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Research Letters

# Alien Express: The threat of aquarium e-commerce introducing invasive aquatic plants in Brazil

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ABSTRACT

Aquarium market is one of the main causes of exotic species dispersion, as it promotes the introduction of potential invaders on natural environments. In this scenario, e-commerce provides easy access of invasive plants from around the world. Despite the economic importance of this trade, few studies have addressed the patterns and extension of environmental problems associated with this market. Using search engines and specialized literature, we characterized the e-commerce of freshwater aquarium plants in Brazil, including its commercial flow, traded species and invasive potential of exotic species. We observed that Brazilian e-commerce provides easy access to multiple aquatic plants, which are generally sold at low cost and as vegetative parts. From the 287 species of aquatic plants for sale, distributed in 58 families, 188 were exotic species, originated from Oriental biogeographic region. The trade of exotic species is a potential problem if they (1) are recognized as highly invasive in many parts of the world, (2) belong to genera and families very distinct from native species and could occupy empty niches, and (3) may hybridize with native species, creating lineages with increased potential for invasion. Although Brazilian laws regulating the trade of exotic species are adequate, there is a widespread illegal e-commerce of aquatic plants. The invasive potential of aquarium plants species traded via e-commerce should be a major concern and become the focus of increasing inspections and law compliance.



## Introduction

Species loss is one of the most important issues in the current scenario of extensive human impacts (Sala et al., 2000; Bland and Collen, 2016). We are facing a period of intense species extinction (Wittenberg and Cock, 2001; McGill et al., 2015), which threatens a probably larger number of species that have not been documented yet (Mora et al., 2011). In this context, biological invasions are recognized as one of the major causes of biodiversity loss (Padilla and Williams, 2004; Hussner, 2012), threatening multi-scale conservation and ecosystem integrity (Vilà et al., 2010). Aquatic macrophytes comprise an important part of plant biodiversity in the Neotropics, often presenting high endemism (Chambers et al., 2008). However, human impacts have been disastrous for this biota, which typically occur in heterogeneous and economically and socially attractive environments (Dudgeon et al., 2006).

Problems associated with species introduction have been recognized as priority since Rio 1992 (Convention on Biological Diversity; Gherardi, 2007), and both economic and ecological impacts attributed to invasive species are recognized throughout the world (Vilà et al., 2010). In the USA alone, losses associated with invasive species exceed U$ 122 billion per year (Ellstrand and Schierenbeck, 2000; Schierenbeck and Ellstrand, 2009). The introduction of invasive species in rivers and lakes are among the first and most well-documented cases of biological invasion (Francis and Chadwick, 2012). The success of invasions in freshwater environments is attributed to the frequency, duration and magnitude of anthropogenic impacts (Gherardi, 2007; Richardson et al., 2007). The number of exotic aquatic species causing economic and ecological impacts is proportionately higher than that of terrestrial species (Vilà et al., 2010), being one of the most important threats to freshwater ecosystems (Martin and Coetzee, 2011).

Biological invasion is a multi-stage process (Dietz and Edwards, 2006) in which dispersion is a crucial step (Gherardi, 2007). Humans have become ecologically significant dispersion vectors, moving species and their hitchhikers at high rates and over long

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distances (Ellstrand and Schierenbeck, 2000; Patoka et al., 2016), with numerous new and faster trade routes being created by the globalized world (Francis and Chadwick, 2012). Regarding aquatic plants, the major cause of introduction of exotic species is the aquarium market (Naylor et al., 2001; Padilla and Williams, 2004; Francis and Chadwick, 2012). The aquaculture market is a fast-growing segment of the world economy, with aquarium trade accounting for more than $25 billion per year (Francis and Chadwick, 2012). Although one-third of the world's worst invasive aquatic species are related with escapes from aquariums (Padilla and Williams, 2004), controlling agencies rarely recognize the aquarium market as a potential cause of introduction of invasive species (Gherardi, 2007; Keller and Lodge, 2007). Although laws in many countries restrict species transportation, there has been a dramatic increase of both transport and trade of aquatic species (Patoka et al., 2018).

Accessing plants from anywhere in the world has become easy and unrestricted. In Germany, Hussner et al. (2010) reported a significant relationship between the number of exotic aquatic plants introduced and the number of inhabitants per region; the access to these plants becomes easier as the population size of a region increases, independently of other factors. The Internet and the possibilities generated by the e-commerce are among the main reasons for this pattern (Padilla and Williams, 2004; Humair et al., 2015). E-commerce is the main mechanism for distribution of aquatic plants by the aquarium market (Kay and Hoyle, 2001) and has become the main source of dispersion of invasive aquatic plants worldwide (Padilla and Williams, 2004; Meyerson and Mooney, 2007).

