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Risk assessment of the ornamental fish trade in Mexico: analysis of freshwater species and effectiveness of the FISK (*Fish Invasiveness Screening Kit*)

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Abstract Aquarium trade has been recognized as one of the major pathways of introduction of non-native fishes into new regions. Nearly 43 million freshwater ornamental fish of different species and varieties are annually commercialized in Mexico and there is a high probability for the establishment of some of these species because of their invasive attributes and the diverse climatic zones existing in the country. Within this context, the identification of high-risk species is of paramount importance considering the potential threat to Mexico's great biological diversity. In the present study 700 freshwater aquarium fish species commonly imported and produced in the country were filtered for synonyms/varieties, resulting in 368 species, which where submitted to revision for invasive reports using specialized invasive species databases. This allowed ranking the main invasive species and the top 30 were subjected to risk analysis using the *Fish Invasiveness Screening Kit* (FISK). Calibration of FISK was carried out after generating the reports. A receiver operating characteristic curve was made to determine the FISK ability to discriminate between invasive and non-invasive species in Mexico. Thereafter, Youden's index was calculated and a threshold of 24 was obtained, representing the cut-off value for defining high-risk species. A total of 17 species out of 30 were classified under a high-risk category, among them several species of the genus *Xiphophorus*, *Pterygoplichthys* and *Poecilia*. Most of the species were native to Asia, Central and South America. Some of these species are already invasive in Mexico.

Keywords Freshwater fish · Ornamental trade · FISK · Mexico

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Introduction

Worldwide, aquarium trade is a multi-million dollar industry. The global ornamental fish industry (including dry goods) is valued at approximately US $15 billion dollars (Bartley 2000) and currently about one billion ornamental fish are traded annually (Whittington and Chong 2007), with an approximate value of US $6 billion dollars (Holthus and Gamain 2007). This industry keeps on growing worldwide by 14 % annually (Padilla and Williams 2004) and Mexico is not far behind with an annual growth of 8 % (Mendoza et al. 2010).

During many years ornamental aquaculture has developed significantly with little or no analysis of the ecological risks and consequences of the impressive movement of fish worldwide (Tlusty 2004). Unlike the foodfish industry, where a relatively small number of

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species are cultured, aquarium fish represent a huge reservoir of invasive species with more than 5000 species traded globally (McDowall 2004). Much of the current production of ornamental fish occurs outside its native range and the production of South American freshwater fish in Singapore and Florida are primary examples (Tlusty 2004). As a consequence, the aquarium trade represents one of the five major avenues of introduction of non-indigenous aquatic species (Ruiz et al. 1997) and until 2004 at least 150 invasive species, mainly freshwater fishes (115), were known to have been introduced throughout the world from aquarium trade (Padilla and Williams 2004). Indeed, it has been the major pathway of introduction of exotic species in some regions (Lintermans 2004; Cobo et al. 2010; Low 2011) and is expected to increase in the future (Copp et al. 2007; Wolter and Röhr 2010; Ishikawa and Tachihara 2014).

In Mexico the lack of regulations for the establishment and operation of ornamental fish farms has led to the establishment of non-native fishes in nine out of the ten continental aquatic regions of the country, with some severe environmental damage (60 % of fish extinctions in Mexico have been associated to the presence of non-native species, Contreras Balderas et al. 2003) and economic impacts (Mendoza et al. 2010). Additionally to escapes from farms, the dumping of unwanted organisms, the drainage of water containing organisms from tanks and public aquariums are recognized vectors associated to the aquarium trade in Mexico (Mendoza et al. 2014).

In order to prevent future invasions it is imperative to identify high-risk species and its mechanisms of transport (Kolar and Lodge 2001; Rixon et al. 2005). Among the different approaches to identify high-risk species the Fish Invasiveness Screening Kit (FISK) has been widely used. FISK is an adaptation of the Australian weed risk assessment (WRA) (Pheloung et al. 1999) for freshwater fishes (Copp et al. 2005a, b). The initial version (v1) of FISK has been calibrated and used for identifying high-risk fishes in UK (Copp et al. 2009), Belarus (Mastitsky et al. 2010), Brazil (Troca and Vieira 2012) and Japan (Onikura et al. 2011). Recently, FISK was updated for broader climatic zones (Lawson et al. 2013), and its feasibility has been confirmed for Australia (Vilizzi and Copp 2013), Balkans Region (Simonović et al. 2013), Finland (Puntila et al. 2013), Iberian Peninsula (Almeida et al. 2013), Turkey (Tarkan et al. 2014), Portugal (Range 2013), Hong Kong (Ho 2013) and Hungary (Ferincz 2014). Moreover, FISK has been evaluated among other risk analysis with positive results (Snyder et al. 2013) thus becoming a useful screening tool for potential invasive species (Copp 2013).

