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Small size today, aquarium dumping tomorrow: sales of juvenile non-native large fish as an important threat in Brazil

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Informal sales of large-bodied non-native aquarium fishes (known as "tankbusters") is increasing among Brazilian hobbyists. In this study, we surveyed this non-regulated trade on Facebook® from May 2012 to September 2016, systematically collecting information about the fishes available for trading: species, family, common/scientific names, native range, juvenile length, behavior, number of specimens available in five geographical regions from Brazil. We also assessed the invasion risk of the most frequently sold species using the *Fish Invasiveness Screening Test* (FIST). We found 93 taxa belonging to 35 families. Cichlidae was the dominant family, and most species were native to South America. All species are sold at very small sizes (< 10.0 cm), and most display aggressive behavior. The hybrid *Amphilophus trimaculatus* × *Amphilophus citrinellus*, *Astronotus ocellatus*, *Uaru amphiacanthoides*, *Osteoglossum bicirrhosum*, *Cichla piquiti*, *Pangasianodon hypophthalmus*, *Datnioides microlepis* and *Cichla kelberi* were the main species available. The southeast region showed the greatest trading activity. Based on biological traits, the FIST indicated that *Arapaima gigas*, *C. kelberi* and *C. temensis* are high-risk species in terms of biological invasions via aquarium dumping. We suggest management strategies such as trade regulations, monitoring, euthanasia and educational programs to prevent further introductions via aquarium dumping.

Keywords: Aquarium releases, Aquarium trade, Biological invasions, Invasiveness, Propagule pressure.

A venda de juvenis de peixes não-nativos de grandes dimensões, chamados de "peixes jumbo", está aumentando entre aquaristas no Brasil. Neste trabalho, pesquisou-se este comércio informal pelo Facebook® de maio/2012 a setembro/2016, coletando-se informações sobre espécies, família, nomes vulgares/científicos, origem, tamanho juvenil, comportamento e número/frequência de exemplares disponíveis nas cinco regiões geográficas do Brasil. Também avaliou-se o risco de invasão das espécies mais vendidas usando o protocolo *Fish Invasiveness Screening Test* (FIST). Foram encontradas 93 espécies pertencentes a 35 famílias. Cichlidae foi a família dominante, e a maioria das espécies é nativa da América do Sul. Todas as espécies foram vendidas como juvenis (< 10.0 cm), e a maioria exibe comportamento agressivo. O híbrido *Amphilophus trimaculatus* × *Amphilophus citrinellus*, *Astronotus ocellatus*, *Uaru amphiacanthoides*, *Osteoglossum bicirrhosum*, *Cichla piquiti*, *Pangasianodon hypophthalmus*, *Datnioides microlepis* e *Cichla kelberi* foram as espécies mais comercializadas. A região sudeste apresentou a maior porcentagem de vendas, e o FIST mostrou que *Arapaima gigas*, *C. kelberi* e *C. temensis* foram consideradas de alto risco para desencadear invasões biológicas mediadas por descarte de aquários. Recomendações como a regulação do comércio, monitoramento, sacrifício das espécies e campanhas educacionais para os aquaristas são sugeridas para evitar futuras introduções de peixes via descarte de aquários.

Palavras-chave: Comércio ornamental, Invasividade, Invasões biológicas, Pressão de propágulos, Solturas de aquaristas.

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Introduction

Fishkeeping is a worldwide hobby appretiated by people of all ages (CBD, 2010). It has been shown that aquarium keeping improves human well-being in many aspects, *e.g.* the development of responsibility in children (Edwards, Beck, 2002), reduction of stress levels in adults, and improved physical and psychological well-being in the elderly (Reaser, Meyers, 2007). The United States is the leading country in the number of hobbyists, with about 20 million enthusiasts (Chapman, 2000). Estimates indicate that american homes have 151.6 million ornamental fishes (APPMA, 2008), followed by the United Kingdom, with 140 million fishes (Marine & Coastal Committee, 2005). In Brazil, it is a growing hobby with 26 million fishes belonging to more than 300 species, being the second most frequent pet (AquaA3, 2015).

