Neotropical Ichthyology, 11(2):433-441, 2013

Invasion risks posed by ornamental freshwater fish trade to southeastern Brazilian rivers

André Lincoln Barroso de Magalhães[1] and Claudia Maria Jacobi[2]

A model was developed to assess the risk of invasion of ornamental non-native fishes to six rivers in the state of Minas Gerais, southeastern Brazil, with focus on species popularity. Thirty-nine aquarium shops, in six cities, were visited monthly from January to December 2007. In each city, fish species were identified, and their biology and invasion history information was obtained from the literature. We calculated the annual frequency of occurrence and average number of specimens monthly available in stores. Quarterly water temperature and dissolved oxygen data from 1997 to 2007 were obtained for the Velhas, Muriaé, Uberabinha, Sapucaí-Mirim, Doce and Todos os Santos Rivers from public databases. The invasion risk of each species was assessed through a model comprising nine parameters grouped in four variables: (i) Invasiveness (thermal and dissolved oxygen ranges, diet, parental care or fecundity), (ii) History of invasions (establishment), (iii) Propagule pressure (commercial success, comprising annual frequency of occurrence and number of specimens available monthly at stores), and (iv) Invasibility (water temperature and dissolved oxygen in the target river compatible with the species ranges). Of the 345 ornamental fish species for sale, 332 are non-native to either Minas Gerais (n = 151) or Brazil (n = 194). Based on the proposed cutting values, in particular the compatibility between species and recipient thermal ranges, five ornamental non-native species (*Cyprinus rubrofuscus*, *Carassius auratus*, *Xiphophorus hellerii*, *Poecilia reticulata*, and *P. latipinna*) can potentially invade the Velhas and Muriaé Rivers, four species (*Cyprinus rubrofuscus*, *Carassius auratus*, *X. helleri*, and *P. reticulata*) the Uberabinha River, four species (*Cyprinus rubrofuscus*, *Carassius auratus*, *X. maculatus*, and *P. reticulata*) the Sapucaí-Mirim River, three species (*Carassius auratus*, *X. hellerii*, and *P. reticulata*) the Doce River, and three species (*Cyprinus rubrofuscus*, *P. reticulata*, and *Amatitlania nigrofasciata*) can potentially invade the Todos os Santos River. Six recommendations are suggested to reduce the invasion risk of non-native fish on the rivers surveyed posed by aquarium trade.

Um modelo foi desenvolvido para avaliar o risco de invasão de peixes ornamentais não-nativos em seis rios do estado de Minas Gerais, sudeste do Brasil, com foco na popularidade das espécies. Trinta e nove lojas de aquário em seis cidades foram visitadas mensalmente de janeiro a dezembro de 2007. Em cada cidade, as espécies foram identificadas e suas biologias e histórias de invasão foram obtidas da literatura. Calculou-se a frequência de ocorrência anual e quantidade média mensal de exemplares disponíveis nas lojas. Foram obtidas temperaturas trimestrais da água e dados de oxigênio dissolvido de 1997 a 2007 dos rios Velhas, Muriaé, Uberabinha, Sapucaí-Mirim, Doce e Todos os Santos a partir de bases de dados públicas. O risco de invasão de cada espécie foi avaliado através de um modelo composto por nove parâmetros agrupados em quatro variáveis: (i) Invasividade (limite de alcance térmico/oxigênio dissolvido, dieta, cuidado parental ou fecundidade), (ii) Histórico de invasões (estabelecimento), (iii) Pressão de propágulos (sucesso comercial, composto pela frequência de ocorrência anual e número de exemplares disponíveis mensalmente nas lojas), e (iv) Invasibilidade (temperatura da água/oxigênio dissolvido dos rios compatível com o limite de alcance térmico/ oxigênio dissolvido das espécies). Das 345 espécies de peixes ornamentais para venda, 332 são não-nativos para Minas Gerais (n = 151) ou Brasil (n = 194). Com base nos valores de corte propostos, cinco espécies de peixes ornamentais não-nativos (*Cyprinus rubrofuscus*, *Carassius auratus*, *Xiphophorus hellerii*, *Poecilia reticulata* e *P. latipinna*) podem potencialmente invadir os rios Velhas e Muriaé, quatro espécies (*C. rubrofuscus*, *C. auratus*, *X. helleri*, *P. reticulata*) podem invadir o rio Uberabinha, quatro espécies selecionadas (*Cyprinus rubrofuscus*, *Carassius auratus*, *X. maculatus* e *P. reticulata*) podem invadir o rio Sapucaí-Mirim, três espécies (*Carassius auratus*, *X. hellerii* e *P. reticulata*) podem invadir o rio Doce, e três espécies (*Cyprinus rubrofuscus*, *P. reticulata* e *Amatitlania nigrofasciata*) podem potencialmente invadir o rio Todos os Santos. Seis recomendações são sugeridas para reduzir o risco de invasão por peixes não-nativos nos rios pesquisados, representado pelo comércio de peixes ornamentais.

Key words: Aquarium shops, Aquarium dumping, Fishkeeping, Invasion risk assessment, Non-native fishes.

[1]Universidade Federal de Minas Gerais, Programa de Pós-Graduação em Ecologia, Conservação e Manejo de Vida Silvestre, Av. Antônio Carlos, Pampulha, 6627, 31270-901 Belo Horizonte, MG, Brazil. andrebiomagalhaes@gmail.com
[2]Universidade Federal de Minas Gerais, Departamento de Biologia Geral, Instituto de Ciências Biológicas, Av. Antônio Carlos, Pampulha, 6627, 31270-901 Belo Horizonte, MG, Brazil. jacobi@icb.ufmg.br

Introduction

Worldwide, keeping freshwater and marine ornamental fish in aquaria is a popular hobby in both homes and public spaces. Currently, the global ornamental fish trade generates about US$ 3 billion/year and an equipment and literature industry that exceeds US$ 15 billion/year (Dawes, 2001). In spite of the popularity of fishkeeping, not all amateurs persevere in adequately caring for their aquaria due to unwelcome difficulties such as excessive growth of individuals and aggressiveness of some species. Upon giving up their hobby, many aquarium owners are reluctant to sacrifice their pets, and end up discarding them directly in artificial (Fuller *et al*., 1999) and natural environments (Semmens *et al*., 2004).