The present research was aimed at: (1) identifying high-risk invasive fish among the most common ornamental species introduced and produced in Mexico and (2) calibrating FISK to determine its usefulness in discriminating invasive from non-invasive freshwater aquarium fish species in Mexico.

Materials and methods

A list of 700 fish species, obtained from a workshop (Risk assessment screening of potential invasive ornamental fish, Mexico City, February 2009) with the main ornamental fish importers and producers from Mexico, was filtered for synonyms/varieties. A total of 368 freshwater aquarium fish species commonly traded in the ornamental industry in Mexico were taxonomically validated with the collaboration of an expert ichthyologist (Dr. Salvador Contreras Balderas). The species where submitted to revision for introduction/invasion reports elsewhere using databases such as Fishbase, Invasive Species Specialist Group (ISSG), Database on Introduction of Aquatic Species (DIAS), Global Biodiversity Information Facility (GBIF), Inter-American Biodiversity Information Network (IABIN), Nonindigenous Aquatic Species (NAS), National Exotic Marine and Estuarine Species Information System (NEMESIS), Nonindigenous Species Database Network (NISBase) and European Network on Alien Invasive Species (NOBANIS). These databases were also consulted to determine different pathways of introduction of these species besides aquarium trade. All species were ranked according to the number of sites where they had been considered established, irrespective of the database, as this not only reflects the propagule pressure but also their adaptability to different environmental conditions. Priority was given to records of invasion, i.e. species a priori classified as invasive, species already established and species potentially occurring in the wild, and the top 30 species were selected to perform the calibration of FISK. Among these 30 species are the most imported into the country and the most produced in Mexico (Ramírez et al. 2010).

Version 2 of FISK was used as it incorporates characteristics for application in all climatic zones. For a detailed example of this assessment see Lawson et al. (2013). Briefly, FISK comprises a set of 49 questions divided in 8 subsets: domestication/cultivation, climate and distribution, invasive elsewhere, undesirable traits, feeding guild, reproduction, dispersal mechanisms and persistence attributes. Each question requires a response "yes/no" accordingly or "don't know" when information is not available and a level of certainty. As each response of FISK for a given species is allocated a certainty score (1 = very uncertain; 2 = mostly uncertain; 3 = mostly certain; 4 = very certain), a "certainty factor" (CF) was computed as: Σ (CQi)/(4 $\times$ 49)(i = 1,…,49), where CQi is the certainty for question i, 4 is the maximum achievable value for certainty (i.e. "very certain"), and 49 is the total number of questions comprising the FISK tool. The CF therefore ranges from a minimum of 0.25 (i.e. all 49 questions with certainty score equal to 1) to a maximum of 1 (i.e. all 49 questions with certainty score equal to 4) (Almeida et al. 2013; Simonović et al. 2013). All responses are answered according to the information available from literature. After the questionnaire is completed a report is given showing a score ranging from −11 to 53 and details of the score partition (individual scores for each subset of questions), number of questions answered, sectors affected (aquacultural, environmental and nuisance) and a certainty factor. The authors reviewed all questionnaires and answers. Information sources were scientific articles and available books, online databases and fish-specialized websites. In order to answer questions relative to climatic similarity, two modeling algorithms; the Genetic Algorithm for Rule-Set Prediction (GARP) and the Maximum Entropy Method (Maxent) were used for each species in order to predict which areas within the country would satisfy the requirements of the species' ecological niche and thus the species' potential distribution (Anderson and Martínez-Meyer 2004). Taxonomic information for each species was gathered from ITIS, the Integrated Taxonomic Information System (http://www.itis.gov) and Fishbase (www.fishbase.com).