Fishkeeping is increasing in popularity, but hobbyists are poorly informed or reckless about environmentally friendly practices (Duggan *et al*., 2006; Gertzen *et al*., 2008; Holmberg *et al*., 2015; Maceda-Veiga *et al*., 2016). For example, excessive growth and unexpected aggressive behavior of fishes may lead to environmental problems, *i.e*, aquarium dumping (Duggan *et al*., 2006; Gertzen *et al*., 2008). Under these circumstances, many hobbyists are poorly informed about adequate practices (*i.e*, correct disposal of pets or even sacrifice), and discard unwanted pets into nearby waterways (Duggan *et al*., 2006; Gertzen *et al*., 2008; Magalhães, Jacobi, 2013a; Azevedo-Santos *et al*., 2015; Maceda-Veiga *et al*., 2016). Pet abandonment has become one of the most challenging issues in biosecurity concerning species invasions (CBD, 2010). For instance, in Australia, Taiwan, Singapore and Japan, aquarium dumping is the main cause of non-native fish species introduction (Bomford, Glover, 2004; Liang *et al*., 2006; Ng, Tan, 2010; Ishikawa, Tachihara, 2014). In Brazil, where native fish diversity is high (Frehse *et al*., 2016), official reports of aquarium dumping are rare, but evidence indicates that this activity is frequent and increasing in several regions (Gomes *et al*., 2011; Magalhães, Jacobi, 2013a; Garcia *et al*., 2014; Azevedo-Santos *et al*., 2015; França *et al*., 2017). There are records regarding small characids, osphronemids and poeciliids (Magalhães, Jacobi, 2013a; Azevedo-Santos *et al*., 2015), but the market of large-bodied non-native aquarium fishes may represent an important source of fish propagules. Sales of large ornamental species, known as "tankbusters" among hobbyists, has grown rapidly in the last decade (Magalhães, Jacobi, 2010; Gomes *et al*., 2011; Magalhães, Jacobi, 2013a; Garcia *et al*., 2014; França *et al*., 2017). Different large species have been translocated among watersheds, including fishes from the Amazon basin (*e.g.* freshwater stingrays *Potamotrygon* spp., sailfin catfishes *Pterygoplichthys* spp.) and/or imported from other countries (*e.g.* alligator gar *Atractosteus spatula* (Lacepède, 1803), striped catfish *Pangasianodon hypophthalmus* (Sauvage, 1878)) (Garcia *et al*., 2014; Azevedo-Santos *et al*., 2015). As ornamental fishkeeping practices spread in Brazil (Gomes *et al*., 2011; Magalhães, Jacobi, 2013a; Assis *et al*., 2014; Garcia *et al*., 2014; Magalhães, 2015), an informal trade system has developed among hobbyists, which is currently non-regulated, non-monitored and apparently not recognized by environmental agencies (Magalhães, 2015).

In order to understand this non-regulated market and the environmental risks associated, this study evaluated the sales of juvenile non-native large fish (JNLF, hereafter) among Brazilian hobbyists, via face-to-face personal contacts. So far, the importance of this new vector had not been evaluated consistently in Brazil, an here we present an overview of species available for trading, quantity, sizes, origin and ecological information related to their invasion risk. Based on this data, we discuss management strategies to prevent further invasions into Brazilian water bodies via aquarium dumping.

Material and Methods

Data sampling. We surveyed the informal ornamental trade in the Facebook® (www.facebook.com) from May-2012 to September-2016. Ten hobbyist groups (*i.e*, exclusive sale groups of ornamental large fishes) were chosen randomly using standardized keywords (*e.g.* jumbo fishes, jumbo fish sales, jumbo cichlids, Brazil jumbo fishes, jumbo fishkeepers, keeping large fish, Central American cichlids) and monitored four times every month (once a week in the same day). To conduct the monitoring, one researcher (A.L.B. Magalhães) became a member of the group but did not contact any hobbyist during the period, so the trading process was not disturbed. The trade operates as follows: the hobbyist announces the species showing a picture, common or scientific name, juvenile length, price (Real currency) and location. When the purchase is agreed, hobbyists schedule to meet and complete the deal in privacy.

To determine the availability of JNLF for sale, we surveyed only fish species with maximum adult lengths above 20 cm. When a hobbyist announced the same species in more than one group, replicates were discarded. From the ten Facebook® aquarium groups, we recorded information about the fishes on sale: length, number of specimens and geographical availability, considering 11 large urban centers of the north (Belém), northeast (São Luís, Fortaleza, João Pessoa, Recife, Salvador), mid-west (Brasília), southeast (Belo Horizonte, Rio de Janeiro, São Paulo), and south (Curitiba) regions of Brazil (Fig. 1). In addition, the family, common/scientific names, native range, maximum adult length and aggressiveness of these species were consulted in Axelrod (1992), Sandford, Crow (1996), Axelrod *et al*. (2005), Liew *et al*. (2012), Motionaquaticsuk (2016), Froese, Pauly (2016), Nelson *et al*. (2016), and Eschmeyer *et al*. (2017).

Fig. 1. Five main geopolitical regions of Brazil and the 11 cities where we monitored the unregulated market of juveniles of non-native large fishes. Brazilian cities/population/states surveyed: BE - Belém/1,446,042 inhabitants/Pará, SL - São Luís/1,082,935 inhabitants/Maranhão, FO - Fortaleza/2,609,716 inhabitants/Ceará, JP - João Pessoa/801,718 inhabitants/Paraíba, RE - Recife/1,625,583 inhabitants/Pernambuco, SA - Salvador/2,938,092 inhabitants/Bahia, BR - Brasília (capital city of Brazil)/2,977,216 inhabitants/Distrito Federal, BH - Belo Horizonte/2,513,451 inhabitants/Minas Gerais, RJ - Rio de Janeiro/6,498,837 inhabitants/Rio de Janeiro, SP - São Paulo/12,038,175 inhabitants/São Paulo, CU - Curitiba/1,893,997 inhabitants/Paraná (IBGE, 2016).

