been raising pirarucu since the 1970s. Although the Madeira River rapids had formerly represented a geographical barrier to this invasion by limiting floodplain habitats, the construction of the Santo Antônio and Jirau dams in 2011 flooded the two most important falls, replacing the rapids stretch with a lentic or semi-lentic habitat favoring the invasion of *A. gigas*. Since construction of the dams, fisheries reports have been marked by the decrease of traditional commercial species, coupled with the presence of invasive populations of *A. gigas*. This example highlights a major emergent threat to artisanal fishing in the Amazonian freshwater system: government policies favoring dam construction and the consequent spread of native fish species used in aquaculture to new regions upstream of waterfalls where they are not native.

Key words: fisheries, freshwater impacts, biological change, aquaculture, dam impact

Introduction

The future of traditional artisanal fisheries in the Amazon is threatened by large infrastructural development projects such as roads, piers, waterways, mining, and hydroelectric dams (Castello and Macedo 2016), as well as by the expansion of aquaculture (Pauly 2018). The cumulative and synergistic effects of these threats can lead to unpredictable impacts on artisanal fisheries (Lima-Junior et al. 2018). These threats are directly related to governmental policies in developing countries, such as Brazil, designed to foster economic growth.

In the Amazon, aquaculture competes with artisanal fisheries. However, aquaculture may offer fish of lower economic value than those traditionally caught in artisanal fisheries and promotes invasions or extirpations of fish species and genetic homogenization through introgression resulting from the introduction of non-native populations or genes. On the other hand,

the expansion of the range of a species native to a large portion of a river basin to parts of the same basin where it has never occurred before is rare. *Arapaima gigas* (Schinz, 1822), known locally as *pirarucu*, is widely distributed in the Amazon River basin, with the exception of a few regions where it was not known to occur previously, including the Bolivian portion of the Amazon River and the Madeira River. However, *A. gigas* invaded Bolivian rivers during the 1970s (Miranda-Chumacero et al. 2012; Carvajal-Vallejos et al. 2011) and, more recently, the Madeira River, with serious deleterious effects on traditional fishing.

A biological invasion from a purely ecological perspective occurs when a population of a species acquires a competitive advantage following the disappearance of natural obstacles hindering its proliferation. This allows it to spread rapidly and to conquer novel areas in the recipient ecosystem, where it may become a dominant component of the system (e.g. Valéry et al. 2008; Simberloff and Vitule 2014). In general, an organism is considered native to a given region if its presence is the product of natural processes. It is also expected that some organisms found in places where they are not expected to occur naturally will do so because they derive some benefit from human activities (Bezerra et al. 2019a, b). Often, non-native species, defined as organisms that have been introduced to a new area by human activities, become invasive species resulting in high economic costs related to the efforts taken to control and manage them (GB NNESS 2015; Eischer and Johnson 2002; Leung et al. 2002; Pimentel et al. 2005).

Arapaima gigas is among the largest living fish species in the Amazon, reaching about 3 m in length and more than 200 kg in weight. *Arapaima gigas* is naturally distributed in most Amazon River Basins with the notable exception of the upstream section of the Madeira River Basin in Bolivia and Peru (Queiroz et al. 2013), where a series of rapids probably acted as a geographical barrier to its upstream dispersal (Torrente-Vilara et al. 2011). On the other hand, a century of exploitation in the floodplain areas in central Amazônia has depleted the natural populations of *A. gigas* (Hrbek et al. 2005), justifying its inclusion in the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES II). However, human introduction of *A. gigas* in Peru in the 1970s (Miranda-Chumacero et al. 2012) demonstrated its ability to colonize habitats in the Madre de Dios and Mamoré floodplains upstream of the Madeira River rapids. Considering that *A. gigas* usually feeds on insects, shrimp, and crabs during the early stages of its life, and feeds on more than 10 abundant commercial Amazon fish species as an adult (Fontenele 1952; Romero 1960; Lüling 1964), the species has the potential to colonize and impact a large area of the Amazon basin. The progressive spread of *A. gigas* over most of the Amazon Basin has been predicted due to increases in the mean temperature associated with climate change, limited only by altitude and

the absence of floodplain environments (Oberdorff et al. 2015). However, these predictions did not consider the introduction of *A. gigas* as non-native populations in a set of sub-basins upstream of the Madeira River rapids where large floodplains (natural habitats in Madre de Dios and Mamoré rivers) and reservoirs have been established (Doria et al. 2018) thereby enhancing its potential for invasion.

