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Aquarium trade and fish farms as a source of non-native freshwater fish introductions in French Guiana

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Abstract – Rivers of French Guiana are still little invaded by non-native fish, but several fish introductions were recently recorded through the development of aquarium fish trade and fish farms. Here we report records of 11 non-native fish species. Among them, four (*Cichla monoculus*, *Heros efasciatus*, *Mesonauta guyanae* and *Poecilia reticulata*) are established and one of them (*Heros efasciatus*) is rapidly increasing its spatial range. Two species (*Hyphessobrycon eques* and *Pterophyllum scalare*) were not retrieved in recent records and are probably extinct from French Guiana. The establishment status of the five other species (*Arapaima gigas*, *Colossoma macropomum*, *Cyprinus carpio*, *Oreochromis mossambicus* and *Osteoglossum bicirrhosum*) is uncertain and only a few specimens were observed in the wild. Nevertheless, these species, intensively reared in nearby countries, belong to highly invasive species able to cause detrimental impacts on recipient ecosystems. Those first occurrences of invasive fish species in French Guiana should therefore act as an early warning for both researchers and environmental managers.

Keywords: Biological invasions / invasion pathways / Neotropics / propagule pressure / South America / river

1 Introduction

Freshwater fish invasions are widespread across the world (Leprieur *et al.*, 2008) and are recognised as one of the main causes of global changes on aquatic ecosystems (Sala *et al.*, 2000; Butchart *et al.*, 2010). The Neotropical zone was known as less impacted by freshwater fish invasions than the other realms (Leprieur *et al.*, 2008), but recent reports show a growing invasion trend (Daga *et al.*, 2016; Bezerra *et al.*, 2019; Vitule *et al.*, 2019). The establishment of several non-native species in Amazonian rivers had detrimental effects on aquatic ecosystems and native fish communities (Vitule *et al.*, 2009; Pelicice *et al.*, 2017; Bezerra *et al.*, 2019).

French Guiana is bordered by Brazil and Suriname and share with them part of the Maroni and Oyapock (also called

Oiapoque) drainages, which represent the border between French Guiana and those two countries (Fig. 1). While Brazil is now recognised as a hotspot for fish biological invasions (Bezerra *et al.*, 2019; Vitule *et al.*, 2019), previous reports record few freshwater fish invasions in French Guiana. Indeed a few ancient introduction attempts did not led to durable establishment of the introduced species. *Hyphessobrycon eques* (Steindachner, 1882) and *Heros efasciatus* Heckel, 1840 were the only non-native species reported as established in French Guiana by Planquette *et al.* (1996) and Keith *et al.* (2000). Nevertheless, recent reports attest for the establishment of at least one more non-native species, the guppy (*Poecilia reticulata*), that originates from Trinidad, Tobago and coastal areas of North-East South America, including Venezuela and Guyana (Deacon *et al.*, 2011; Bragança *et al.*, 2020). Moreover, the demographic rise of human population in French Guiana led to trigger the development of aquarium trade and aquaculture, increasing therefore the risk of new

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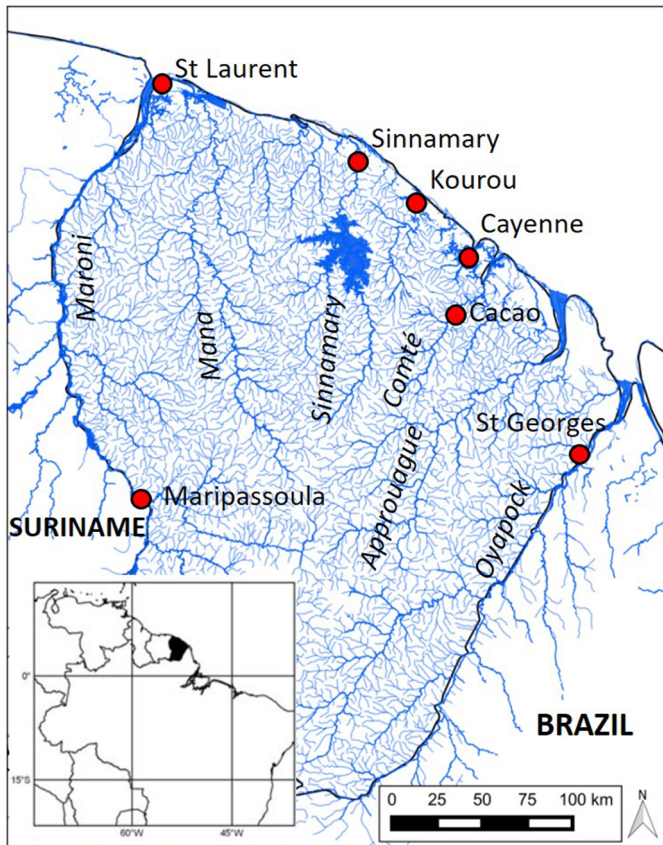