Data analysis. We calculated the total number of species available in the market, and according to families and native origin. We also calculated specimens availability, for each species and geographical region. The Kruskal-Wallis non-parametric analysis of variance (Sokal, Rohlf, 1995) was used to test differences in mean length between juvenile fishes on sale and their maximum lengths when adults. This test considered only the 15 most frequently available (announced for sale) species, which were pooled across species to test overall differences in length.

We also assessed the invasion risk of these top 15 species using a simple risk assessment protocol named *Fish Invasiveness Screening Test* (FIST) (Singh, Lakra, 2011). This index includes the screening of potential biological traits related to invasion risk, such as maximum adult length, aggressiveness, tolerance to salinity, history of establishment, breeding in the wild and competition with local species. For each species, traits were classified as + (low), ++ (moderate) and +++ (high), according to the literature (Nico *et al*., 2007; Ng, Tan, 2010; Herder *et al*., 2012; Jaafar *et al*., 2012; Liew *et al*., 2012; Carvalho *et al*., 2014; Pelicice *et al*., 2015; Motionaquaticsuk, 2016; Froese, Pauly, 2016). Traits were categorized in the following way: 1) Maximum adult length (+ = 20.0 to 40.0 cm, ++ = 40.1 to 60.0 cm, +++ = above 60.1 cm); 2) Aggressiveness (+ = harmless, ++ = peaceful, +++ = aggressive); 3) Tolerance to salinity (+ = freshwater, ++ = freshwater/brackish, +++ = saltwater); 4) History of establishment (+ = 0 to 7 countries, ++ = 8 to 15 countries, +++ = more than 16 countries); 5) Breeding in the wild (+ = absent, ++ = low to moderate, +++ = high); 6) Competition with local species (+ = absent, ++ = low to moderate, +++ = high). We then calculated the frequency (FD%) of the +++ class among the six screened traits, and used this value to determine the risk level for each species. To determine invasion risk associated with aquarium dumping, we used criteria similar to Singh, Lakra (2011), where species with FD% above 50% were classified as high-risk, species with FD% between 30 and 50% were classified as medium-risk, and species with FD% below 30% were classified as low-risk.

Results

We encountered sales of 93 taxa of JNLF, being 89 valid species and four hybrids (Appendix **S1** - Available only as online supplementary file accessed with the online version of the article at http://www.scielo.br/ni). These taxa belonged to 35 families, native to six continents and one region. Among the families, Cichlidae was the dominant (34 species), followed by Polypteridae, Loricariidae and Cyprinidae (four species each). Potamotrygonidae, Osteoglossidae, Notopteridae and Serrasalmidae were represented by three species, while the remaining were represented by two or one species (Fig. 2). According to their native origin, 43 species (46.24%) were native to South America, especially the Amazon region (36.56%), followed by Africa and Asia (17.20% each), Central America (11.83%), North America (4.30%), Oceania (2.15%) and Caribbean (1.08%) (Fig. 3).

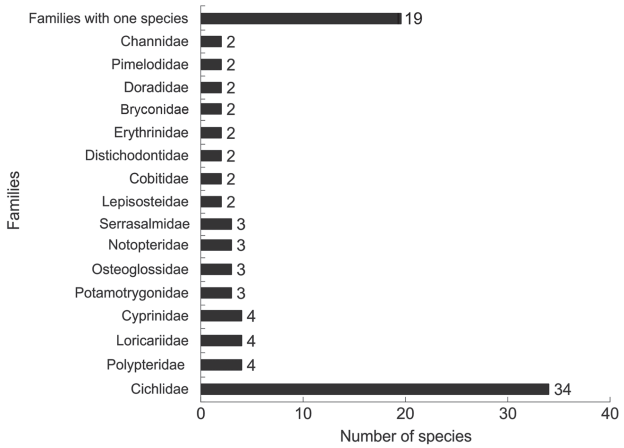

Fig. 2. Number of species of non-native large fish according to each family, recorded in the informal market held by Braziliam hobbyists, from May-2012 to September-2016. Families with only one species: Protopteridae, Arapaimidae, Mormyridae, Cynodontidae, Prochilodontidae, Ctenoluciidae, Pangasiidae, Bagridae, Mochokidae, Claroteidae, Clariidae, Auchenipteridae, Ictaluridae, Apteronotidae, Eleotridae, Osphronemidae, Centrarchidae, Sciaenidae, Datnioididae.