Despite the growing concern about the potential impact of e-commerce on the spread of invasive aquatic plants (Padilla and Williams, 2004; Gherardi, 2007; Martin and Coetzee, 2011; Francis and Chadwick, 2012), few studies have addressed the profile and scale of environmental problems for this market (Lenda et al., 2014). In addition, Brazil is a megadiverse country where the impacts of introducing invasive plant species are both environmentally and economically severe (Paini et al., 2016). Therefore, our objective was to characterize the e-commerce trade of aquatic plants in Brazil. We conducted a survey of all the species advertised on websites of aquarium products in Brazil, and identified the origin, life form, commercial flow and invasive potential of the exotic species traded.

## Methods

Four people using different computers collected data with Google™ search engine (www.google.com.br) from April to May 2014. We searched for websites selling aquatic plants using the following keywords: 'venda' (sale), 'plantas' (plants), 'aquáticas' (aquatics), 'Brasil' (Brazil), 'aquariofilia' (aquarium or aquarism). We also used different keyword arrangements (e.g. combinations of two or more words), accessed the first 100 results of each search, and selected: (i) stores that effectively trade aquatic plants; (ii) stores both selling and offering online payment (e-commerce); (iii) stores offering express delivery all over Brazil. We analyzed approximately 1000 search results and 18 stores fulfilled the above requirements. We noticed that the records were repeated in further searches, suggesting that this sampling was sufficient. Among the selected websites, Mercado Livre™ (www.mercadolivre.com.br) hosted advertisements from several sellers; therefore, we also searched within it using the same keywords. Since the same store could show more than one advertisement, we searched for as many records as possible, considering them as independent advertisements. The search engines used by the websites allowed us to find all the relevant advertisements within the first dozen results, which ensured sampling sufficiency.

We surveyed vegetative plants or seeds for sale in each advertisement and collected the available information about: (i) scientific and vernacular names; (ii) plant parts being sold (seeds, branches, whole plant or set of plants), since vegetative parts and the whole plant could develop faster than seeds; (iii) average retail price of each unit, since the easier access to such plants (including shipment) may increase the introduction potential; (iv) growth difficulty level advised (easy, medium or hard), which could be a measure of the species invasive potential under Brazilian conditions.

We built a database with all common or scientific advertised plant names, which had their scientific name consulted using specialized bibliography (e.g. Suzuki, 2011; Randall, 2012; Flora do Brasil, 2018; Tropicos.org, 2018). Afterwards, we consulted their scientific names in the botanical information database from the Missouri Botanical Garden (Tropicos.org, 2018) to ascertain taxonomic status and link correct names with their respective botanical families. Names attributed to plant varieties or infraspecific lineages were associated only with the specific name. We identified the species that are considered invasive based on Randall's book entitled 'A Global Compendium of Weeds' (Randall, 2012), which compiles information from 1285 scientific sources of invasive plants worldwide. We identified the Brazilian native species and their respective biome based on the List of Brazilian Flora Species (Flora do Brasil, 2018). The origin of the exotic species was based on several sources (e.g. Tropicos.org, 2018; Randall, 2012; papers of taxonomic specific group) and associated with biogeographical regions worldwide.

## Results

All the online stores accessed had a user friendly interface and an effective product search engine. In addition, all of them offered mechanisms to facilitate the purchase (ticket, credit card, etc.), provided delivery services throughout the Brazilian territory covered by postal services, and guaranteed both the delivery and arrival of the living plants. Most sellers also guaranteed product replacement in case of delivery problems, reinforcing the potential of dispersion of the advertised species.

The sale price of the plants were affordable, ranged from US$ 0.13 to 25.00 (R$ 0.50 to R$ 100.00, average price of R$ 2.65 $\pm$ 3.69, $n = 228$), and 82.5% of the plants could be purchased by US$ 3.00 (R$ 12.00) plus delivery costs. Plants were available for sale predominantly as vegetative parts (parts of plants, whole plants or plant clusters) (Fig. 1). We found only four species sold as seeds, including three nympheas (*Nymphaea caerulea*, *N. colorata* and *N. lotus*) and *Nelumbo nucifera*.