Fig. 1. Map of French Guiana indicating the main river basins and human settlements. Inset map indicate French Guiana location in South America.

introductions of non-native species. Here we made an update of non-native freshwater fish introductions in French Guiana, and indicate the current distribution of those species. Although the impact of those non-native species on the Guianese fauna and ecosystems is still unknown, our work provide a state of the art of non-native fish species introductions in French Guiana.

2 Material and methods

We made an exhaustive survey of non-native fish observations and captures in the Guianese freshwaters based on scientific fish inventories, water management surveys and angling reports collected by the NGO Guyane Wild Fish and the HYDRECO laboratory during the last 10 years (2010–2020). All the species were observed and/or collected by the authors and only reports associated to the collection of a specimen or to a good quality picture permitting to certify the species identity were considered. Fish identifications were done according to Planquette *et al.* (1996), Keith *et al.* (2000) and Le Bail *et al.* (2000). The species not described in those identification guides were validated by professional fish taxonomists (RC & PYLB). All doubtful or unverified information were deleted. A species was considered as non-native if it does not naturally belongs to the drainage basin

where it was observed, excluding therefore natural spread of native species. We therefore considered both non-Guianese species (exotic species) and Guianese species introduced in one or several river basins where they do not naturally belong (translocated species, Leprieur *et al.*, 2008). We however not considered species translocated within the same river basin. Non-native species occurrences were plotted on a map of French Guiana to show their non-native distribution range (Fig. 2), and information about the establishment status of the species were collected. Establishment was considered when stable or spatially expanding populations were recorded over the last ten years (2010–2020), with collection of all size and age classes, testifying for the establishment success of the species (*sensu* Lockwood *et al.*, 2013). When a species was not retrieved in the known introduction locality despite recent (>5 years) and repeated inventories including angling, net catches and underwater observations, it was considered as extinct from the locality.

3 Results

Among the 11 non-native fish species recorded on the Guianese territory, two species (*Hyphessobrycon eques* and *Pterophyllum scalare* (Schultze, 1823)) were not retrieved in their invasion range in recent records, and nine non-native species are therefore currently present in French Guiana. Among these species, four originate from coastal swamps of Amapá, Brazil and occasionally enter the Oyapock River (Jégu and Keith, 1999; Lemopoulos and Covain, 2019). They are therefore native from the Oyapock drainage basin, which main course represents the frontier between Brazil and French Guiana (Fig. 1). Those species, belonging to the Cichlidae (*Cichla monoculus* (Spix & Agassiz, 1831); *Heros efasciatus* and *Mesonauta guyanae* (Schindler, 1998)) and Osteoglossidae (*Osteoglossum bicirrhosum* (Cuvier, 1829)) families were recently observed in other Guianese basins where they do not naturally belong (Fig. 2). One species (*Heros efasciatus*) established and is rapidly expanding its spatial range. Two other species (*Cichla monoculus*, and *Mesonauta guyanae*) also established, with captures of both juveniles and adults for more than 10 years, but did not expanded out from their introduced localities (Tab. 1).

Three other species belong to the Neotropical zone, but are naturally absent from French Guiana (*Arapaima gigas* (Schinz, 1822); *Colossoma macropomum* (Cuvier, 1816); and *Poecilia reticulata* (Peters, 1859); Fig. 2). Among these three species, only *Poecilia reticulata* currently established, whereas only a few observations were reported for the two former species, and their establishment status in French Guiana is therefore uncertain (Tab. 1).

The two last species belong to Eurasia (Common carp, *Cyprinus carpio* (Linnaeus, 1758)) and Africa (*Tilapia*, *Oreochromis mossambicus* (Peters, 1852)). They were reported from few localities in French Guiana and their establishment status remain uncertain (Fig. 2 and Tab. 1).