Aquarium dumping, according to Fuller *et al.* (1999), is the second main cause of non-native species introduction in the US. In Brazil, most of the information about fish introductions concerns escapees from fish farms for food production, while reports of aquarium dumping are rare (Magalhães, 2010). Attention has been paid to non-native ornamental fish species in Brazil, as well as elsewhere in the world, only after they have settled into a new environment (Alves *et al.*, 2007). Once established, it becomes virtually impossible to eradicate aquatic species (Gozlan *et al.*, 2010). In order to prevent future invasions in Brazilian water bodies via aquarium trade, it is necessary to identify species of ornamental fish that pose high invasion risks, as well as to monitor the events that may lead to these introductions (such as new species offered by the market, environmental changes, and urban growth).

According to Bomford & Glover (2004), simple risk assessment models that predict invasion risk by non-native species are a low-cost alternative to guide management policies. Risk models were originally developed to deal with chemical pollution, and have only recently been adapted for other stressors, including non-native species (Calado & Chapman, 2006). Invasion risk models by non-native ornamental fish exist for temperate regions, such as those of Gertzen *et al*. (2008), Kolar & Lodge (2002), Rixon *et al.* (2005), Chang *et al.* (2009), Strecker *et al*. (2011) for North America, and for sub-tropical/tropical regions such as the one developed by Bomford & Glover (2004) for Oceania.

Kaplan & Garrick (1981) define risk as the probability of ocurrence of an unwanted event, along with an assessment of its consequences. In the case of aquarium trade, the undesired event is the release of non-native ornamental fish by hobbyists, while consequences include establishment through reproduction in new environments and ensuing damages such as changes in the original structure of native fish communities. Our study applies for the first time a simple risk model of ornamental non-native fish invasion in southeastern Brazil, based on species biological traits and invasion history, popularity, availability, and abiotic features of the recipient environment, along with a discussion of aquarium dumping consequences and recommendations to restrain this practice.

Material and Methods

Predicting potential invaders in six rivers of Minas Gerais State. A model was applied to predict probable non-native fish invasions through aquarium fish trade in rivers of Minas Gerais State. This southeastern Brazilian state is the fourth in size, and the second most populous, with a current population of more than 18 million (Alves *et al*., 2007). A donor source of species, represented by ornamental fish trade, was identified and adopted as a vector for deliberate human dumping, in order to create a predictive model that combined biological, historical, and commercial variables, as proposed by Rixon *et al*. (2005), with abiotic criteria, as proposed by Chang *et al*. (2009).

The first of these four variables is the invasiveness ability of each species, assessed by four parameters: thermal range, dissolved oxygen tolerance, type of diet, and parental care or fecundity (representing reproductive attributes). The attributes assumed to facilitate the invasion of ornamental fish were the ability to tolerate changes in water temperature and dissolved oxygen levels, omnivorous diet (feeding on at least two items among organic debris, micro- or macrophytes, micro- or macro-invertebrates) and either parental care (by male, female, or both) or high fecundity (high numbers of oocytes). These are important prerequisites for the establishment of ornamental non-native species in any freshwater body (Moyle & Marchetti, 2006). The second variable is the history of worldwide invasions, adapted from Drake (2007), defined as $H = Pe/Pi \times 100$, where H = history of invasions, Pe = number of countries where the species has successfully established itself, Pi = number of countries where the species was introduced. The third variable is propagule pressure, estimated by the number of individuals released, a primary factor in establishment success (Vander Zanden & Olden, 2008). Assuming that popular species (*i.e.* hardy and easy to feed) sold in considerable numbers ($\geq$ 100 specimens per month) have a greater probability of being released in the environment by hobbyists, we used the annual frequency of occurrence in stores, and number of specimens of each species available monthly for sale as measures of commercial success. The fourth variable is invasibility of the recipient river, assessed as the compatibility of its water temperature range (mean autumn-winter and spring-summer, Table 1) with the thermal ranges tolerated by the invading species, as proposed by Chang *et al*. (2009). Dissolved oxygen was also assessed because urban portions of most Brazilian rivers are usually polluted by domestic and industrial sewage and would be less suitable for fish survival (IGAM, 2009). All these variables are important steps in successful biological invasions by aquatic species according to Lockwood *et al*. (2007). To be considered a potential invasive species in any of the six rivers, a species had to fulfill rigorously the cutting values of all four variables and nine parameters described above (Table 2).

Data sampling and analysis

Nineteen aquarium shops were visited monthly from January to December 2007 in the city of Belo Horizonte (Velhas

Table 1. Water temperature and dissolved oxygen (mean ± SD) of the six target rivers in Minas Gerais State, from 1997 to 2007. Source: IGAM (2009).

River (watershed)	Autumn-winter	Spring-summer
Velhas (São Francisco)	22.0 ± 2.1ºC 6.6 ± 1.1 mg/L	25.1 ± 1.5ºC 6.1 ± 0.4 mg/L
Muriaé (Paraíba do Sul)	23.0 ± 1.5ºC 7.5 ± 0.3 mg/L	26.4 ± 0.6ºC 6.7 ± 0.4 mg/L
Uberabinha (Paranaíba)	22.7 ± 1.3ºC 6.4 ± 0.3 mg/L	25.9 ± 1.0ºC 6.2 ± 0.2 mg/L
Sapucaí-Mirim (Grande)	19.0 ± 2.0ºC 7.6 ± 0.4 mg/L	22.4 ± 1.6ºC 6.4 ± 0.3 mg/L
Doce (Doce)	22.0 ± 0.6ºC 7.8 ± 0.2 mg/L	25.2 ± 0.1ºC 7.1 ± 0.1 mg/L
Todos os Santos (Mucuri)	23.6 ± 1.1ºC 7.0 ± 0.2 mg/L	26.5 ± 1.4ºC 6.3 ± 0.5 mg/L

River, São Francisco River basin), four in the city of Muriaé (Muriaé River, Paraíba do Sul River basin), four in Uberlândia (Uberabinha River, Paranaíba River, upper Paraná River basin), four in Pouso Alegre (Sapucaí-Mirim River, Grande River, upper Paraná River basin), four in Governador Valadares (Doce River, Doce River basin) and four in Teófilo Otoni (Todos os Santos River, Mucuri River basin) (Fig. 1). The number of stores surveyed corresponds to 100% in Muriaé, Pouso Alegre and Teófilo Otoni, and approximately to 90% in Belo Horizonte, Uberlândia and Governador Valadares. This estimate was obtained consulting the specific store directory records of each city. The rivers were chosen because part of their course is within these urban areas, where dumping is more likely. We calculated the annual frequency of occurrence and the monthly average number of fish for sale at stores in each region.