Calibration of FISK was carried out after generating the reports of the 30 species. A Receiver Operating Characteristic (ROC) curve was made in order to determine the FISK ability to diagnose correctly the outcome (i.e. discriminate between invasive and non-invasive species). A ROC curve is a statistical method to assess the diagnostic accuracy of a test. It is a graph of the sensitivity versus 1—specificity of the test (Y and X axis, respectively), where sensitivity is the proportion of true positives identified by the test (i.e. correctly identified invasive species) and specificity is the proportion of true negative identified (i.e. correctly identified non-invasive species). From this graph the Area Under the ROC curve (AUROC) was determined. The AUROC provides a measure of a test ability to discriminate, in this case, between invasive from non-invasive species. AUROC areas are values between 0.5 and 1, with higher values indicating a better diagnostic ability of the test. In this regard, according to information from literature, species were classified into invasive (non-indigenous or translocated species either abundant or with any impact reported) or non-invasive for Mexico, corresponding to the actual positive and negative outcome, respectively. After this, Youden's index (*J*) was estimated. For this purpose, Youden's index is the FISK score where both sensitivity and specificity are maximized. This index was used to determine the best cut-off value for high-risk species (Bewick et al. 2004; Copp et al. 2009; Tricarico et al. 2010). All statistical analysis was performed using SPSS v.20.

Results

From the 30 species analyzed (Table 1), 27 were native to Asia, Central and South America. Taxonomically, the species were classified in 12 families. Cichlidae and Poecilidae were the families with highest number of representatives, followed by Cyprinidae and Loricariidae. Some species were reported in the databases and the literature as introduced from different pathways besides the aquarium trade, namely through fisheries, aquaculture, gamefish, bait, food fish, and biocontrol (Fig. 1).

FISK scores varied from 7 for *Beaufortia leveretti* and *Rineloricaria parva* to 34 for *Pterygoplichthys disjunctivus* (Fig. 2). The percentage of questions answered (i.e. either yes/no) ranged from 44.9 % for *R. parva* to 94 % for *Carassius auratus* and *P. hypophthalmus*, with an overall mean of 78 %. The mean certainty for all species was 0.9 (90 % of certainty), fluctuating from a minimum of 0.83 for

Table 1 Species assessed in this study

Species	Common name	Family	Status in Mexico	Origin
Arapaima gigas	Arapaima	Arapaimidae	Nonnative	South America
Beaufortia leveretti	Butterfly loach	Balitoridae	Nonnative	Asia
Channa micropeltes	Giant snakehead	Channidae	Nonnative	Asia
Astyanax mexicanus	Mexican tetra	Characidae	Native/invasive	North America
Amatitlania nigrofasciata	Convict cichlid	Cichlidae	Nonnative/invasive	Central America
Amphilophus citrinellus	Midas cichlid	Cichlidae	Nonnative	Central America
Astronotus ocellatus	Oscar	Cichlidae	Nonnative	South America
Cichlasoma salvini	Yellow belly cichlid	Cichlidae	Native	Central America
Hemichromis guttatus	Spotted jewelfish	Cichlidae	Nonnative/invasive	Africa
Parachromis managuensis	Jaguar guapote	Cichlidae	Nonnative/invasive	Central America
Thorichthys meeki	Firemouth cichlid	Cichlidae	Native	Central America
Misgurnus anguillicaudatus	Pond loach	Cobitidae	Nonnative	Asia
Barbonymus schwanenfeldii	Tinfoil barb	Cyprinidae	Nonnative	Asia
Carassius auratus	Goldfish	Cyprinidae	Nonnative/invasive	Asia
Cyprinus carpio	Common carp	Cyprinidae	Nonnative/invasive	Europe, Asia
Puntius semifasciolatus	Chinese barb	Cyprinidae	Nonnative	Asia
Hypostomus plecostomus	Spotted pleco	Loricariidae	Nonnative	South America
Pterygoplichthys disjunctivus	Vermiculated sailfin catfish	Loricariidae	Nonnative/invasive	South America
Pterygoplichthys pardalis	Amazon sailfin catfish	Loricariidae	Nonnative/invasive	South America
Rineloricaria parva	Whiptail catfish	Loricariidae	Nonnative	South America
Betta splendens	Siamese fighting fish	Osphronemidae	Nonnative	Asia
Trichopodus trichopterus	Three spot gourami	Osphronemidae	Nonnative	Asia
Pangasianodon hypophthalmus	Striped catfish	Pangasiidae	Nonnative	Asia
Poecilia reticulata	Guppy	Poecilidae	Nonnative/invasive	South America
Poecilia sphenops	Molly	Poecilidae	Native	Central and South America
Poecilia velifera	Sail-fin molly	Poecilidae	Native	Central America
Xiphophorus hellerii	Green swordtail	Poecilidae	Native/invasive	North and Central America
Xiphophorus maculatus	Southern platyfish	Poecilidae	Native/invasive	North and Central America
Xiphophorus variatus	Variable platyfish	Poecilidae	Native/invasive	North America
Piaractus brachypomus	Pirapitinga	Serrasalmidae	Nonnative	South America

Taxonomic information was obtained from ITIS and Fishbase. Status in Mexico was based on literature

Barbonymus schwanenfeldii to a maximum of 0.96 for *Xiphophorus hellerii* (Fig. 2).