4 Discussion

The Guianese rivers were for long considered pristine, and as an exception compared to most of the world rivers that

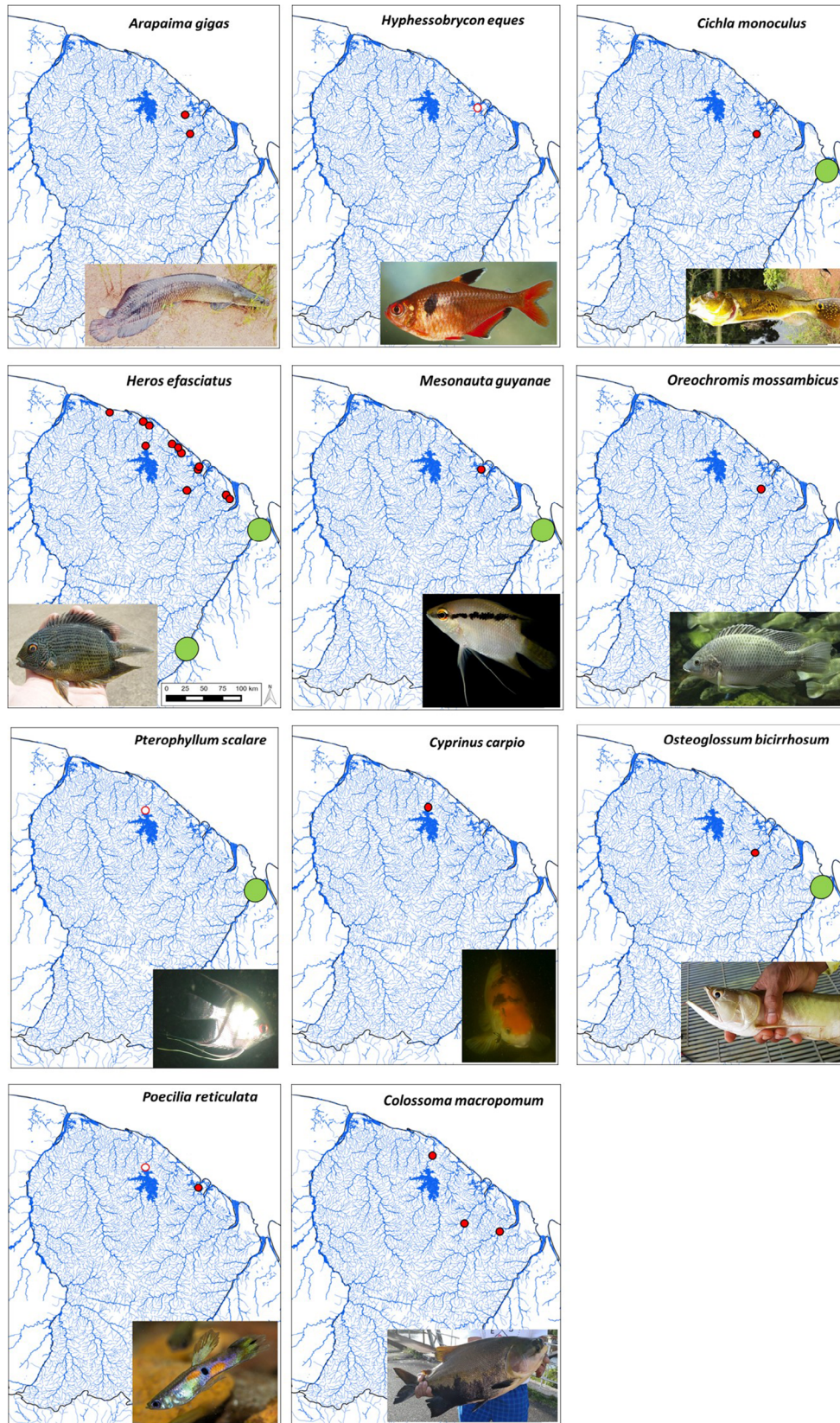


Fig. 2. Distribution maps for the 11 non-native species. Red dots represent current observations and open dots indicate extinct populations. Green dots indicate the native distribution range in French Guiana for the species occurring at least sporadically as native in French Guiana. Photographs are fish observed or collected in French Guiana (photo supplied by the authors), except for *Oreochromis mossambicus* (photo by G. Hume).

Table 1. List of the non-native species and families, region or basin of origin, human use, status (established, non-established, extinct or unknown), date of first observation as non-native in French Guiana and river basins where the species has been observed as non-native (AP: Arouague; CO: Comté; CR: coastal rivers and swamps; OY: Oyapock; SI: Sinnamary).