In 2011, two large hydropower dams were constructed in the Madeira River Basin, flooding the two most important falls along the rapids, which had previously acted as natural geographic barriers to the spread of *A. gigas* (Cella-Ribeiro et al. 2017). At the same time, Carvajal-Vallejos et al. (2011) detected a drastic change in landings by artisanal fisheries, showing that *A. gigas* reached approximately 40% and 50% of the catch in the most important fish markets in Bolivia (Riberalta and Porto Rico, respectively). These were believed to be aquaculture escapes from Peru (Miranda-Chumacero et al. 2012). Since then, *A. gigas* has spread its distribution upstream in the Madeira River Basin, thereby increasing its abundance in the fish market on the Brazil-Bolivia border. This has resulted in a drastic change in the fish production chain over the last 30 years (Carvajal-Vallejos et al. 2011; Lizarro et al. 2017).

In order to obtain information concerning the first occurrence of *A. gigas* in fish markets on the Brazil-Bolivia border and information about the fish's origin and increasing abundance, interviews were conducted through a semi-structured questionnaire with local fishermen.

Results and discussion

The results indicate that *A. gigas* was absent from the study area before the 1990s (Figure 1A) and suggest its invasion originated with escapes from fish farms in Bolivia (45%), Peru (21%), and/or Brazil (14%) (Figure 1B; Supplementary material Table S1). Moreover, according to the fishermen, the invasion and the increasing abundance of *A. gigas* could be seen in Brazil since 2000, with an emphasis on 2014 (70% of interviewers), a year when there was a historic atypical flood along the Madeira River (Fearnside 2014). Our results suggest that *A. gigas* has expanded its distribution from the Mamoré River to the Madeira River to at least the Brazil-Bolivia border during the last 10 years, reinforced by the atypical flood of 2014, and presently extends to the reservoir of the Santo Antônio Dam, a semi-lentic habitat (Figures 2, 3).

As the largest Amazonian piscivorous fish species, the *A. gigas* invasion poses a major threat to native species that are already vulnerable to environmental change and habitat destruction. Because of the *A. gigas* invasion, native fish now have to coexist with an invasive apex predator as well as the parasites, microorganisms, and diseases that potentially accompany *A. gigas*, leading to increased mortality and loss of the genetic variability in the natural populations (Waples and Drake 2004; Villanúa et al. 2008; Laikre et al. 2010).