According to previous reports 12 species were already considered invasive in Mexico (Fig. 2). This result provided a starting point for the calibration of FISK consisting on a ROC curve analysis, with the invasive and non-invasive status as positive and negative outcomes, respectively. From this analysis an AUROC of 0.829 (0.683–0.974, 95 % CI) was obtained (Fig. 3), meaning that FISK was able to discriminate to a good extent, and with statistical significance, between invasive and non-invasive species in Mexico.

Thereafter, Youden's index was calculated. A threshold of 24 was obtained, representing the cut-off value that maximizes both sensitivity and specificity and, henceforth, the appropriate value for defining high-risk species. Medium-risk species have been defined by previous studies as those with a score higher than 1 and lower than the value obtained after the Youdeńs index is calculated (Puntila et al. 2013; Tarkan et al. 2014), so this ranking was considered here. Taking into account the threshold of 24, 17 species were classified into the high-risk category, 11 of which were already considered invasive in Mexico and 6 (*M. anguillicaudatus*, *P. hypophthalmus*, *P. sphenops*, *T. trichopterus*, *Arapaima gigas* and *C. micropeltes*) that did not have any reports of impacts in Mexico yet (Table 2).

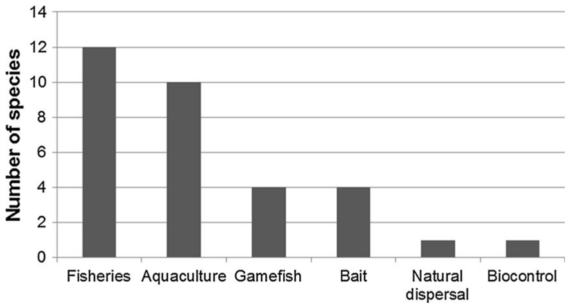

Fig. 1 Number of species associated to different introduction pathways besides aquarium trade, from the 30 species most imported into the country and most produced in Mexico

The remaining 13 species belong to the medium-risk category; of these species only *A. mexicanus* is considered invasive in Mexico. As expected, no species were classed under the low risk category.

Discussion

The adequate identification of potential nuisance species and their vectors is an essential task in Mexico, as the country has one of the richest faunas of the world. It is among the 12 countries that host most (60–70 %) of the biological diversity of the world (one of the so-called megadiversity countries) (Arita 1997). Unfortunately, according to the Mexican National Fisheries Chart (DOF 2004) different water bodies of 9 of the 10 aquatic provinces of the country already host several non-native ornamental fish species in the wild. A dreadful example is Morelos, the leading state in ornamental fish production in Mexico, where fish communities have suffered from fish introductions for several years and as a result one-third of the state