Family	Species name	Native origin	Human use	Status in French Guiana	First observation in French Guiana	River basins
Arapaimidae	<i>Arapaima gigas</i> (Schinz, 1822)	Amazon and Essequibo	Aquaculture	Unknown	2020	CO, CR
Characidae	<i>Hyphessobrycon eques</i> (Steindachner, 1882)	Amazon and Paraguay	Ornamental	Extinct	1996	CR
Cichlidae	<i>Cichla monoculus</i> (Spix & Agassiz, 1831)	Amazon and Oyapock	Aquaculture	Established	2010	CO
Cichlidae	<i>Heros efasciatus</i> (Heckel, 1840)	Amazon and Oyapock	Ornamental	Established	1984	CO, CR, OY, SI
Cichlidae	<i>Mesonauta guyanae</i> (Schindler, 1998)	Amazon, Essequibo, Oyapock	Ornamental	Established	2009	CR
Cichlidae	<i>Oreochromis mossambicus</i> (Peters, 1852)	Africa	Aquaculture	Unknown	2003	CO
Cichlidae	<i>Pterophyllum scalare</i> (Schultze, 1823)	Amazon, Essequibo, Oyapock	Ornamental	Extinct	2018	SI
Cyprinidae	<i>Cyprinus carpio</i> (Linnaeus, 1758) (koi strain)	Eurasia	Ornamental	Non-established	2015	SI
Osteoglossidae	<i>Osteoglossum bicirrhosum</i> (Cuvier, 1829)	Amazon, Oyapock	Aquaculture	Non-established	2018	CO
Poeciliidae	<i>Poecilia reticulata</i> (Peters, 1859)	North-East of South America	Ornamental	Established	2005	SI, CR
Serrasalminidae	<i>Colossoma macropomum</i> (Cuvier, 1816)	Amazon and Orinoco	Aquaculture	Unknown	2018	AP, CO, SI

experienced several non-native species introductions and subsequent establishment (Leprieur *et al.*, 2008). Indeed, Planquette *et al.* (1996), Le Bail *et al.* (2000) and Keith *et al.* (2000) reported only two non-native fish species in French Guiana. Among these two species, *Hyphessobrycon eques* was no longer retrieved in French Guiana, and this introduced population is probably currently extinct (Quartarollo and Lalagüe, 2019). In contrast, *Heros efasciatus* is still present in French Guiana, and its non-native spatial repartition, initially clustered to the vicinity of Kourou (North of French Guiana, Keith *et al.*, 2000) extended to the swamp habitats from most of the Guianese littoral area. Recent observations indicate high densities of the species in the initial introduction area, close to the city of Kourou, and growing populations in the other localities, indicating the species is established and expanding. Such spatial range extension can be due to several introduction events, or to the species spread from its initial introduction locality through coastal swamp corridors. We nevertheless cannot exclude a natural spatial expansion of *Heros efasciatus* to Kaw swamps located ca. 50 kilometres west from the native range of the species.

More than a decade after Planquette *et al.* (1996), Le Bail *et al.* (2000) and Keith *et al.* (2000), an updated checklist of freshwater fish of French Guiana only report one more introduction, with the presence of *Poecilia reticulata* in the vicinity of Cayenne city (Le Bail *et al.*, 2012). This species is still present in this locality, and established durable populations in the ponds and streams of the Rorota mount, a natural area close to Cayenne. This species has also been introduced in

2016 in a gravel pit located 60 km east from Cayenne, but this population probably collapsed, because the species was not retrieved in this site since 2018. In addition to the latter species we here report for the first time the introduction of eight more non-native species in Guianese waters. Although captures or observations of these species are scarce, and establishment status of some species unknown, such observations should be considered as an early signal of potential establishment and subsequent invasion.

The presence of non-native species in Guianese freshwaters should be related to two distinct human activities. *Cyprinus carpio* (koi strain), *Heros efasciatus*, *Hyphessobrycon eques*, *Mesonauta guyanae*, *Poecilia reticulata* and *Pterophyllum scalare* are popular ornamental species, which were probably released in the natural environment by fish hobbyists (*i.e.* aquarium dumping). This explains their introduced locations nearby cities, to the exception of *Cyprinus carpio* and *Pterophyllum scalare*, which were introduced in a gravel pit (Crique Crabe drainage, near the Petit-Saut hydroelectric dam) commonly used by local people for recreation activities and diving. The other species (*Arapaima gigas*, *Colossoma macropomum*, *Cichla monoculus*, *Osteoglossum bicirrhosum* and *Oreochromis mossambicus*) are intensively reared in aquaculture farms in Suriname and Brazil, and illegally reared in artisanal fish ponds close to Cacao and Montsinery villages (Cambou & Thonnel 2010). Some individuals probably escaped from these ponds explaining the occurrence of some of these species in the nearby Comté River. It should nevertheless be noticed that the occurrence of *Colossoma macropomum* in

the Approuague and Sinnamary rivers suggest the presence of this species in other fish ponds from the littoral zone of French Guiana.