The common and scientific names of all species were recorded in the aquarium shops, and keys or distinguishing characteristics were compared and confirmed with those in Fryer & Iles (1972), Géry (1977), Rosen (1979), Merrick & Schmida (1984), Burgess (1989), Page & Burr (1991), Talwar & Jhingran (1992), Kottelat *et al*. (1993), Kullander & Hartel (1997), and Nelson (2006). Color photographs of live species in Axelrod *et al*. (1997) were used to confirm specimens. Information regarding thermal ranges, diet, reproduction, worldwide invasion events were obtained from the reliable website Froese & Pauly (2006) for most of the species. The thermal range of *Carassius auratus* was obtained from Ford & Beitinger (2005), the diet of *T. lalius* and *T. leeri*, and the fecundity of *P. conchonius* were obtained respectively from Richter (1988), Degani (1990) and Çek & Gökçe (2005). The threshold of dissolved oxygen considered acceptable for

Table 2. Cutting values of parameters used in the model. Sources: Richter (1988), Degani (1990), Lawson (1995), Ford & Beitinger (2005), Çek & Gökçe (2005), Froese & Pauly (2006).

Parameters	No/Low risk	Yes/High risk
Invasiveness		
Thermal range tolerance	< 6.0ºC	≥ 6.0ºC
Minimum of dissolved oxygen	≥ 5.0 mg/L (warm water species) ≥ 6.0 mg/L (cold water species)	< 5.0 mg/L (warm water species) < 6.0 mg/L (cold water species)
Type of diet	1 food category (invertivore/herbivore)	> 1 food category (omnivore)
Parental care	No parental care	≥ 1 type (parental care)
Fecundity	< 100.000 oocytes (low fecundity)	≥ 100.000 oocytes (high fecundity)
Invasion history		
Pe/Pi×100	< 50 % (countries)	≥ 50 % (countries)
Propagule pressure		
Frequency of occurrence (FO)	< 50 % (FO in stores)	≥ 50 % (FO in stores)
Numbers available for sale/month	< 100 individuals (sold/month)	≥ 100 individuals (sold/month)
Invasibility		
Water temperature (mean)		
Velhas	< 22.0 or > 25.1ºC	22.0 - 25.1ºC
Muriaé	< 23.0 or > 26.4ºC	23.0 - 26.4ºC
Uberabinha	< 23.7 or > 25.9ºC	22.7 - 25.9ºC
Sapucaí-Mirim	< 19.0 or > 22.4ºC	19.0 - 22.4ºC
Doce	< 22.0 or > 25.2ºC	22.0 - 25.2ºC
Todos os Santos	< 23.6 or > 26.5ºC	23.6 - 26.5ºC

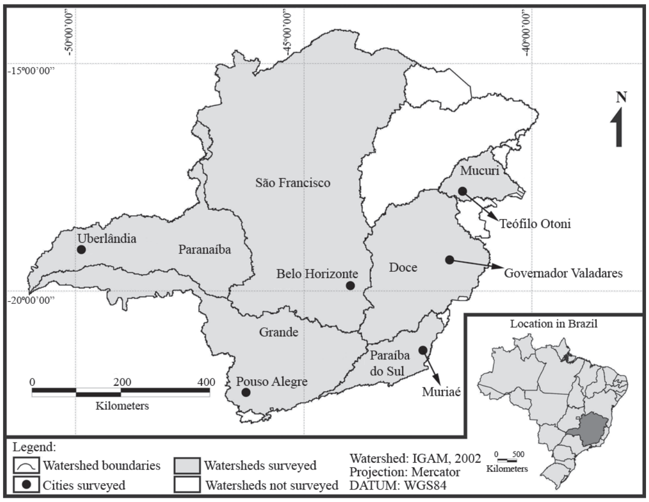

Fig. 1. Cities and watersheds within the Minas Gerais State, Brazil, where the 39 ornamental fish stores were visited.

freshwater fish was taken from Lawson (1995).

Quarterly data from 1997 to 2007 of water temperature and dissolved oxygen for the six rivers were obtained from the public database of the Minas Gerais Institute of Water Management (IGAM) (2009). Water temperature (ºC; thermometer) and dissolved oxygen (mg/L; Winkler's method by Golterman *et al*., 1978) were measured downstream and upstream of each city (average distance: 19,8 ± 11,6 km) at 1 m depth in the main channel of each river.

Results

We found 345 species of ornamental fish belonging to 58 families on sale at stores, of which 332 were non-native either to the watersheds studied (151 species from the Pantanal and Amazonian basins) or to Brazil (194 species from North America, Central America, South America, Africa, Asia, and Oceania). In Belo Horizonte we recorded 166 fish species (five native and 161 non-native) belonging to 37 families, with an average number of 40.2 ± 30.2 species per store. In Muriaé, we recorded 52 species (eight native and 44 non-native) belonging to 15 families, with an average number of 33.7 ± 7.7 species per store. In Uberlândia, 83 species (all of which non-native) belonging to 16 families were found, with an average of 26.3 ± 16.7 species. We recorded 29 species (all of which non-native) belonging to seven families in Pouso Alegre, with an average of 11.1 ± 0.5 species per store. In Governador Valadares, we found 15 species (all of them non-native) belonging to six families, with an average of 10.2 ± 3.5 species per store and finally, in Teófilo Otoni, 14 species (all of them non-native) belonging to five families, with an average of 10.4 ± 2.5 species per store. Fishes well-known by hobbyists such as cyprinids, poeciliids, and osphronemids, all with non-native representatives, were the most traded. Usually large (*e.g.*, the striped catfish *Pangasianodon hypophthalmus* and the clown knifefish *Chitala ornata*), aggressive (the golden mbuna *Melanochromis auratus* and the giant snakehead *Channa micropeltes*), expensive (the discus fish *Symphysodon discus* and the sixbar distichodus *Distichodus sexfasciatus*), and rare species (the short-tailed pipefish *Microphis brachyurus* and the marble goby *Oxyeleotris marmorata*) were available in less than 50% of the stores.