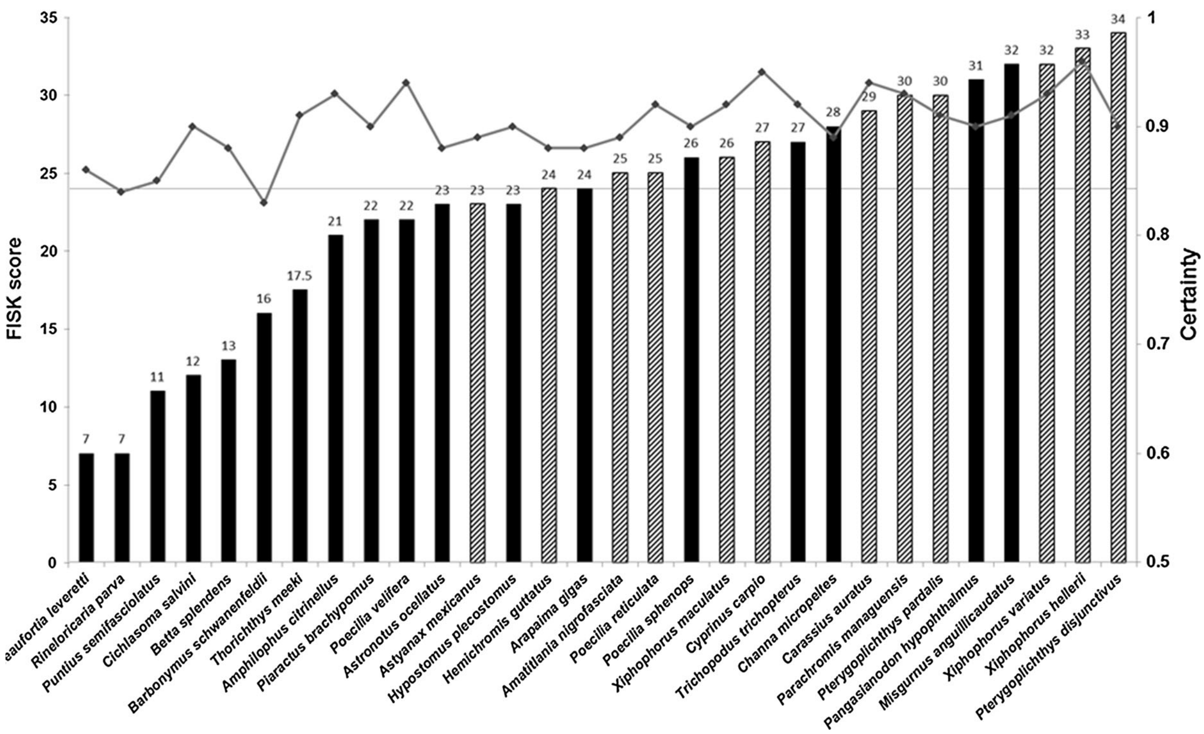

Fig. 2 FISK scores (*bars*) for the 30 species analyzed. *Numbers* above *bars* indicate the FISK score. *Line* across *bars* corresponds to the threshold resulting from Youden's index. *Striped bars* correspond to invasive species already established in Mexico. Certainty for each species is shown (*line graph*) with values in the secondary axis

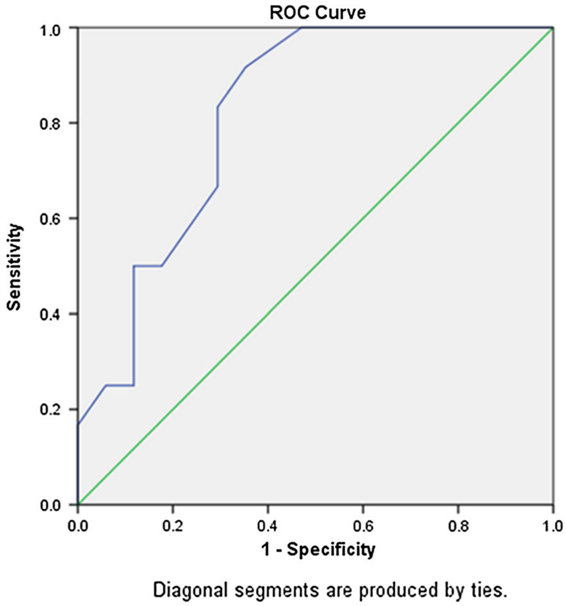

Fig. 3 Receiver operating characteristic (ROC) curve for the assessment of 30 freshwater aquarium fish species in Mexico using FISK

ichthyofauna is now represented by non-native ornamental species (Contreras-Macbeath et al. 1998). Even worst, some of these exotic species have reached critical areas characterized by a high endemism such as Mexico's Natural Protected Areas (García et al. 2014). At the present some of the most traded species represent a real threat according to the evaluation using FISK, yet there might be some species with an important invasive potential among the species that were not analysed and even among those with relative low scores. FISK scores for the species assessed were in the rank of 7–34. A positive correlation between both the percentage of answered questions and the certainty with FISK scores was noticed (data not shown). In line with the above mentioned, this indicates that the experience of assessors and the available information are significant factors in the categorization of high-risk species, and therefore those species with the lowest certainty could have higher scores as new information becomes available. For example the absence of invasive behaviour of some species may be assumed to indicate a low risk, however it does not indicate a zero risk, particularly if there is little data available. Indeed, current predictions for climate change under scenarios of global warming could lead to some species becoming invasive (Copp et al. 2005a, b).