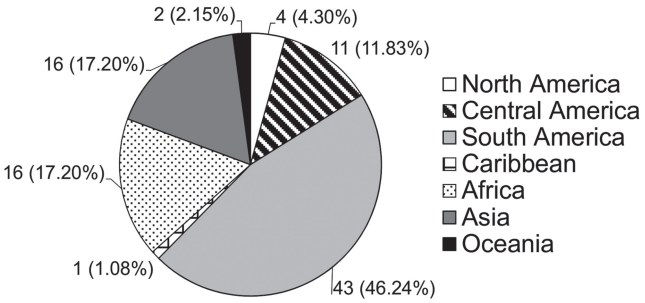

Fig. 3. Origin of non-native large fish species available among Brazilian hobbyists in the informal market.

Considering the 15 most traded species, juvenile length ranged from 3.0 cm (*Heros severus* Heckel, 1840) to 35.0 cm (*Arapaima gigas* (Valenciennes, 1847)), while their maximum adult length found in the literature ranged from 20.0 cm (*H. severus* and *Herichthys carpintis* (Jordan & Snyder, 1899) + *Amphilophus citrinellus* (Günther, 1864) × *Vieja melanura* (Günther, 1862)) to 450.0 cm (*A. gigas*). The mean length of juvenile fish on sale was significantly lower than their maximum lengths (Fig. 4a). JNLF are able to reach (on average) 7.5 times their sizes at retail, and they are usually sold with ca. 20% of their maximum lengths (Fig. 4b). All species are sold at very small sizes (< 10.0 cm on average), and some show contrasting lengths if compared to their maximum adult length, such as *Cichla temensis*, *Lepisosteus oculatus*, *Osteoglossum bicirrhosum* (Cuvier, 1829), *Pangasianodon hypophthalmus* and *A. gigas* (Fig. 4c).

The number of specimens traded among the ten hobbyist groups averaged 10.5 individuals/species, considering the entire study period. The main species available were (Tab. 1): hybrid cichlid flowerhorn *Amphilophus trimaculatus* (Günther, 1867) × *Amphilophus citrinellus*, oscar *Astronotus ocellatus* (Agassiz, 1831), uaru *Uaru amphiacanthoides* Heckel, 1840, arowana *O. bicirrhosum*, blue peacock bass *Cichla piquiti* Kullander & Ferreira, 2006, striped catfish *P. hypophthalmus*, finescale tigerfish *Datnioides microlepis* Bleeker, 1854 and yellow peacock bass *C. kelberi* Kullander & Ferreira, 2006.