Based on the model proposed (Fig. 2) only seven non-native species may potentially invade and establish themselves in the rivers surveyed if dumped by hobbyists, and most of them are common to several rivers. Five non-native species (*Cyprinus rubrofuscus*, *Carassius auratus*, *X. hellerii*, and *P. reticulata*, *P. latipinna*) are a threat to both the Velhas and Muriaé Rivers. In the Uberabinha River we found four potential invaders (*Cyprinus rubrofuscus*, *Carassius auratus*, *X. hellerii*, and *P. reticulata*), four in the Sapucaí-Mirim River (*Cyprinus rubrofuscus*, *Carassius auratus*, *X. maculatus*, and *P. reticulata*), three (*Carassius auratus*, *X. hellerii*, and *P. reticulata*) in the Doce River, and three species (*Cyprinus rubrofuscus*, *P. reticulata*, and *Amatitlania nigrofasciata*) in the Todos os Santos River (Table 3).

The model excluded *M. anguillicaudatus* (Muriaé), *B. splendens* (Velhas, Muriaé, Uberabinha, Sapucaí-Mirin, Doce, and Todos os Santos), *X. hellerii* (Sapucaí-Mirim), *X. maculatus* (Velhas, Muriaé, Uberabinha, Doce, and Todos os Santos), *T. lalius* (Velhas and Muriaé), *G. ternetzi*, *Pethia conchonius*, *Puntius semifasciolatus* (Velhas and Muriaé), *T. trichopterus* (Velhas, Muriaé, Uberabinha, Grande, and Doce), *T. leeri* (Velhas), and *Maylandia lombardoi* (Muriaé) as potential invaders because none of these 11 species have a thermal range compatible with the recipient environments. In addition, *M. anguillicaudatus*, *B. splendens*, *T. lalius*, *G. ternetzi*, *T. trichopterus*, and *T. leeri* are not omnivorous, and *M. anguillicaudatus*, *G. ternetzi*, *P. conchonius* and *P. semifasciolatus* lack parental care, have low fecundity or absence of data. Also, *T . trichopterus* and *M. lombardoi* were available in very low amounts. On the other hand, dissolved oxygen levels were adequate in all sites, and did not discriminate species (Table 3).

Discussion

Our survey of ornamental fish stores in Minas Gerais State showed that the number of species available for sale is relatively large (n = 345), and that although these species are of tropical origin, the great majority is non-native to the state or country (96,23%). For these reasons, their trade as an introduction pathway deserves better investigation and regulation by environmental authorities. Concern about the predominance of non-native fishes in aquarium trade was recently addressed by Gertzen *et al.* (2008) in Canada, and by Chang *et al.* (2009) and Strecker *et al.* (2011) in the states of California and Washington, US. Of 252, 432 and 400 species available at stores in the respective regions surveyed by these authors, the absolute majority was of tropical origin.

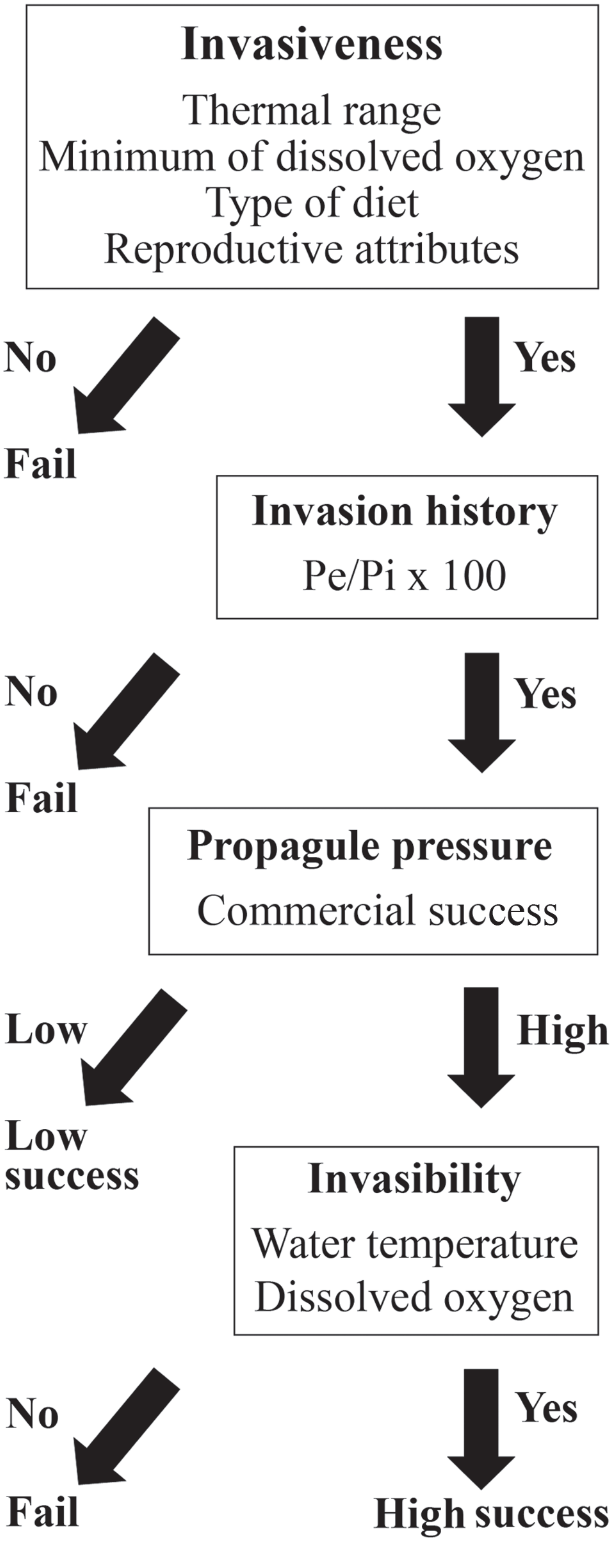

Fig. 2. A model describing the invasion stages that species must pass in order to represent an invasion risk for rivers in Minas Gerais State, Brazil.