In light of such considerations the AUROC value of 0.829 obtained from this assessment indicates that FISK is able to discriminate, with statistical significance, between invasive and non-invasive ornamental fish species in Mexico. This result is in agreement with prior FISK analysis (Copp et al. 2009; Onikura et al. 2011; Simonović et al. 2013; Almeida et al. 2013; Puntila et al. 2013; Tarkan et al. 2014) in which AUROCs obtained varied from 0.67 in the Balkans Region to 0.88 in the Iberian Peninsula. It should be pointed out that the sensitivity of the ROC curve was not as high as it could be expected since some of the high-risk invasive species are not established yet. However, considering the biological characteristics of these species, their history of invasion elsewhere, the climatic similarity with their native range and the number of individuals imported (Table 2), there is strong possibility for their establishment.

According to the cut-off value of 24 derived from Youden's index (J) calculation, a total of 17 species were classified under a high-risk category. These results are in agreement with several risk assessments made in other countries, which have classified as high-risk the best part of these species (Bomford 2008; Bomford and Glover 2004; Moore et al. 2010; Range 2013; Almeida et al. 2013). This cut-off value for Mexico is higher than those reported for other countries. Previous calibrations have resulted in lower cut-off values: 9.5 for the Balkans Region (Simonović et al. 2013); 19 for UK (Copp et al. 2009); 19.8 for Japan (Onikura et al. 2011); 20.5 for Iberian Peninsula (Almeida et al. 2013); 22.5 for Finland (Puntila et al. 2013) and 23 for Turkey (Tarkan et al. 2014). The cut-off value (Youden's index) is based on the FISK score of the different species and their a priori category as invasives. Therefore, because the species have higher FISK scores compared to other countries the cutoff is higher. That just means that for different reasons the species, in general, tend to reach higher values in some countries and lower values in others, and after the calibration this results in higher or lower Youden index, respectively. However, in all of these studies where an important number of species have been evaluated less than half of the species used for the calibration were classed as high risk species, with the exception of the Balkans region and the present study.

Table 2 Summary of high-risk species attributes and invasion potential (References are omitted. consult the authors for bibliographical information)

Species	Invasive attributes and invasion potential							
	Sanitary threats	Hardiness	Predation potential	Agonistic behavior	Reproduction	Propagule pressure	Impacts	Presence in natural protected areas in Mexico
Xiphophorus species (*X. hellerii*, *X. maculatus*, *X. variatus*)	Vectors of potentially harmful pathogens, e.g *Mycobacterium marinum*	Broad oxygen tolerances through surface air-breathing	Omnivores	Territorial and aggressive	Iteropatric Internal livebearers May spontaneously change sex	Popular aquarium fishes Among the tenth most produced species in Mexico	Predation on eggs/juveniles of native species Extinction of native species (*Skiffia francesae* and *Allotoca goslinei*)	*X. hellerii* and *X. maculatus* are established in the natural protected area of Sierra la Laguna, Baja California Sur, Mexico
Pterygoplichthys disjunctivus and *P. pardalis*	Harbor parasites, including flukes, roundworms and protozoans	Loricariids can breathe atmospheric air	Incidental ingestion of substrate-attached eggs	Aggressive defense of territory Extensive schooling behavior	Fecundity of loricariids is moderately high Burrow spawners and show parental care	Popular fish in the aquarium trade in Mexico	Alteration of bank structure and erosion, disruption of aquatic food chains, alteration of riverine biogeochemical cycles, competition with native species, damage to fishing gear	Loricariid species are established in some Natural protected areas in Mexico (Yaxchilán, Lacantún and Montes Azules in Chiapas, Mexico)
Amatitlania nigrofasciata	Associated to different helminths	Eurytherm	Omnivores with a carnivorous tendency	Aggressive fish that competes with native fishes for spawning sites	Parents incubate eggs (100–150) and guard young	Highly commercial in the aquarium trade	Displacement of native cichlid species (*Cichlasoma istlanum*)	Not reported
Parachromis managuensis	Host of different trematodes	Inhabits turbid and oxygendepleted waters and mud bottoms of highly euthropic lakes	The most predatory of all guapotes	Highly piscivorous and aggressive	Deposits up to 5000 eggs Biparental care	Very popular in aquarium trade and aquaculture	Outcompeted native species in Mexico Displacement of species that are far more beneficial in terms of their marketability	Established in the natural protected area of Pantanos de Centla, Tabasco, Mexico