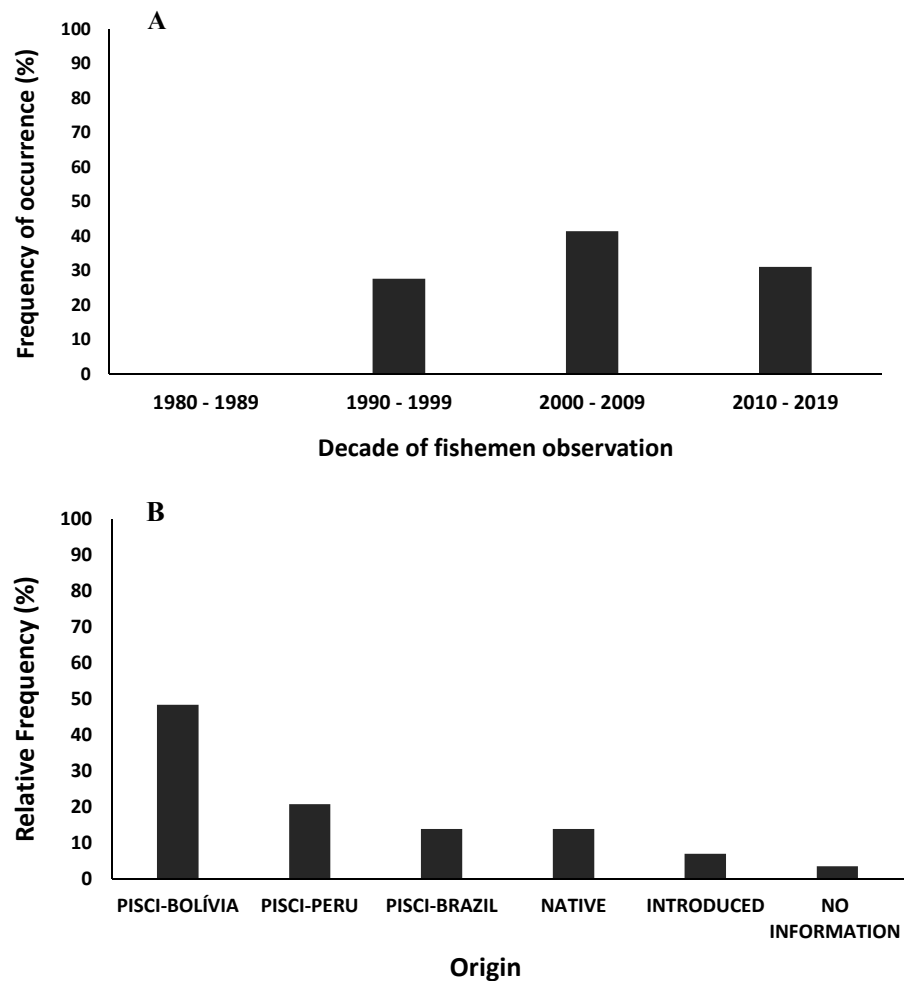


Figure 1. A) First sightings of *Arapaima gigas* (pirarucu) by fishermen in the area of the Santo Antônio reservoir (Madeira River) by decade; B) the possible origin of *Arapaima gigas* (pirarucu) in the Brazil-Bolivia border fish market and in the Santo Antônio Reservoir, where new occurrences are reported. Legend: Piscis = Fish farming.

Further downstream, the genetic integrity of a native population of *A. gigas* in a stretch of the Madeira River close to central Amazonia (about 500 km from the Brazil-Bolivia border) is threatened by *A. gigas* introduced into the upper Madeira River Basin (in Peru) through aquaculture escapes. These fish have an unknown stock origin.

The invasion of *A. gigas* over a large area (about 350,000 km²; Doria et al. 2018), where it was never recognized as a native species, is associated with its increasing abundance in the artisanal fishery (42%) harvest on the Brazil-Bolivia border in the last decade (Figure 1; data from: Fisher Association of the Guajará Mirim/Brazil). This represents almost half of the artisanal fishery production, ample evidence to consider *A. gigas* as an invasive species upstream of the Santo Antônio Dam, and therefore it should be urgently monitored and controlled.

The threats and losses to Amazonian biodiversity, which presage the future of traditional artisanal fishing, are largely promoted by governmental policies aimed at fostering the expansion of infrastructure projects. The impacts of these projects have caused large disturbances in