In our survey, Cyprinidae, Poeciliidae, and Osphronemidae were the most popular families in stores. A similar trend was found by Duggan *et al*. (2006) in Toronto, Canada, and Macomb County, Michigan, US. According to these authors, popular families available to hobbyists have a tendency to be introduced more frequently and in greater numbers than rare families. Members of these 'high-risk' families are usually sturdy, have low aggressiveness, and are small enough to be kept in large numbers, thus adding to propagule pressure. Some exceptions are *Cyprinus rubrofuscus* and *Carassius auratus*, which are comparatively large, yet sold in large numbers. Most of these sales, however, are of juveniles, and both species have high indices of rejection when they attain their adult size. The model created for Minas Gerais State predicts that only four poeciliids, two cyprinids, and one cichlid are potential invaders of the six rivers surveyed. These families were also highlighted by Bomford & Glover (2004), whose model for the Australian tropical region identified poeciliids and cyprinids as the highest risk taxa, followed by cichlids, which posed moderate risk. The very short list of potential invaders, when compared to the number of available non-natives, is the result of several restrictive model parameters, and mainly of the mismatch between species thermal ranges and the recipient river temperature. This rigorous selection also occurs in the model proposed by Chang *et al*. (2009), which detected five potential invasive species for the cold scenario (autumn-winter) in the San Francisco Delta Bay, California, and 27 species for the warm scenario (spring-summer). However, when both scenarios were considered, only five ornamental species were qualified as potential invaders.

Aside from the thermal incompatibility discussed above, diet, parental care, fecundity, and number os specimens for sale contributed to eliminate 11 other species as potential invaders. Fish species that have thermal ranges incompatible with the location to be invaded, affecting embryo and egg development (Milton & Arthington, 1983), that have specialized feeding habits, lack parental care, have low fecundity (Moyle & Marchetti, 2006), and are commercially undesired by humans (Duggan *et al*., 2006), are seldom considered potential invaders (Strecker *et al*., 2011).

Except for *Cyprinus rubrofuscus* (common variety) and *P. reticulata* introduced in the Velhas River (unknow introduction pathways, no evidence of reproduction) (Alves & Pompeu, 2001), there are no published records regarding the introduction of *Carassius auratus*, *Cyprinus rubrofuscus* - koi, *P. latipinna*, *X. maculatus*, *X. hellerii*, and *A. nigrofasciata* in this river. Similarly, there are no records regarding the introduction of *Carassius auratus*, *Cyprinus rubrofuscus* - koi, *P. reticulata*, *P. latipinna*, *X. maculatus*, *X. hellerii*, and *A. nigrofasciata* in Muriaé, Uberabinha, Sapucaí-Mirim, Doce and Todos os Santos Rivers. There are also no records of introduction of *A. nigrofasciata* in other sites in Brazil. Of the seven potential invaders traded in Minas Gerais and detected by the model, *Carassius auratus*, *P. reticulata*, *X. maculatus*, and *X. hellerii* have been introduced by

Table 3. Biological, historical and species frequency/numbers variables in 39 stores surveyed in Minas Gerais State. Only species with at least 50% occurrence are listed, in decreasing order of annual frequency of occurrence (FO). Cities: B = Belo Horizonte, M = Muriaé, U = Uberlândia, P = Pouso Alegre, G = Governador Valadares, T = Teófilo Otoni. Sources: Richter (1988), Degani (1990), Lawson (1995), Ford & Beitinger (2005), Çek & Gökçe (2005), Froese & Pauly (2006).

Common name Scientific name	Cities	Thermal range (ºC) and dissolved oxygen (mg/L) (in brackets)	Diet	Reproductive attributes	Invasion history (%)	Annual FO (%) in all stores and numbers available for sale monthly in all stores (in brackets)
koi carp *Cyprinus rubrofuscus*	B, M, U, P, T	3-35 (6.0)	omnivore	high fecundity	52.30	91.25 (937.4 ± 177.8)
pond loach *Misgurnus anguillicaudatus*	M	5-25 (6.0)	invertivore	no parental care low fecundity	88.89	89.58 (224.2 ± 218.4)
Siamese fighting fish *Betta splendens*	B, M, U, P, G, T	24-30 (5.0)	invertivore	uniparental care (♂)	44.44	88.29 (112.4 ± 199.6)
goldfish *Carassius auratus*	B, M, U, P, G	0-41 (6.0)	omnivore	high fecundity	79.31	86.18 (1095.7 ± 236.4)
green swordtail *Xiphophorus hellerii*	B, M, U, P, G	22-28 (5.0)	omnivore	uniparental care (♀)	67.74	80.50 (787.2 ± 140.5)
southern platyfish *Xiphophorus maculatus*	B, M, U, P, G, T	18-25 (5.0)	omnivore	uniparental care (♀)	65.00	79.61 (724.7 ± 156.6)
guppy *Poecilia reticulata*	B, M, U, P, G, T	18-28 (5.0)	omnivore	uniparental care (♀)	72.13	78.09 (586.8 ± 155.5)
dwarf gourami *Trichogaster lalius*	B, M	25-28 (5.0)	invertivore	uniparental care (♂)	50.00	76.20 (342.4 ± 104.2)
black tetra *Gymnocorymbus ternetzi*	B, M	20-26 (5.0)	invertivore	no parental care fecundity not available	50.00	73.63 (449.1 ± 217.9)
rosy barb *Pethia conchonius*	B, M	18-22 (5.0)	omnivore	no parental care low fecundity	50.00	71.71 (292.6 ± 132.1)
three spot gourami *Trichopodus trichopterus*	B, M, U, P, G	22-28 (5.0)	invertivore	uniparental care (♂)	58.33	71.67 (99.7 ± 143.3)
Chinese barb *Puntius semifasciolatus*	B, M	18-24 (5.0)	omnivore	no parental care low fecundity	50.00	69.19 (317.4 ± 114.1)
sailfin molly *Poecilia latipinna*	B, M	20-28 (5.0)	omnivore	uniparental care (♀)	76.92	68.80 (417.3 ± 121.9)
convict cichlid *Amatitlania nigrofasciata*	T	20-36 (5.0)	omnivore	biparental care	70.00	66.67 (331.2 ± 175.1)
pearl gourami *Trichopodus leerii*	B	24-28 (5.0)	invertivore	uniparental care (♂)	60.00	51.32 (150.7 ± 47.7)
cobalt *Maylandia lombardoi*	M	24-26 (5.0)	omnivore	uniparental care (♀)	100.00	50.00 (6.2 ± 5.0)