Table 2 continued

Species	Invasive attributes and invasion potential							
	Sanitary threats	Hardiness	Predation potential	Agonistic behavior	Reproduction	Propagule pressure	Impacts	Presence in natural protected areas in Mexico
Pangasianodon hypophthalmus	Host of several pathogens and parasites e.g. a highly invasive strain of *Edwardsiella ictaluri* that provokes Bacillary Necrosis of *Pangasius*	They can survive in salinities up to 20 ppt and can withstand long periods out of the water as they can breathe atmospheric air	Carnivorous and highly voracious	Aggressive fish that competes with and predates on native fish	A 10 kg female can spawn up to one million eggs They can hybridize with other *Pangasius* species	Introduced to several countries by aquarium trade Popular in aquaculture	Predation of mollusks, fish and birds	Not reported
Hemichromis guttatus	Host of trematodes and harmful microorganisms, such as *Mycobacterium ulcerans*, pathogenic to humans	Excellent tolerance to salinity, temperature and low dissolved oxygen levels	Omnivorous, voracious, cannibalistic	Very aggressive cichlid	Oviparous, prolific (200–500 oocytes) exhibit biparental care. Females are very aggressive after spawning	Introduced to several countries by aquarium trade	Has outcompeted and provoked the decline of endemic fish populations (*Herichthys minckleyi*)	Established in the natural protected area of Cuatro Cienegas, Coahuila, Mexico
Carassius auratus	Associated with the spread of harmful fish parasites. Carriers of the highly contagious Koi Herpes Virus	Large anoxia, salinity and temperature tolerance	Feed on a wide range of food including plants and small animals	Not aggressive	Rreproductive period covers a broad time-span Fecundity up to 210,000 eggs	The most important species in aquarium trade in Mexico, occasionally used as bait	Competes with native fish species, increases water turbidity and depletes aquatic vegetation	This species is established in one natural protected area (Islas del Golfo de California, Mexico)
Channa micropeltes	Snakeheads are often associated with several pathogens and parasites	They can tolerate hypoxic conditions because they are airbreathers	All snakehead species are carnivorous thrust predators as adults, consuming mainly fishes	Considered the most ferocious and ravenous of snakeheads	The species exhibit parental care Guarding continues after hatching, probably until young become demersal	Popular in the aquarium trade. Used also in aquaculture and as a gamefish	They have the potential to significantly impact native fish	Not reported

Table 2 continued

Species	Invasive attributes and invasion potential							
	Sanitary threats	Hardiness	Predation potential	Agonistic behavior	Reproduction	Propagule pressure	Impacts	Presence in natural protected areas in Mexico
Poecilia reticulata; P. sphenops	Known carriers of trematode parasites, which may affect native fish populations	*Poecilia* species have wide ecological tolerances: they are eurythermal, euryhaline and hypoxia tolerant	Wild guppies feed on diatoms, invertebrates, plant fragments, aquatic insect larvae, but will also eat fish eggs	Agonistic hierarchies or relationships have been observed for several species of poeciliid teleosts	Highly prolific livebearers Females promiscuously mate with multiple males and can store sperms for later fertilization	Among the most produced species for aquarium trade in Mexico	*Poecilia* species have invaded multiple sites in Mexico, including the last few remaining localities of some endangered goodeids and cyprinids	*P. reticulata* is established in the Natural Protected Areas of Sierra La Laguna, Baja California Sur and Alto Golfo de California- El Pinacate, Sonora, Mexico
Misgurnus anguillicaudatus	Host of monogenean parasites, e.g. *Gyrodactylus macracanthus*	Broad temperature tolerance Utilize atmospheric air to survive low oxygenated waters and withstands moderate salinity	*M. anguillicaudatus* preys on insects, insect larvae, crustaceans, annelids, algae, detritus, and other small aquatic organisms	High competitive ability	High reproductive capacity. They are multiple spawners and lay approximately 1800–15,000 eggs per event	Ornamental fish common to aquarium trade and used in aquaculture	Cause significant reductions in macroinvertebrate populations Alteration of habitat; and decreased water quality (elevated ammonia, nitrate/nitrite, and turbidity levels)	Not reported
Arapaima gigas	Host of several bacteria and fungi	The fish is an obligatory air-breather allowing it to thrive in oxygen deprived waters	Carnivorous. Feeding habits involving the consumption of a wide variety of prey items	Aggressive fish	Fecundity, more than 600,000 eggs per female. The arapaima male is a mouthbrooder	Present in the international aquarium trade, popular un aquaculture and as a gamefish	Reduction of native fish populations, including many fish of high commercial value	Not reported