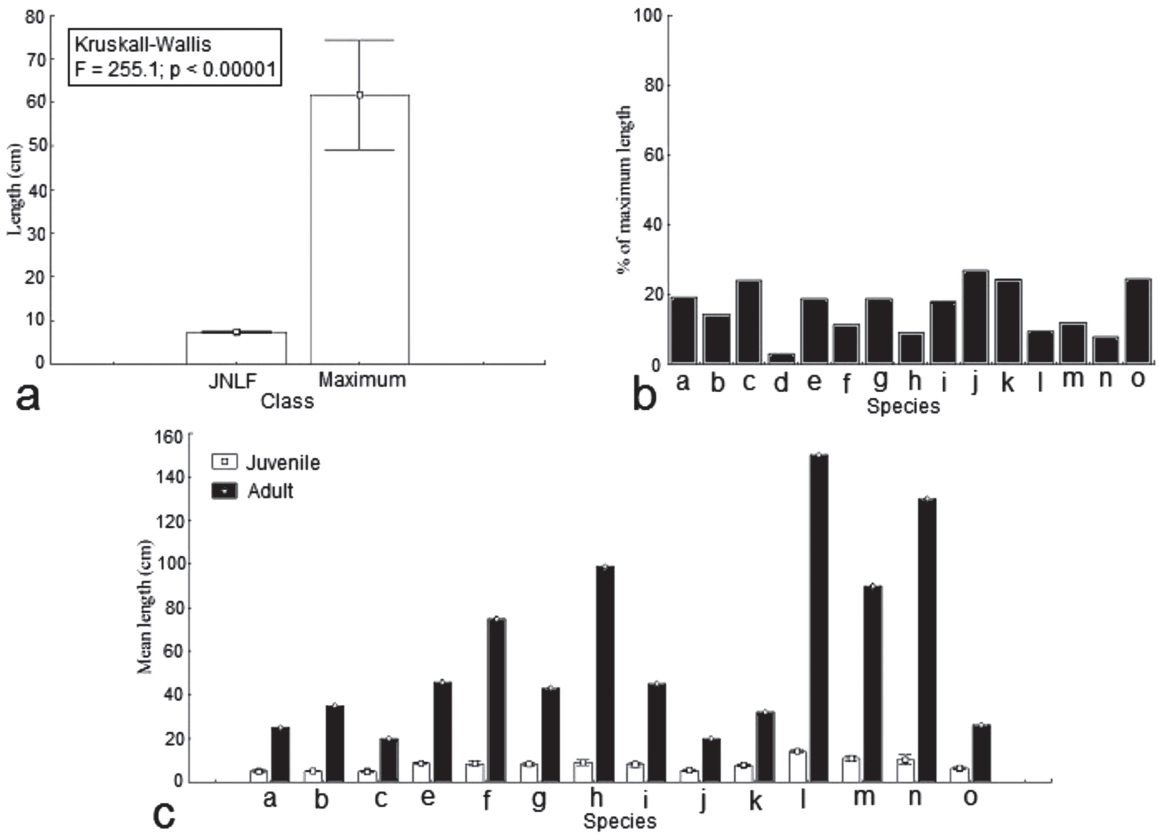

Fig. 4. Length data of non-native large fish, considering the top 15 species available among hobbyists in the unregulated market. **a.** Mean length of 768 juvenile specimens (± 95% CI) and mean maximum lengths of available species (tested through non-parametric Kruskall-Wallis); **b.** Sizes of available fishes as percentage of their maximum lengths; **c.** Mean length of species available in the market and their respective maximum lengths. Species codes: a = *Amphilophus citrinellus* × *Vieja melanura*; b = *Amphilophus trimaculatus* × *Amphilophus citrinellus*; c = *Herichthys carpintis* + *Amphilophus citrinellus* × *Vieja melanura*; d = *Arapaima gigas*; e = *Astronotus ocellatus*; f = *Cichla kelberi*; g = *Cichla piquiti*; h = *Cichla temensis*; i = *Datnioides microlepis*; j = *Heros severus*; k = *Hoplarchus psittacus*; l = *Lepisosteus oculatus*; m = *Osteoglossum bicirrhosum*; n = *Pangasianodon hypophthalmus*; o = *Uaru amphiacanthoides*. The species *Arapaima gigas* was ommited from figure **c** because of its large size (mean JNLF = 13.6 cm; maximum = 450.0 cm).

Tab. 1. Top 15 non-native large fishes available in the unregulated market, monitored between May-2012 and September-2016. The table shows information about family, common/scientific name, native origin, juvenile and maximum adult length (cm), aggressiveness, number of specimens available (N) and their relative frequency (%). * References - 1: Axelrod, 1992; 2: Sandford, Crow, 1996; 3: Axelrod *et al*., 2005; 4: Nico *et al*., 2007; 5: Ng, Tan, 2010; 6: Herder *et al*., 2012; 7: Jaafar *et al*., 2012; 8: Liew *et al*., 2012; 9: Carvalho *et al*., 2014; 10: Pelicice *et al*., 2015; 11: Motionaquaticsuk, 2016; 12: Froese, Pauly, 2016.

Family	Common name Scientific name	Origin	Juvenile (range)	Adult	Behavior	N	%	* Refs.
Cichlidae	flowerhorn *Amphilophus trimaculatus* × *Amphilophus citrinellus*	Asia	4.0-9.0	35.0	Aggressive	294	30.28	4, 5, 6, 7
Cichlidae	oscar *Astronotus ocellatus*	South America	5.0-13.0	45.7	Aggressive	66	6.80	1, 2, 3, 8, 12
Cichlidae	uaru *Uaru amphiacanthoides*	South America	5.0-9.0	26.0	Harmless	50	5.15	3, 12
Osteoglossidae	arowana *Osteoglossum bicirrhosum*	South America	7.0-20.0	90.0	Aggressive	45	4.63	1, 2, 3
Cichlidae	blue peacock bass *Cichla piquiti*	South America	5.0-16.0	43.0	Aggressive	42	4.32	9, 12
Pangasiidae	striped catfish *Pangasianodon hypophthalmus*	Asia	4.0-40.0	130.0	Harmless	40	4.12	3, 12
Datnioididae	finescale tigerfish *Datnioides microlepis*	Asia	5.0-14.0	45.0	Aggressive	35	3.60	5, 12
Cichlidae	yellow peacock bass *Cichla kelberi*	South America	6.0-15.0	75.0	Aggressive	32	3.29	9, 10
Lepisosteidae	spotted gar *Lepisosteus oculatus*	North America	10.0-27.0	150.0	Aggressive	28	2.88	3, 12
Cichlidae	blood parrot *Amphilophus citrinellus* × *Vieja melanura*	Asia	4.0-9.0	25.0	Aggressive	28	2.88	8
Cichlidae	lowland cichlid-blood parrot *Herichthys carpintis* + *Amphilophus citrinellus* × *Vieja melanura*	Asia	4.0-8.0	20.0	Aggressive	27	2.78	11
Cichlidae	parrot cichlid *Hoplarchus psittacus*	South America	7.0-9.0	32.0	Aggressive	23	2.37	3, 12
Cichlidae	speckled pavon *Cichla temensis*	South America	7.0-15.0	99.0	Aggressive	22	2.27	8, 12
Cichlidae	banded cichlid *Heros severus*	South America	3.0-7.0	20.0	Aggressive	22	2.26	5, 12
Arapaimidae	giant arapaima *Arapaima gigas*	South America	9.0-35.0	450.0	Aggressive	14	1.44	3, 12

The risk assessment (FIST) for potential biological invasion via aquarium dumping indicated that three species were considered high-risk, seven are moderate-risk and five are low-risk (Tab. 2). One important aspect is that most of the top 15 species display aggressive behavior (86.67%), a trait commonly associated with pet rejection among hobbyists and the consequent dumping into the new environments.