hobbyists (with no evidence of reproduction) in the São Francisco River basin (*X. hellerii*) (Chaves & Magalhães, 2010), in the Paraíba do Sul River basin (*Carassius auratus*, *P. reticulata*, *X. maculatus*, and *X. hellerii*) (Melo *et al*., 2006; Alves *et al*., 2007), in the Doce River basin (*Carassius auratus* and *X. hellerii*) (Alves *et al*. 2007), in the Jequitinhonha River basin (*P. reticulata*) (Neto, 2010), and in the Mucuri River basin (*P. reticulata*) (Pompeu, 2010). *P. reticulata* was also introduced and is reproducing in the São Francisco and Doce River basins respectively (Magalhães, 2008). These data attest the imminent risk of invasion posed by aquarium dumping and reinforce the need of aquarium trade regulation in Minas Gerais State. *Cyprinus rubrofuscus* (common variety) that escaped from fish farms has great importance in commercial fishing in several lotic and lentic environments in the Doce River basin (Vieira, 2010). The same trend of spread may occur with *Cyprinus rubrofuscus* - koi if released by hobbyists in the studied rivers. Feral koi carp released by aquarium amateurs has established itself and dispersed in a number of rivers and lakes of New Zealand (Tempero *et al*., 2006). There are no studies showing the adverse ecological effects of introducing *Cyprinus rubrofuscus* - koi, *Carassius auratus*, *P. latipinna*, *X. maculatus*, and *X. hellerii* by hobbyists in Minas Gerais or elsewhere in Brazil. On the other hand, the ecological effects of *P. reticulata* are known not only in the state but other locations in Brazil: this poeciliid has negatively changed fish community structures in streams of southern Brazil (Vieira & Shibatta, 2007; Cunico *et al*., 2009).

The model selected relatively few species as potential invaders because it requires that all nine parameters be met, but according to Chang *et al*. (2009), this does not mean that the risk may be low. Firstly, the list of potential invading species is constantly increasing due to the aquarium trade search for new species that appeal to its customers. Recent examples are the cichlids, the flowerhorn *Amphilophus trimaculatum* (= '*Cichlasoma*' *trimaculatum*) × *Amphilophus citrinellum*, the black diamond cichlid *Paratilapia polleni*, and the freshwater stingrays *Potamotrygon* spp. (A. L. B. Magalhães, pers. obs.). Secondly, there are presently in the state more than 2,000 dammed water bodies (Alves *et al*., 2007), many located in the surroundings of the six cities studied. Impoundments often exhibit marked fluctuations in nutrient content, a condition that increases invasibility for aquarium fishes pre-adapted to lacustrine environments (Magalhães, 2010). Lastly, with the demographic growth of the six cities in the last ten years, together with the aquarium hobby expansion in Minas Gerais and Brazil (ANFALPET, 2010), the frequency of introductions and subsequent establishment of aquarium fish species through this vector will surely increase with time.

Management recommendations. This study focused on the risk-enhancing role of physical aquarium shops in six cities of Minas Gerais State. The negative consequences of e-commerce via virtual shops and auctions were not analysed, but should not be underestimated. For example, *Carassius auratus*, *Cyprinus rubrofuscus*, *Poecilia latipinna*, *P. reticulata*, *Xiphophorus maculatus*, *X. hellerii*, and *A. nigrofasciata* are available on e-commerce at very affordable prices (Magalhães & Jacobi, 2010). In view of this, the potential impact of e-commerce as a disseminating source of non-native species in Minas Gerais State ought to be urgently investigated. The quantities sold by means of these two types of retailing (fixed location and online) should in turn reflect the probability of escape from fish farms, a problem which has already caught attention of the Brazilian environmental authorities (Magalhães, 2010).

Brazil is signatory to the Convention on Biological Diversity. Article eight of this treaty establishes that each country that is party to the Convention has to make efforts to avoid the introduction of non-native species (Alho *et al*., 2011). One way to greatly reduce the potential impact that aquarium trade may cause on the water bodies of Minas Gerais State is by better informing those involved in this market, such as sectors dealing with importation, breeding, transportation and trading of aquarium fish, as well as hobbyists.

To put this into practice, we suggest the following recommendations for aquarium trade in Minas Gerais State, and Brazil as a whole: (i) instruct suppliers and retailers to sell only males of the potential invader cyprinids *Cyprinus rubrofuscus* - koi (veil variety), *Carassius auratus* (veiltail, telescope-eye, bubble-eye and celestial-eye varieties) and poeciliids *Xiphophorus hellerii*, *X. maculatus*, *Poecilia reticulata*, *P. latipinna* (veiltail and lyretail varieties) and female of the cichlid *A. nigrofasciata* (striped variety). These are more colorful (cyprinids, poeciliids, cichlid) and swim with difficulty due to the long fins (cyprinids, poeciliids) or have protuberant eye bulbs (*Carassius auratus*), which renders them more susceptible to native predators; (ii) inform hobbyists of proper locations to hand over their fish (Brazilian federal or state environmental agencies, return to the fish farm or aquarium shop), thus avoiding indiscriminate dumping in nature; (iii) with the assistance of qualified personnel, identify species that may be used as viable alternatives in each region without risks of invasion; (iv) acknowledge and apply laws of fish import and quarantine; (v) inform the hobbyist about the species characteristics when young and adult, so as to reduce rejection and fish dumping, and allow for proper care; (vi) display posters and flyers informing about "non-native species", along with a notice in bags, packaging paper and website (if any) of the aquarium shop. This notice must inform customers that in case they no longer want their fishes, they should never free them in either natural (creeks, streams, rivers or lakes) or artificial water bodies (channels, ponds or dams).