The explanation for higher FISK scores for many of the species evaluated in this study is very likely the result of the combination and conjunction of different factors such as: (a) the biogeographic conditions present in Mexico. Indeed, Mexico is in a transitional zone between the two large neotropical and neartic regions hosting diverse climatic zones. This would imply a higher chance for some species to become established, resulting in higher scores. In relation to this, it has been stated that impacts of introductions vary with geography, time and species (Courtenay 1995), and previous reports have already highlighted that independent FISK analysis should be performed for distinct climatic zones as different risk classifications may arise due to differences in species-environment matches for different biogeographical regions (Onikura et al. 2011; Verbrugge et al. 2012). (b) The important propagule pressure of several high risk species, which are among the most produced and most imported into the country (Ramírez et al. 2010), and that have also been introduced by other pathways besides aquarium trade (Fig. 1; Table 2). The popularity and propagule pressure of these species have certainly contributed to their eventual release as it has been demonstrated for numerous ornamental fish species (Duggan et al. 2006). Unfortunately, their presence in the natural environment coupled with their high reproductive capacity have favored their establishment in several regions of the country including numerous Mexico's Natural Protected Areas. (c) The different inherent attributes displayed by these 17 species (Table 2), such as their hardiness and high adaptability to a wide range of environmental conditions and thus their pre-adaptations for human-altered environments (Sax and Brown 2000), their broad trophic spectrum and their association with different pathogens and parasites. Altogether these characteristics denote their potential as successful and high impact invaders.

The remaining 13 species were classified under the medium risk category and from these only *A. mexicanus* has established invasive populations in the country. It should be noted that the score obtained for this species (23) is very close to the threshold. Although these species may signify a less severe risk, as information becomes available their certainty factors could increase, especially those close to the cut-off value. For this reason it is recommended to consider these species in further assessments.

Aquarium trade has shown an accelerated increase during the last decade (Padilla and Williams 2004) that parallels the boost of exotic species in the Mexico. The number of exotic species has increased from 55 in the 80s to 115 at the present, from which 67 have already established (Mendoza et al. 2014). Several facts contribute to explain this: (a) the huge number of species and varieties imported (700 from 117 families) compared to the low amount of varieties cultured in Mexico (61 varieties pertaining to 19 species, (b) the number of fish imported in Mexico; 43 million ornamental fish are traded annually, of which 45 % are imported while 55 % are captive bred, (c) the lack of official regulations for the establishment and operation of farms producing ornamental fish and for the translocation of these within the country. Some of these species have already severely impacted the environment and the economy in most regions of the country and as this study shows many of the most dangerous species are already established in several Natural Protected Areas, constituting a serious threat to the Mexican biodiversity. Some additional difficulties for the management of some of these species rely on their various pathways of introduction.

Other issues arise from the standpoint of the geographical origin of these species. For example, those species imported from Central and South America are often wild-caught and thus there is a high probability for their establishment if they ever escape or are released, because it is very likely that they will find similar environmental conditions to those of their original ecosystems and because they are adapted to hunt, compete and search for a mate in the wild. Whereas those imported from Asia, despite being mostly captive-reared, represent a more important sanitary risk because of the parasites and pathogens they often carry and that are uncommon for native species.

Altogether, this study highlights the importance of identifying high-risk species to prevent future invasions. In this line, although some measures have already been established by the Mexican government to counteract and attack this important problem, such as the mandatory risk assessment for the importation of new species and some important modifications to the environmental law, there is still a strong need to implement other essential actions, namely: (a) increase the biosafety measures in production facilities and establish better management practices, particularly for the exotic species that are currently cultivated for aquarium trade, (b) encourage the production of native species, (c) provide financial support and grant fiscal incentives to those producers that are environmental responsible, (d) implement a continuous monitoring system nearby the import and production facilities for early detection and rapid response of potential invasive species, (e) strengthen the technical and material capacities for the detection and management of important diseases, and (f) establish a permanent environmental educational program addressed to traders, petshop owners and employees and hobbysts.

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