The southeast region (93.59%), represented by the cities of São Paulo (SP: 77.62%), Rio de Janeiro (RJ: 12.72%) and Belo Horizonte (BH: 3.25%), showed the greatest informal trade activity. The northeast region (5.62%), represented by the cities of São Luiz (SL: 0.10%), Fortaleza (FO: 0.29%), João Pessoa (JP: 0.20%), Recife (RE: 3.05%) and Salvador (SA: 1.98%), showed much lower activity (Fig. 5).

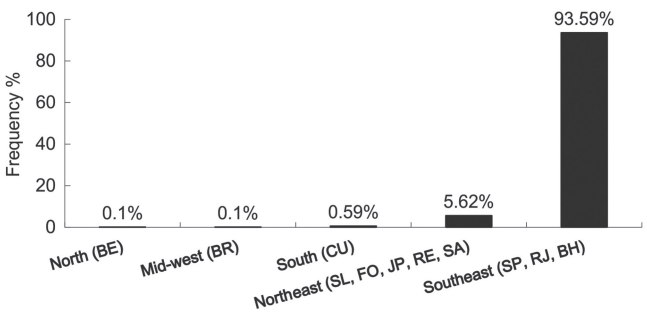

Fig. 5. Five Brazilian geopolitical regions and the 11 big cities (BE - Belém, BR - Brasília, CU - Curitiba, SL - São Luís, FO - Fortaleza, JP - João Pessoa, RE - Recife, SA - Salvador, SP - São Paulo, RJ - Rio de Janeiro, BH - Belo Horizonte) where hobbyists traded juveniles of non-native large fish, between May-2012 and September-2016.

Tab. 2. Results of the *Fish Invasiveness Screening Test* (FIST) calculated for the 15 most available non-native large fishes. 1: Maximum adult length (cm), 2: Aggressiveness, 3: Tolerance to salinity, 4: History of establishment, 5: Ability to breed in the wild, 6: Competition with native species, +: low; ++: moderate, +++: high. FD% = frequency of +++ among traits.

Species invasiveness assessment	Invasiveness screening criteria						Risk (FD %)
	1	2	3	4	5	6	
Arapaima gigas	+++	+++	+	+	+++	+++	High (66.67)
Cichla kelberi	+++	+++	+	++	+++	+++	High (66.67)
Cichla temensis	+++	+++	+	+	+++	+++	High (66.67)
Astronotus ocellatus	++	+++	+	++	+++	+++	Medium (50.00)
Cichla piquiti	++	+++	+	++	+++	+++	Medium (50.00)
Amphilophus trimaculatus × *Amphilophus citrinellus*	+	+++	++	+	+++	+++	Medium (50.00)
Heros severus	+	+++	++	+	+++	++	Medium (33.33)
Hoplarchus psittacus	+	+++	+	+	+++	++	Medium (33.33)
Lepisosteus oculatus	+++	+++	+	+	++	++	Medium (33.33)
Osteoglossum bicirrhosum	+++	+++	+	+	++	++	Medium (33.33)
Datnioides microlepis	++	+++	+	+	+	+	Low (16.67)
Uaru amphiacanthoides	+	+	+	+	+++	++	Low (16.67)
Pangasianodon hypophthalmus	+++	+	+	++	+	+	Low (16.67)
Amphilophus citrinellus × *Vieja melanura*	+	+	+	+	+	+	Low (0)
Herichthys carpintis + *Amphilophus citrinellus* × *Vieja melanura*	+	++	+	+	+	+	Low (0)

Discussion

We found a large number of species (n=93), most native to South America and traded among Brazilian hobbyists over the study period (almost five years), indicating that many ornamental non-native large fishes are available in the unregulated market. Our study is just a sample of the non-regulated market, so the number of new species and flow of fish among hobbyists must be much higher. For example, sales of largemouth bass *Micropterus salmoides* (Lacepède, 1802), Mexican mojarra *Mayaheros urophthalmus* (Günther, 1862) and Ginean bichir *Polypterus ansorgii* Boulenger, 1910, juveniles emerged in one of the monitored groups during March and April 2017 (A.L.B. Magalhães, pers. obs.), although these non-native species were not detected in our survey. In addition, we monitored only ten aquarium groups, but a quick search on Facebook® showed the existence of at least 20 groups selling JNLF. Large-bodied species were formerly sold only in aquarium stores, but the popularity of social media and e-commerce increased the potential market. At present, JNLF can be easily purchased by consumers located outside large urban centers, a non-monitored system that may enhance aquarium dumping and fish invasions across the country.