It should be made clear that these recommendations are not intended to harm aquarium trade activities, because its economic importance for the Minas Gerais State and for Brazil is undeniable. Instead, they should be seen as a powerful set of tools for disseminating environmental conservation. Already in the early 1970s, Courtenay *et al*. (1974) suggested similar measures for aquarium trade in the state of Florida, US, in order to prevent non-native ornamental fish species dumping by people practising this hobby. Since our recommendations are more than 35 years late in comparison to the US, and the Brazilian culture traditionally remediates environmental disasters rather than prevents them (Guerra, 1995), it is adviseable that such measures be put in practice without delay. Otherwise, the future of many water bodies in Brazil and especially in Minas Gerais State is foreseeingly disturbing adding the environmental damages caused by non-native aquarium fish species to those of ongoing landscape changes, among which urban pollution, siltation, riparian forest destruction, and impoundments. Finally, it should be reminded that our recommendations were intended for ornamental aquarium species, and that other commercially important non-native fishes (such as those for human consumption), deserve equal attention and specific invasion risk studies.

Acknowledgments

We thank the owners of aquarium shops in the cities of Belo Horizonte, Muriaé, Uberlândia, Pouso Alegre, Governador Valadares, and Teófilo Ottoni for allowing access to their stores. The Graduate Program in Ecology, Conservation and Management of Wildlife (Universidade Federal de Minas Gerais) is partially supported by the US Fish and Wildlife Service. This program contributes to the implementation of the Convention for the protection of flora, fauna and scenic beauties of the countries of the Americas (1940) and the Ramsar Convention on Wetlands (1971) in Latin America and the Caribbean. This paper was greatly improved by the suggestions of three reviewers.

Literature Cited

Alho, C. J. R., S. Mamede, K. Bitencourt & M. Benites. 2011. Introduced species in the Pantanal: implications for conservation. Brazilian Journal of Biology, 71: 321-325.

Alves, C. B. M. & P. S. Pompeu. 2001. Peixes do rio das Velhas: passado e presente. Belo Horizonte, Segrac.

Alves, C. B. M., F. Vieira, A. L. B. Magalhães & M. F. G. Brito. 2007. Impacts of non-native fish species in Minas Gerais, Brazil: present situation and prospects. Pp. 291-314. In: Bert, T. M. (Ed.). Ecological and genetic implications of aquaculture activities. Dordrecht, Springer Press.

ANFALPET. 2010. Mercado Pet 2010, Associação Nacional dos Fabricantes de Alimentos para Animais de Estimação, São Paulo. Available from: http://www.anfalpet.org.br/ (04 July 2010)

Axelrod, H. R., W. E. Burgess, N. Pronek & J. G. Walls. 1997. Dr. Axelrod's atlas of tropical freshwater aquarium fishes. Neptune City, T.F.H. Publications.

Bomford, M. & J. Glover. 2004. Risk assessment model for the import and keeping of exotic freshwater and estuarine finfish. Canberra, Bureau of Rural Sciences, 125p.

Burgess, W. E. 1989. An atlas of freshwater and marine catfishes: a preliminary survey of the Siluriformes. Neptune City, T. F. H. Publications.

Calado, R. & P. M. Chapman. 2006. Aquarium species: deadly invaders. Marine Pollution Bulletin, 52: 599-601.

Çek, A. & M. A. Gökçe. 2005. Evaluation of the photocopy method for counting *Puntius conchonius*'s eggs. Turkish Journal of Veterinary and Animal Sciences, 29: 685-689.

Chang, A. L., J. D. Grossman, T. S. Spezio, H. W. Weiskel, J. C. Blum, J. W. Burt, A. A. Muir, J. Piovia-Scott, K. E. Veblen & E. D. Grosholz. 2009. Tackling aquatic invasions: risks and opportunities for the aquarium fish industry. Biological Invasions, 11: 773-785.

Chaves, M. R. & A. L. B. Magalhães. 2010. Peixes ornamentais não-nativos introduzidos por aquaristas em um parque urbano de Belo Horizonte, MG. Boletim da Sociedade Brasileira de Ictiologia, 101: 6-7.

Courtenay Jr., W. R., H. Sahlman, W. W. Miley & D. J. Herrema. 1974. Exotic fishes in fresh and brackish waters of Florida. Biological Conservation, 6: 292-302.

Cunico, A. M., W. J. Graça, A. A. Agostinho, W. M. Domingues & J. D. Latini. 2009. Fish, Maringá urban streams, Pirapó river drainage, upper Paraná river basin, Paraná State, Brazil. Check List, 5: 273-280.

Dawes, J. 2001. International aquatic industry perspectives on ornamental fish conservation. Pp. 100-121. In: Chao, N. L., P. Petry, G. Prang, L. Sonnesachien & M. Teusty (Eds.). Conservation and management of ornamental fish resources of the Rio Negro Basin, Amazônia, Brasil - Project Piaba. Manaus, Editora da Universidade do Amazonas.

Degani, G. 1990. The effect of temperature, light, fish size and container size on breeding of *Trichogaster trichopterus* (B&S 1801). Aquacultural Engineering, 9: 367-375.

Drake, J. M. 2007. Parental investment and fecundity, but no brain size, are associated with establishment success in introduced fishes. Functional Ecology, 21: 963-968.

Duggan, I., C. A. M. Rixon & H. J. MacIsaac. 2006. Popularity and propagule pressure: determinants of introduction and establishement of aquarium fish. Biological Invasions, 8: 377-382.

Ford, T. & T. L. Beintinger. 2005. Temperature tolerance in the goldfish, *Carassius auratus*. Journal of Thermal Biology, 30: 147-152.

Froese, R. & D. Pauly. 2006. Data bank, World Wide Web electronic publication. Available from: http://www.fishbase.org/home.htm (23 April 2006)

Fryer, G. & T. D. Iles. 1972. The cichlid fishes of the Great Lakes of Africa: Their Biology and Evolution. Edinburgh, Oliver and Boyd.

Fuller, P. L., L. G. Nico & J. D. Williams. 1999. Nonindigenous fish introduced into inland waters of the United States. Bethesda, American Fisheries Society.

Gertzen, E., O. Familiar & B. Leung. 2008. Quantifying invasion pathways: fish introductions from the aquarium trade. Canadian Fisheries and Aquatic Sciences, 65: 1265-1273.