The non-native species were to date recorded only in the littoral zone of French Guiana, and recent fish inventories did not report captures in other locations (*e.g.* Allard *et al.*, 2016; Cilleros *et al.*, 2017; Brosse *et al.*, 2013, 2019), indicating that those species did not disperse far from the introduction sites. Nevertheless, the capture of one *Colossoma macropomum* on the Comté River more than 25 kilometres upstream from Cacao village, the supposed introduction site, attests for the survival and dispersion of the species in Guianese rivers, although its establishment success remains unknown. Among the 11 species, at least four successfully established (*Cichla monoculus*, *Heros efasciatus*, *Mesonauta guyanae* and *Poecilia reticulata*) in natural swaps and artificial ponds, corresponding to the natural habitat of those species. *Cyprinus carpio* is known from a single locality, and only adults have been observed, suggesting the species failed to establish. The establishment status of the remaining species (*Arapaima gigas*, *Colossoma macropomum*, *Osteoglossum bicirrhosum* and *Oreochromis mossambicus*) remain unknown, but they are recognised as potentially invasive species in the literature. *Oreochromis mossambicus* is indeed one of the most invasive fish species (IUCN, 2020), which established in most tropical regions (Rahel, 2007; Pelicice *et al.*, 2017). *Colossoma macropomum* and *Arapaima gigas* were also reported to establish and spread in several Neotropical and Central American localities (Vitule *et al.*, 2009; Van Damme *et al.*, 2015; Pelicice *et al.*, 2017). The establishment of those species is therefore likely in Guianese waters.

Such establishment or the spread of already established species could cause detrimental impacts on the native fauna. Non-native species are indeed recognised as one of the main cause of biodiversity erosion (Butchart *et al.*, 2010) and freshwater fish invasions already had pervasive impacts throughout South America (Vitule *et al.*, 2009; Pelicice *et al.*, 2017). More specifically *Cichla* invasion has been reported to cause a biodiversity collapse of the lake Panama ecosystem in the seventies (Zaret and Paine, 1973), and *Cichla ocellaris*, a species closely related to *Cichla monoculus*, is currently invading the Upper Parana river (Espinola *et al.*, 2015). Tilapia (*Oreochromis* sp.) severely impacted native Cichlidae species in the Amazonas basin (Bittencourt *et al.*, 2014), and *Arapaima gigas* rapidly extends its geographical range in the Bolivian Amazon, putting at risk native fish populations (Van Damme *et al.*, 2015). Although the state of invasion of those species in French Guiana is still in an early stage, the current human demographic increase triggers the demand for fish production, and increases risks of further introductions. For instance, the highly invasive armoured catfishes from the *Pterygoplichthys* genus appear as candidates for forthcoming introduction. Indeed, *Pterygoplichthys disjunctivus* (Weber, 1991) has been detected in 2010 in lower Suriname River (Suriname), and since then regularly found in Paramaribo fish market where it replace *Hypostomus plecostomus* (Linnaeus, 1758) (J. Mol, pers. com.). Those fishes already recently dispersed to the West, in lower Saramacca drainage (Makhan, 2017), and might already settled in French Guiana given that Commewijne River, located West of lower Maroni River, shares a common mouth

with the Suriname River. Such forthcoming introductions risks are also reinforced by the development of ornamental fish trade. Aquaculture and ornamental trade therefore represent a source of further introductions for the already introduced, but still not established species, as well as a source of new species introductions, as already experienced in Brazilian freshwaters (Junior *et al.*, 2018; Patoka *et al.*, 2018). Increasing both the number of introduced species and introduction events reinforces establishment probability (Leprieur *et al.*, 2008), and given that once a non-native species is established, its control and eradication is almost impossible (Pimentel *et al.*, 2005), the non-native species records reported here should act as an early warning to control and limit further introductions. Such limitation could be achieved through laws banning the potentially invasive species form fish trade, including fish farms and ornamental pet shops that are a major source of non-native species introductions in the Neotropics (Britton and Orsi 2012; Magalhães and Jacobi 2013; Magalhães *et al.*, 2020). In addition, awareness campaigns are also needed to educate people on the pervasive effects of non-native species, and hence reduce the human assisted spread of already established species.

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