In our survey, Cichlidae was the main family in the informal market. Cichlids are among the most popular aquarium fishes due to aesthetic aspects such as diversity of colors (Mann, Sefc, 2013) and easiness of rearing in aquaria (Liang *et al*., 2006). Many hobbyists maintain their own breeding stocks, which also explains the desirability for this family (Liew *et al*., 2012). Several cichlids, however, are highly territorial, predatory and grow to large sizes, *i.e*, traits that make theses fishes good candidates to become undesirable and dumped. In the wild, large cichlids exhibit extended breeding seasons and aggressive parental care (Bomford, Glover, 2004), enhancing survival of the young and granting them competitive advantage over native species (van Breukelen, 2015). In addition, some non-native species found here such as hybrid flowerhorn, oscar, banded cichlid and the lowland cichlid *Herichthys carpintis* are euryhaline, able to survive in mesohaline conditions for extended periods of time (Jaafar *et al*., 2012; Liew *et al*., 2012; Gutierre *et al*., 2016; Froese, Pauly, 2016), with the possibility to use brackish waters of mangroves/estuaries as dispersal routes (*i.e*, dispersion bridges) (Gutierre *et al*., 2014). Of the 11 cities evaluated, seven (63.64%) have mangroves and estuaries in their urban perimeters; if these euryhaline species invade these environments, the chance of establishment is high.

All species recorded were traded as juveniles at very small lengths, but all can attain large sizes at maturity; in addition, the majority display aggressive behavior. The same trend was found by Holmberg *et al*. (2015) for more than 700 large marine aquarium fish species, such as the giant grouper *Epinephelus lanceolatus* (Bloch, 1790) and the lionfish *Pterois volitans* (Linnaeus, 1758), sold in the U.S.A. aquarium trade. The small size at the retailing stage is a key factor behind the introduction of large-sized fishes, because many hobbyists are ignorant about species biology and behavior. Species biology may influence the likelihood of deliberate releases in two ways: first and most important, fish become too large and aggressive (Duggan *et al*., 2006; Gertzen *et al*., 2008); and second, proliphic species (*e.g.* some cichlids) may quickly overpopulate the aquaria, especially because fecundity is size-dependent (Liew *et al*., 2012). Both aspects are the main reasons for deliberate aquarium fish releases (Bomford, Glover, 2004; Magalhães, Jacobi, 2013a).

Top eight JNLF commonly sold in Brazil have already invaded different regions of the planet, some with negative effects on biodiversity. For example, the hybrid flowerhorn is established in Sulawesi and threatens the endemic goby *Glossogobius matanensis* (Weber, 1913) through predation and competition (Herder *et al*., 2012). *Astronotus ocellatus* competes with native species in canals of the Everglades National Park, U.S.A (Trexler *et al*., 2000). *Pangasianodon hypophthalmus* introduced in Poland either hosts or transmitted a monogenoid parasite, *Thaparocleidus caecus* (Mizelle & Kritsky, 1969), posing threat to native fishes (Wiecaszek *et al*., 2009). A concerning trend is the increasing demand for peacock basses (*Cichla*) as pet fish. These fishes are the major group of piscivorous cichlids in South America, successful invaders of environments disturbed by human activities (Espínola *et al*., 2010). In Brazil, two large cichlids, *C. piquiti* and *C. kelberi*, are extensively established in non-Amazonian basins (Carvalho *et al*., 2014), and studies have shown that the introduction of these fishes is associated with deleterious effects on local fish assemblages (Carvalho *et al*., 2014; Pelicice *et al*., 2015). Although the invasion of *Cichla* is usually associated to sport fisheries, the importance of aquarium dumping may increase in next years, since these species are now popular among hobbyists in Brazil and elsewhere. We highlight that the *Fish Invasiveness Screening Test* has identified *A. gigas*, *C. kelberi* and *C. temensis* as high-risk species. As preventive measure, we recommend stringent control on the trade of giant arapaima and peacock basses. Top-predators have great potential to negatively affect the abundance of native biota and cause the extirpations of benthic invertebrates and fish (Gallardo *et al*., 2016).