Most online stores provided information about the difficulty of growing each plant, and although it was based on non-technical criteria, we believe that this feedback is important for predicting the naturalization risk of these species in the Brazilian aquatic environments. Among the species for sale, 67% were considered easy to grow by aquarists, including 63% of exotic species.

Each plant was advertised from one up to 13 of the online stores; however, most species were sold by only one or two of them (51.2%). We found 1787 individual advertisements of aquatic plants with 558 different names. After excluding names without specific epithet, varieties, cultivars and taxonomic synonyms, we obtained a list of 287 species (including green algae, bryophytes, seedless vascular plants and spermatophytes) from 58 families (Supplementary data). The most common families were Araceae, Alismataceae and Hydrocharitaceae, represented by 40, 31 and 16 species, respectively (Fig. 2).

Only 34% of the species (99) were plants of the Brazilian native flora, and the remaining species (188) were exotic

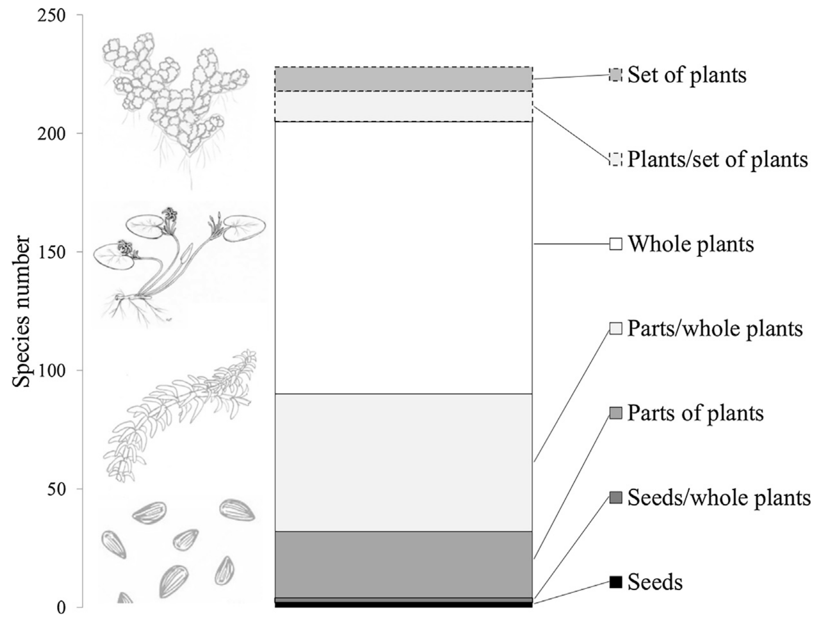


**Fig. 1.** Propagules types advertised in the Brazilian aquarium e-commerce (plants figures extracted from http://www.ufscar.br/ probio/macrof_des.html).

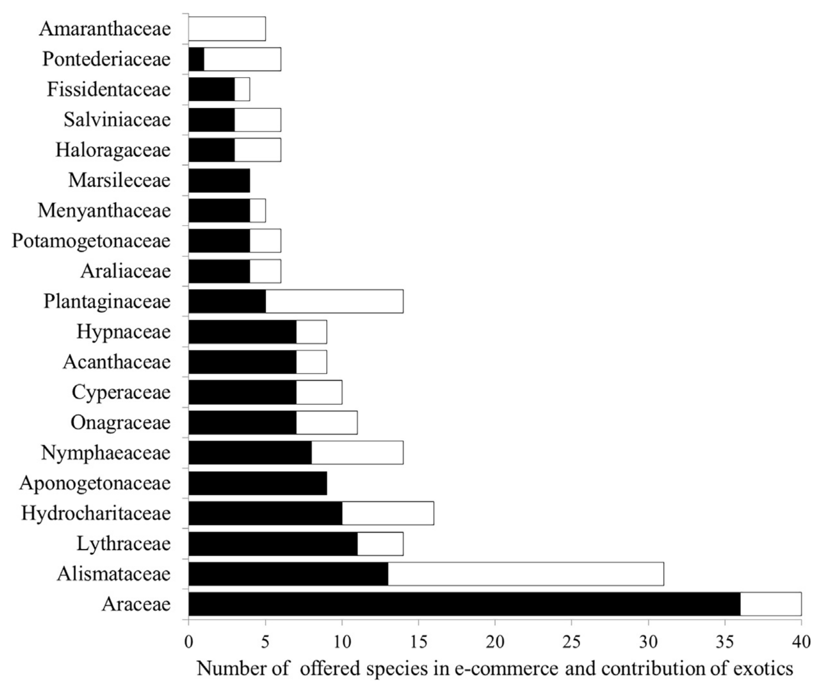


**Fig. 2.** The 20 most represented families in terms of species number (full bar) and contribution of exotic species (black bar) in the Brazilian aquarium e-commerce.