Géry, J. 1977. Characoids of the world. Neptune City, T. F. H. Publications.

Golterman, H., R. S. Clymo & M. A. A. Ohmstad. 1978. Methods for physical and chemical analysis of freshwaters. Oxford, Blackwell Scientific Publication.

Gozlan, R. E., J. R. Britton, I. Cowx & G. H. Copp. 2010. Current knowledge on non-native freshwater fish introductions. Journal of Fish Biology, 76: 751-786.

Guerra, A. J. T. 1995. Catastrophic events in Petrópolis City (Rio de Janeiro), between 1940-1990. GeoJournal, 3: 349-354.

IGAM. 2009. Qualidade da água, Instituto Mineiro de Gestão das Águas, Belo Horizonte. Available from: http://aguas.igam.mg.gov.br (27 April 2009)

Kaplan, S. & B. J. Garrick. 1981. On the quantitative definition of risk. Risk Analysis, 1: 11-27.

Kolar, C. S. & D. M. Lodge. 2002. Ecological predictions and risk assessment for alien fishes in North America. Science, 298: 1233-1236.

Kottelat, M., A. J. Whitten, S. N. Kartikasari & S. Wirjoatmodjo. 1993. Freshwater fishes of Western Indonesia and Sulawesi. Hong Kong, Periplus Editions Ltd.

Kullander, S. O. & K. E. Hartel. 1997. The systematic status of cichlid genera described by Louis Agassiz in 1859: *Amphilophus*, *Baiodon*, *Hypsophrys* and *Parachromis* (Teleosteis: Cichlidae). Ichthyological Exploration of Freshwaters, 7: 193-202.

Lawson, T. B. 1995. Fundamentals of aquacultural engineering. New York, Chapman & Hall.

Lockwood, J. L., M. F. Hoopes & M. P. Marchetti. 2007. Invasion Ecology. Oxford, Blackwell Publishing.

Magalhães, A. L. B. 2010. Efeitos da introdução de peixes ornamentais não-nativos em bacias higrográficas de Minas

Gerais. Unpublished Ph.D. Dissertation, Universidade Federal de Minas Gerais, Belo Horizonte.

Magalhães, A. L. B. 2008. O gupi *Poecilia reticulata* Peters (Osteichthyes, Poeciliidae) introduzido na Serra do Espinhaço, Minas Gerais. Boletim da Sociedade Brasileira de Ictiologia, 92: 5-7.

Magalhães, A. L. B. & C. M. Jacobi. 2010. E-commerce of freshwater aquarium fishes: potential disseminator of exotic species in Brazil. Acta Scientiarum - Biological Sciences, 32: 243-248.

Melo, F. C. S. A., A. C. Machado, A. P. C. Oliveira, J. M. Cruz & A. O. Latini. 2006. Ictiofauna do rio Carangola, bacia do rio Paraíba do Sul, no município de Carangola, Minas Gerais, Brasil. Lundiana, 7: 133-140.

Merrick, J. R. & G. E. Schmida. 1984. Australian freshwater fishes: biology and management. Netley, Griffin Press.

Milton, D. A. & A. H. Arthington.1983. Reproductive biology af *Gambusia affinis holbrooki* Baird and Girard, *Xiphophorus hellerii* (Gunther) and *X. maculatus* (Heckel) (Pisces, Poeciliidae) in Queensland, Australia. Journal of Fish Biology, 23: 23-41.

Moyle, P. B. & M. P. Marchetti. 2006. Predicting invasion success: freshwater fishes in California as a model. Bioscience, 56: 515-524.

Nelson, J. S. 2006. Fishes of the World. New York, John Wiley and Sons.

Neto, F. R. A. 2010. Estado atual do conhecimento sobre a fauna de peixes da bacia do Jequitinhonha. MG.BIOTA, 2: 23-35.

Page, L. M. & B. M. Burr. 1991. A field guide to freshwater fishes of North America north of Mexico. Boston, Houghton Mifflin.

Pompeu, P. S. 2010. Os peixes do rio Mucuri. MG.BIOTA, 2: 36-43.

Richter, H. J. 1988. Gouramis and other Anabantoids. Neptune City, T. F. H. Publications.

Rixon, C. A. M., I. C. Duggan, N. M. N. Bergeron, A. Ricciardi & H. J. MacIsaac. 2005. Invasion risks posed by the aquarium trade and live fish markets on the Laurentian Great Lakes. Biodiversity and Conservation, 14: 1365-1381.

Rosen, D. E. 1979. Fishes from the uplands and intermontane basins of Guatemala: revisionary studies and comparative geography. Bulletin of the American Museum of Natural History, 162: 269-375.

Semmens, B. X., E. R. Buhle, A. K. Salomon & C. V. Pattengill-Semmens. 2004. A hotspot of non-native marine fishes: evidence for the aquarium trade as an invasion pathway. Marine Ecology Progress Series, 266: 239-244.

Strecker, A. L., P. M. Campbell & J. D. Olden. 2011. The aquarium trade as an invasion pathway in the Pacific Northwest. Fisheries, 36: 74-85.

Talwar, P. K. & A. G. Jhingran. 1992. Inland fishes of India and adjacent countries. Rotterdan, A. A. Balkema.

Tempero, G. W., N. Ling, B. J. Hicks & M. W. Osborne. 2006. Age composition, growth, and reproduction of koi carp (*Cyprinus carpio*) in the lower Waikato region, New Zealand. New Zealand Journal of Marine and Freshwater Research, 40: 571-583.

Vander Zanden, M. J. V. & J. D. Olden. 2008. A management framework for preventing the secondary spread of aquatic invasive species. Canadian Journal of Fisheries and Aquatic Sciences, 65: 1512-1522.

Vieira, D. B. & O. A. Shibatta. 2007. Peixes como indicadores de qualidade ambiental do ribeirão Esperança, município de Londrina, Paraná, Brasil. Biota Neotropica, 7: 1-9.

Vieira, F. 2010. Distribuição, impactos ambientais e conservação da fauna de peixes da bacia do rio Doce. MG.BIOTA, 2: 5-22.

Submitted July 13, 2012
Accepted January 11, 2013 by Lilian Casatti
Published June 28, 2013