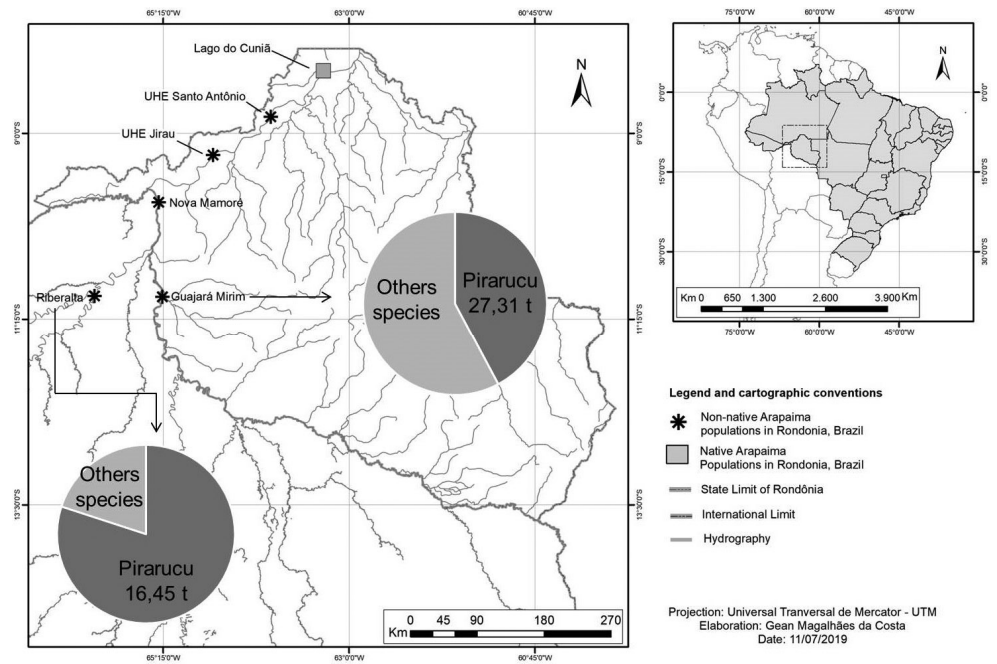


Figure 2. Madeira River study area highlighting the locality (grey square) where the native pirarucu (*Arapaima gigas*) populations exist, and the localities (asterisks) where non-native pirarucu have expanded since 2000 according to the reports of fishermen. Inserted graphs show the fishery production landed in the region of Guajará Mirim (Brazil) in 2016 (Source: present study) and Riberalta (Bolivia) in 2011 (Méndez et al. 2012).



Figure 3. Invasive *Arapaima gigas* (pirarucu) fished by a local angler in Mamoré River at Brazil-Bolivia border (Picture courtesy of: Fishers' Association of Guajará Mirim).

pristine environments, facilitating biological invasions (Lima-Junior et al. 2018; Bezerra et al. 2019b). Aquaculture without adequate controls (e.g., without effective barriers to prevent dispersion of organisms) has the potential to spread alien species (Orsi and Agostinho 1999; Latini et al. 2016; Casimiro et al. 2018). Invasive species released from aquaculture projects generate significant ecological consequences, such as changes in

the structure of the native fish populations, loss of genetic variability (i.e. introgression and genetic homogenization), faunal homogenization, and the decline of native species and populations (Vitule et al. 2009; 2012; Bezerra et al. 2019a, b). Ultimately, invasive species cause changes in ecosystem interactions, affecting human activities such as fishing, and leading to social and economic consequences (Agostinho et al. 2008; Laikre et al. 2010; Attayde et al. 2011; Simberloff and Rejmánek 2011; Méndez et al. 2012).

Local fishermen suffer as a result of the changes in fisheries caused by dams. These changes include a drastic reduction the size of catches and increases in the abundance of invasive species. Despite the fact that fishermen are aware of the fact that catching *A. gigas* is illegal (Rondônia 2015) and that they may be arrested, the *A. gigas* fishery has become the only way to guarantee their income. Nevertheless, it was the fishermen that first called for an understanding of the ecological and social issues associated with *A. gigas* invasion. Based on this understanding and the new scenario, in regions where there are invasive populations fishermen, scholars, and other stakeholders have begun to call for urgent changes in the local fish regulations, including the revision of regulations regarding *A. gigas*, in order to give to the fishermen catch permits. These changes would allow the artisanal fishers to be part of the solution by contributing to control the spread of the invasive species.

Final considerations

The future of artisanal fisheries depends on improving our understanding of how changes in the aquatic environment facilitate the invasion of fish species and how interactions among these factors (biological invasions and environmental changes) influence fisheries outcomes, such as catches and fisher's income. Finally, the development of effective participative management policies is fundamental if we wish to avoid the extinction of artisanal fisheries and native species in developing countries.

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Supplementary material

The following supplementary material is available for this article:

Table S1. Details of fishermen surveys conducted in 2017/2018 in Rondônia, Brazil: location name and coordinates, habitat features, presence of *Arapaima gigas* (pirarucu) near sites where the interviews were held.

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http://www.reabic.net/journals/mbi/2020/Supplements/MBI_2020_Doria_etal_Table_S1.xlsx