from all biogeographic regions in the world. Only 11 traded native plants were native in all Brazilian phytogeographical domains: *Alternanthera tenella*, *Eichhornia azurea*, *Eichhornia crassipes*, *Eleocharis acutangula*, *Heteranthera reniformis*, *Heteranthera zosterifolia*, *Hydromystria laevigata*, *Iresine difusa*, *Mayaca sellowiana*, *Nymphaea amazonum* and *Nymphoides humboldtiana*. For Brazilian phytogeographical domains (biomes), the proportion of non-native species sold (in relation to native species advertised) in e-commerce websites could increase to up to 80–92%, with the worst situation in the Pampa region and the best in the Amazon (Fig. 3). Among the 113 genera found in e-commerce advertisements, 30 (27%) were non-Brazilian genera. Among the 58 families, five (8.6%) were not native from Brazil, including four families of Angiosperms (Aponogetonaceae, Acoraceae, Nelumbonaceae, and Phrymaceae) and one family of liverworts (Monosoleniaceae). Most exotic aquatic plants sold in Brazil are native from the Oriental biogeographic region (apparently India, Sri Lanka and China are the main sources) (Fig. 4).

None of the e-commerce advertisements about the 188 exotic species included information about their potential problems as invasive. The family with the highest number of exotic species was Araceae (36 species), followed by Alismataceae (13 species) and Lythraceae (11 species) (Fig. 2). The genera with the highest number of species exotic to the Brazilian flora were *Cryptocoryne* (Araceae), *Anubias* (Araceae) and *Limnophila* (Plantaginaceae), represented by 24, five and four species, respectively. The Aponogetonaceae family

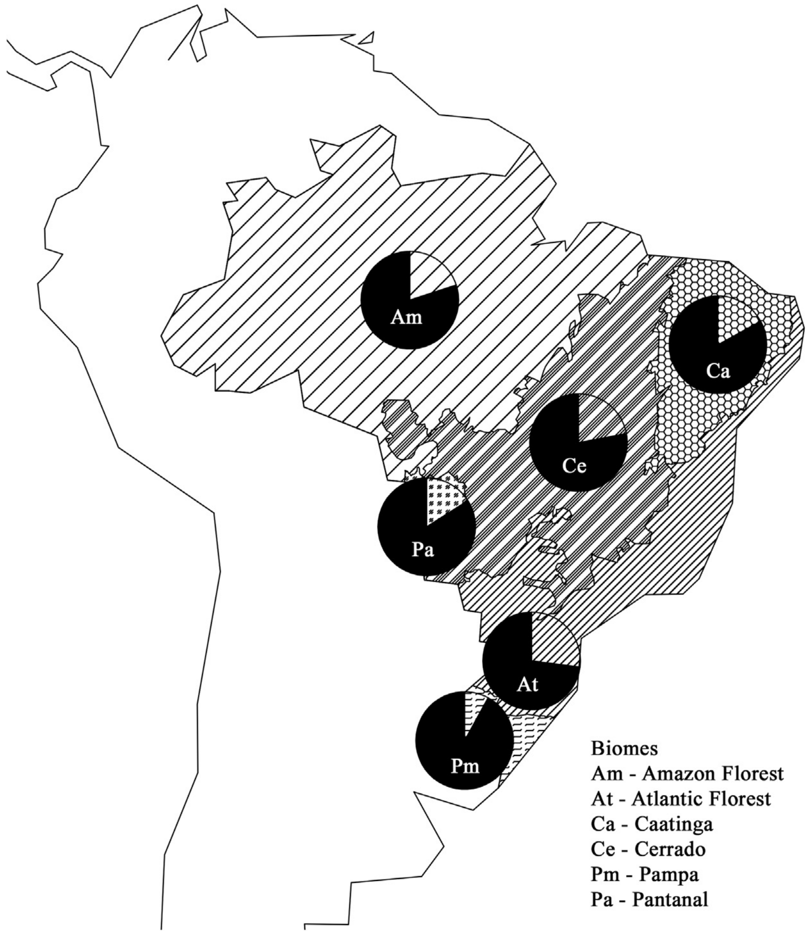


**Fig. 3.** The Brazilian phytogeographical domains (biomes) with the proportion between exotic (black) and native species advertised in aquarium e-commerce.