The southeast region showed the greatest availability of JNLF especially in São Paulo and Rio de Janeiro. These cities, located in areas of Atlantic Rainforest, one of the world's biodiversity hotspots, are the most populous in the country. They are also the main center of aquarium trade, with more than 1,000 aquarium stores (Pinheiro *et al*., 2008) and thousands of fishkeepers (Magalhães, Jacobi, 2010). This geopolitical region has also the highest number of non-native large fishes introduced due to aquarium dumping, such as the goldfish *C. auratus* (Linnaeus, 1758), koi carp *Cyprinus carpio* Linnaeus, 1758, pike cichlid *Crenicichla macrophthalma* Heckel, 1840, eartheater cichlids *Geophagus proximus* (Castelnau, 1855), *G. surinamensis* (Bloch, 1791), pond loach *Misgurnus anguillicaudatus* (Cantor, 1842), *A. ocellatus* and jaguar guapote *Parachromis managuensis* (Günther, 1867) (Gomes *et al*., 2011; Vitule *et al*., 2014a; Latini *et al*., 2016). According to Magalhães (2015), identifying high-risk areas is necessary to devise management measures in geographic regions where invasions are more likely. The release of non-native large fishes into urban waters of Brazil has a recent history, but the scenario indicates that invasibility is high. Many ecosystems are disturbed by multiple human activities such as reservoirs, public ponds and urbanized mangroves/estuaries (Magalhães, Jacobi, 2013a; França *et al*., 2017; Pelicice *et al*., 2017). In adition, several regions in Brazil have a constant warm climate (Magalhães, Jacobi, 2013a; Latini *et al*., 2016; França *et al*., 2017), a scenario that may enhance the establishment of tropical non-native fishes. Therefore, the growing popularity of these fishes (Gomes *et al*., 2011; Magalhães, Jacobi, 2013a; Assis *et al*., 2014; Garcia *et al*., 2014; Magalhães, 2015; França *et al*., 2017), coupled with densely populated cities (IBGE, 2016), indicate that fish invasions and subsequent establishment will increase in next years. We highlight, however, that the successful invasion of some ornamental non-native large fishes does not necessarily demand a high propagule pressure. For instance, the establishment of *C. auratus* in Teller Lake #5, Colorado State (U.S.A), is believed to have stemmed from the release of a small number of founder fish, probably as unwanted pets. This species, with a current population of 3,000 to 4,000 individuals, is now a significant pest threatening local wildlife (Bryner, 2015).

Our findings suggest the need to improve management strategies to prevent further introductions of JNLF via aquarium dumping. Firstly, given that home aquariums are the major potential source of future invaders, a more rigorous system controlling fish keeping should be priority. Thus, we recommend authorities to advise and encourage hobbyists toward better practices concerning the correct disposal of nuisance fish. Aquarium stores and traders could teach hobbyists to return undesirable fishes to retailers (*i.e*, "reverse logistics") or donate to public institutions (*e.g.* schools, zoos). A more stringent and effective measures is euthanizing undesirable fishes (Gomes *et al*., 2011), although hobbyists usually show resistance. Secondly, environmental agencies should work together with Facebook® Serviços Online do Brasil Ltda. to post alert messages in the pictures of JNLF for sale in aquarium groups, indicating simple ecological traits and other information (*e.g.* adult sizes, feeding behavior, tolerance to salinity, aggressiveness, prolificacy, disease vector). Recently, Magalhães, Jacobi (2010) suggested Brazilian virtual petshops and other social media to inform hobbyists about species traits as a means of reducing rejection and subsequent aquarium dumping. Thirdly, environmental agencies (*e.g.* Brazilian Institute of Environment and Renewable Natural Resources-IBAMA) must look for new communication tools, like the newly WhatsApp Messenger (www.whatsapp.com) or develop other smartphone apps, which provides an effective mean to reach hobbyists. For example, environmental agencies of U.S.A, Europe and the Fundación Humedales (Colombia) has developed free apps named respectively IveGot1, That's Invasive! and InvBasa, to provide awareness about new invasions (Adriaens *et al*., 2015; Wallace *et al*., 2016, Fundacion Humedales, 2017). Lastly, and more importantly, it is necessary to implement educational programs to provide high-quality information to hobbyists, retailers and fish farmers (Azevedo-Santos *et al*., 2015), as for example, informing about threats

related to the introduction of non-native fish, and the list of invasive species forbidden in the market (*e.g.* Federal Law 203 of 2008 which prohibits the importation of *P. hypophthalmus*). These programs could be offered by environmental agencies (*e.g.* IBAMA), universities and association of retailers (*e.g.* Brazilian Association of Aquarium Stores-ABLA) (Magalhães, 2015).

By surveying the sales of JNLF through informal markets, we offered an opportunity to understand this new high-risk pathway – especially because this fish trade has public empathy and flourishes in Brazil (Gomes *et al*., 2011; Magalhães, Jacobi, 2013a; Assis *et al*., 2014; Garcia *et al*., 2014; Magalhães, 2015; França *et al*., 2017). Moreover, the new Brazilian Normative Instruction 16 of 2014 (previous Ministry of Fishing and Aquaculture), which allows the trade of hundreds of large ornamental fish species (Vitule *et al*., 2014b), together with Normative Instruction 21 of 2014, which will facilitate the transport of these fishes across the country (Lima-Junior *et al*., 2015), will favor aquarium dumping and further increase biological invasions, with negative effects on native biodiversity - for example, biotic homogenization (*i.e*, the temporal replacement of endemic and specialists native species by generalist and human commensal non-native species) (Vitule *et al*., 2012) or additive heterogenization (*i.e*, non-native species establish, but few become ubiquitous) (Socolar *et al*., 2016). According to Frehse *et al*. (2016), authorities do not recognize the Brazilian aquarium trade as a major introduction pathway; however, in terms of propagule pressure and species diversity, such trade is a major and unpredictable source of introductions. It deserves better investigation, monitoring and control by Brazilian policies and environmental agencies.

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