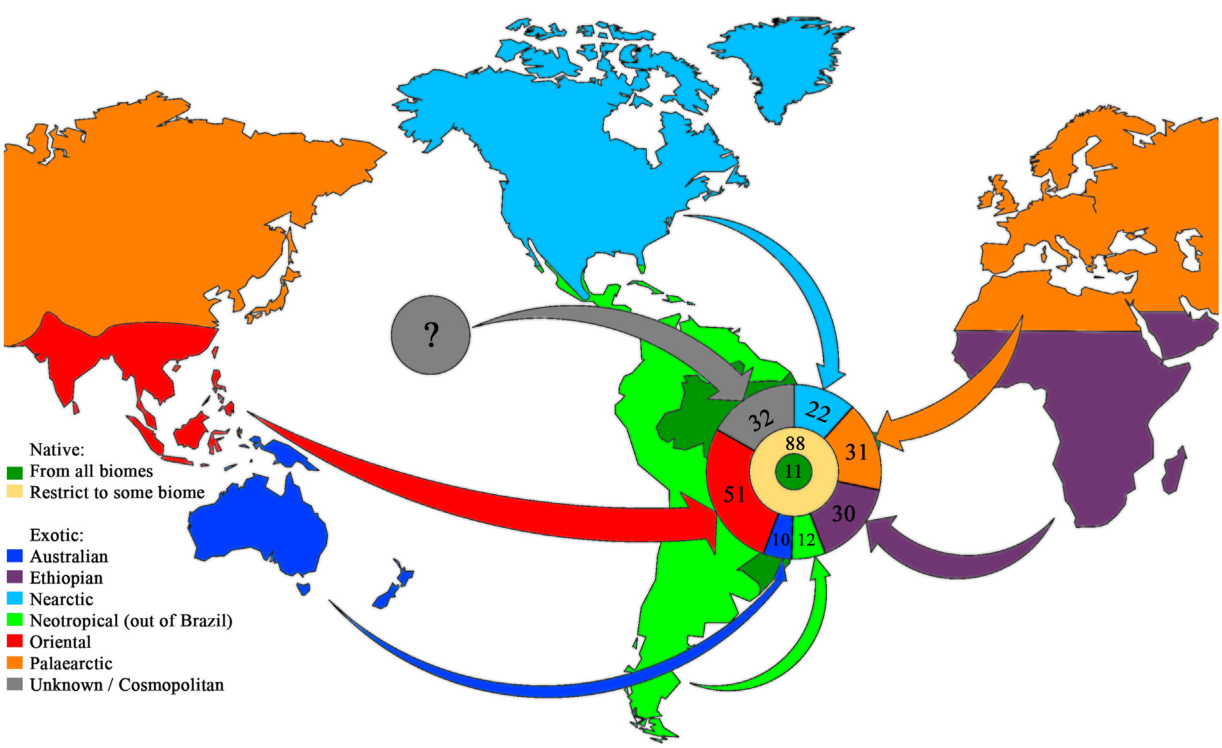


**Fig. 4.** Number of advertised species, native (two inner circles) and exotic (outer circle), with contribution of each biogeographic region to the amount of advertised species in Brazil.

was a special case, as it is exotic in Brazil but nine of its species are sold in the e-commerce.

More than half of the aquatic plants sold in the Brazilian aquarium e-commerce (150 species, 52% of the total) are classified as weeds in the 'A Global Compendium of Weeds' (Randall, 2012). Eleven of these species are classified as problematic or a threat to the native biota in more than 60 lists, databases and research articles from around the world: (i) the natives *Azolla filiculoides*, *Cabomba caroliniana*, *Ceratophyllum demersum*, *Egeria densa*, *Eichhornia crassipes*, *Myriophyllum aquaticum* and *Pistia stratiotes*; and (ii) the non-natives *Colocasia esculenta*, *Hydrilla verticillata*, *Lagarosiphon major* and *Potamogeton crispus*.

## Discussion

One of our most important results is that the Brazilian e-commerce facilitates the trade of aquatic plants, an important factor for the dispersion of potential invaders. The number of aquatic species traded in the e-commerce is greater than that found by local surveys of native aquatic plants (e.g. Henry-Silva et al., 2010; Pereira et al., 2012; Alves-da-Silva et al., 2014), and is only comparable to the 280 species of aquatic plants registered in the Pantanal (Pott et al., 2011), the biome with the most diverse aquatic habitats in Brazil. The acquisition of these species is favored by low cost and easy access to the websites of trading stores through search engines, multiple payment options and delivery throughout the country. Highly invasive species such as *E. densa*, *Eichhornia crassipes*, *H. verticillata*, *M. aquaticum*, and *P. stratiotes* can be purchased for less than US$ 0.40 (R$ 1.50). In addition, the fact that most species are sold as vegetative parts may favor their establishment, since they would not depend on adequate conditions for seed germination (Thiébaut, 2007; Havel et al., 2015). Therefore, the dispersion may be even more effective due to the higher survival probability associated with vegetative reproduction, as well as with the selection of resistant strains at the nurseries (Padilla and Williams, 2004).

The Brazilian e-commerce contributes to increase the number of both individuals introduced to a new system and introductory events, which favor invasion success, especially if combined with environmental disturbances in these areas (Meyerson and Mooney, 2007). Dehnen-Schmutz et al. (2007) analyzed data from 100 years of plant trade and reported that for a potential invader, the period during which a species is available on the market, the number of commercial plant nurseries and the price of the seeds are proportional to the invasion probability. These findings reinforce that there is a clear relationship among ease of acquisition, breakdown of geographical barriers through human dispersion and high propagule pressure, the later being often positively related to the success of exotic aquatic plants in the early stages of invasion (Lenda et al., 2014; Thomaz et al., 2015).

Most traded plant species originate from the Oriental biogeographic region. This finding agrees with previous hypothesis (e.g. Panetta and Mitchell, 1991; Pyšek, 1998; Hussner, 2012), which stated that climatic conditions drive the provenance of introduced aquatic plant species. Although the Palaearctic region was poorly represented in our study, traded species native from this region deserve attention, considering that many European species have high invasive potential (Di Castri, 1989; Pyšek, 1998). Among species from the Brazilian flora, with the exception of the 11 species occurring throughout the territory, all others may become invasive outside their native range in Brazil. Cases of native plant species that have become invasive elsewhere within the same country are not uncommon (e.g. Lowe et al., 2000; Padilla and Williams, 2004; Téllez et al., 2008; Yarrow et al., 2009).

Considering the high vulnerability of aquatic environments (Dudgeon et al., 2006) the dissemination of all aquatic species found in the Brazilian e-commerce deserves attention, especially exotic species. However, some species are of particular concern, such as the 11 species recorded as invasive in more than 60 databases across the world (Randall, 2012). The most notable example is *Eichhornia crassipes*, which was sold in five stores and is considered as an invasive species in 265 databases (Randall, 2012) and listed among the '100 Worst Invasive Alien Species' (Lowe et al., 2000). Other plants also deserve special attention, such as *P. stratiotes*, *E. densa* and *M. aquaticum*, which appear as invasive species in 166, 144 and 132 databases worldwide, respectively (Randall, 2012). Even *H. verticillata*, which is a recent invader in Brazil (whose introduction is attributed to aquarium activities) and has caused major problems in Brazilian reservoirs (Sousa, 2011), is still being advertised in e-commerce. The USA spend more than US$ 100 million per year on the management of *H. verticillata* and *E. crassipes* (Les, 2002). Therefore, it is worrying that recognizably invasive aquatic plants are widely advertised and sold in the Brazilian e-commerce, as there have been also reported for fish (Magalhães and Jacobi, 2013), amphibian and reptile species (Magalhães and São-Pedro, 2012).

One of the problems is the introduction of exotic species phylogenetically distant from native species, as established by the Darwinian Naturalization Hypothesis (DNH – Daehler, 2001). This hypothesis suggests that new genera would show greater naturalization success than those with native representatives due to the lack of competition with related species (Strauss et al., 2006). Despite controversies, the DNH has been corroborated by some studies and it is still the subject of intense discussion (Callaway and Aschehoug, 2000; Ma et al., 2016). Our data showed a high proportion of non-native genera, which may present high invasive potential (Ricciardi and Atkinson, 2004). In fact, we found a high number of species from non-native genera and families in the Brazilian e-commerce, which makes their trade even more worrisome. Although introduced members of Aponogetonaceae and *Cryptocoryne* (non-native family and genus, respectively) are not considered important invaders in Brazil, the DNH predicts that species from these taxa may exhibit high invasive potential.

In contrast, the invasive potential of exotic species may increase because of hybridization (Abbott, 1992; Richardson and Pyšek, 2006). Exotic species reproducing with either native or other exotic species may generate hybrids with high invasive potential (Galatowitsch et al., 1999; Ellstrand and Schierenbeck, 2000; Klonner et al., 2017). Genera represented by a high number of species in both the Brazilian flora and the Brazilian e-commerce (by exotic species), such as *Echinodorus*, *Ludwigia*, *Hygrophila*, *Nymphaea* and *Amania* (with eight, seven, six, six, and five exotic species registered, respectively), are more likely to produce hybrids, which can have devastating effects on the native flora, as reported by Galatowitsch et al. (1999) in North America and Yakandawala and Yakandawala (2011) in Sri Lanka.

It is widely accepted that prevention is the most effective strategy to avoid the further costs of invasive species (Padilla and Williams, 2004). Therefore, the introduction phase (i.e., propagule dispersion in a new area) is a critical step in the invasion (Pyšek, 1998; Thiébaut, 2007). At this point, it seems that the legal mechanisms to avoid the introduction and spread of exotic plants species in Brazil is efficient, as in many other countries (Francis and Chadwick, 2012). For example, the Law number 9605/1998 prohibits the dissemination of species that may cause damage to the fauna, flora or ecosystems; non-observance of this Law imposes imprisonment or fines. IBAMA (Brazilian Institute of Environment and Renewable Natural Resources) ordinance number 145/1998 prohibits the introduction of freshwater species, however, as in many other countries, these laws have not been totally effective and the growth of the e-commerce of plants has made this problem even more serious (Lenda et al., 2014). Considering the introduction as a critical step of the invasion process, Gherardi (2007) argues that the most effective mechanism to minimize the negative impact of freshwater invaders is to prevent species transportation. Brazilian laws are also appropriate, since the Brazilian Postal Service Law (Law 6538/78) prohibits the delivery of any kind of living plant. Thus, it is clear that there is widespread illegality of the e-commerce of aquatic macrophytes, which increases the concern about this growing market.

The experience of other countries has demonstrated the complexity of actions aiming to face the problem of introducing aquatic plants (Hussner, 2012). Probably the most efficient systems to prevent biological invasions are in New Zealand and Australia, where the introduction of an exotic species is only allowed after all the risks involved have been verified (Naylor et al., 2001; Keller and Lodge, 2007). In Brazil, a large and populated country, other strategies to restrict the trade of exotic aquatic species should be considered, such as price increase (Dehnen-Schmutz et al., 2007) to reduce the number of introductions, compensation for the worst invasive cases scenario in the collected taxes (Padilla and Williams, 2004), development of a list of harmful species to be distributed to buyers (Lenda et al., 2014) and dissemination of instructions concerning the correct disposal (Patoka et al., 2018).

Furthermore, it is likely that the control of aquatic plants invasion depends on joint actions between the government and the aquarium fishery market, which should include training of sellers and buyers, certification of the stock and prevention of the release of species (Padilla and Williams, 2004). Information about each species sold in physical or virtual commerce should also be available for buyer, and certification and good practice guidelines should be created within the aquarium industry. In addition, plant species distribution, correct aquarium sterilization and prevention of the release of exotic plants into natural waters should be strongly observed (Padilla and Williams, 2004). Finally, it is evident that avoiding the introduction of exotic and invasive species also depends on awareness campaigns; therefore, costumers should know the potential problems caused by these species and be encouraged to replace them by harmless and preferentially native species (Lenda et al., 2014).

In summary, our data show that the e-commerce of aquatic plants in Brazil allows wide, cheap and easy access to a large number of plant species. There is a high number of exotic species for sale in this market, most of them native from the Oriental biogeographic region, including species recognized as aggressive invaders worldwide. Potentially invasive families and genera, as well as species that are likely to hybridize with native species, are often advertised. Although Brazilian laws restrict the introduction of exotic species and the transport of plants, these mechanisms clearly are not being effective. Awareness programs are needed to provide more information about the economic and environmental damage caused by aquatic invasive species and hence avoiding the release and escape of harmful species.

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## Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.pecon.2018.10.001.

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