

EUROPEAN HUB FOR INVADERS: RISK ASSESSMENT OF FRESHWATER AQUARIUM FISHES EXPORTED FROM THE CZECH REPUBLIC

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Background. The aquarium fish trade is characterized by an enormous number of species. Aquarium fish may have an impact on native biota by means of their invasiveness as well as through pathogen transfer. The Czech Republic has become a gateway for aquatic pets into the European Union. The aims of this study were to identify the most common aquarium fish species on the wholesale market, to estimate temperature suitability for seasonal (winter and summer) survival in the EU, and also to assess the invasiveness risk of the most common aquarium fishes with the strongest temperature matching.

Materials and methods. Data on aquarium fish species, their origin, and availability from producers and traders based in the Czech Republic were collected based on all available sources. The target area was defined as all member states of the EU. Estimation of the temperature suitability for each species was done using Climatch 1.0 software. The Freshwater Fish Invasiveness Screening Kit (FISK) was employed for species with temperature suitability within the target area exceeding 10% in the coldest quarter of the year.

Results. In total, 1118 fish species representing 51 families were identified. Thirty-three species belonging to 13 families were classified as “very common”. Three sources of origin were identified: domestic production within the EU, farm production outside the EU, and wild harvests in the region of origin. The major suppliers outside the EU are in south-east Asia. Only one common species originated from wild harvests. FISK scoring divided the 11 species evaluated as having the strongest temperature suitability in the EU (TSEU) into seven species bearing medium risk and four species representing high risk. The family Cyprinidae was the most frequently represented among all evaluated taxa (seven species), but the majority of high-risk fishes belonged to the family Poeciliidae (three species). The highest score was earned by *Carassius auratus* (Linnaeus, 1758).

Conclusion. The risk potential of aquarium fishes most traded in the EU seems to be not alarming. Attention should be focused on the possibility of novel pathogen transfer to native aquatic biota as an important aspect of regulating the aquarium fish trade.

Keywords: introduction pathway, aquarium trade, invasive species, freshwater fish, risk assessment, FISK

INTRODUCTION

Aquaculture, recreational fisheries, and trade in aquatic pets are considered the main driving forces behind the introduction of non-native aquatic species (Copp et al. 2005a). The aquarium fish trade in particular involves an enormous number of species, of which ca. 5300 and ca. 1800 are of freshwater and marine origin, respectively (Hensen et al. 2010, Rhyne et al. 2012). Approximately 90% of freshwater aquarium fishes originate from aquaculture production (Tlustý 2002) and breeding in captivity is steadily growing, especially in Asia (Jayalal and Ramachandran 2012, Raghavan et al. 2013).

In contrast to the immense diversity of fishes and locations of their native ranges, the international trade is charac-

terized by just several re-exporting hubs that encompass the majority of the world’s aquarium fish supply (Livengood and Chapman 2007, Jayalal and Ramachandran 2012). By far the most important hub is Singapore, which covers about 30% of the total trade (Jayalal and Ramachandran 2012, Rani et al. 2014). The Czech Republic, in addition to its own production, has become a gateway to the European Union (EU) (Livengood and Chapman 2007, Jayalal and Ramachandran 2012, Maceda-Veiga et al. 2013) and constitutes an important hub for imports into the largest markets for aquatic pets (Livengood and Chapman 2007).

Although the majority of freshwater aquarium fishes in Europe are kept within indoor closed systems, some are released into the wild—usually by hobbyists (Copp

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et al. 2007, Patoka et al. 2014b). Released animals may sometimes form viable populations (Elvira and Almodóvar 2001, Koščo et al. 2010, Papavlasopoulou et al. 2013).

Potential invasiveness for the EU has already been assessed for freshwater turtles used as pets (Kopecký et al. 2013, Masin et al. 2014) and crayfish (Chucholl 2013, Papavlasopoulou et al. 2014, Patoka et al. 2014a), but the risk from freshwater aquarium fish has been evaluated only from local perspectives (Copp et al. 2005b, 2005c, Papavlasopoulou et al. 2013, Simonović et al. 2013). Although there is an intuitive assumption that the majority of released fish cannot survive winter in a large part of the EU, the presence of non-native species in the natural environment for only a short period may still affect native biota and aquaculture through such means as pathogen transfer (Peeler et al. 2011). Imported aquarium fishes could be infected by viruses (Vesely et al. 2011), antibiotic-resistant bacteria (Dobiasova et al. 2014, Gerzova et al. 2014), or parasites (Kennedy 1993, Boeger et al. 2002, Sobecka et al. 2012), some of which may have zoonotic potential (Weir et al. 2012, Mehrdana et al. 2014).

Eradication of invaders, diseases, and parasites in aquatic ecosystems is usually very difficult and costly. It is easier to prevent a new introduction than subsequently try to mitigate its environmental impacts (Copp et al. 2005a, Maceda-Veiga et al. 2013). Obviously, early identification of potential invaders, their origins, and the reasons for their possible introductions is crucial for proper environmental management (Kolar and Lodge 2001). The commercial aquarium fish trade sector is directly connected to potential release into the wild of non-native fishes. This is because the distribution channel ends with live fish, which are sold to customers in pet shops (Duggan 2010).

We focused our data collection on wholesale trading within an EU trade hub, because later tracking of fish is very problematic or nearly impossible. The aims of the present work were to identify the most common aquarium fish species on the wholesale market in the Czech Republic, to estimate temperature suitability to survive on EU territory in winter and summer for the most common aquarium fish, and to assess the invasiveness risk of the most common aquarium fish with the strongest temperature matching.

MATERIALS AND METHODS

Identification of the most common aquarium fish species. Over the period of June 2013 to May 2014, we composed a list of aquarium fish species and collected data on their origin and availability from producers and traders based in the Czech Republic. Data were obtained from the offers of five major wholesalers and 93 private producers of aquarium fishes who sell their production abroad. Based on personal consultations and/or physical inspections, we eliminated numerous misnomers and alternative market names from the preliminary summary list. We used the Catalog of Fishes (Eschmeyer 2014) to validate scientific names. Availability on the market was evaluated according to Chucholl (2013).

Target area. The EU states were assumed as the target area, including the autonomous islands of Macaronesia (namely the Azores, Madeira, and the Canary Islands) in a manner similar to Kopecký et al. (2013). Due to their geographical remoteness, other overseas departments and regions were not included into our study as parts of the EU.

Estimation of temperature suitability within the target area. We examined the temperature match between source area and target area for very common aquarium fish. We computed climate match data (Bomford 2008) in Climatch 1.0 (Bureau of Rural Sciences) by source region versus target region for each species. Besides the whole year (used for FISK only) we compared the warmest, and the coldest quarter of the year. Where the model predicted a relatively close climate match between the source area and the meteorological station in the target area according to the temperature variable (score ≥ 7.0), this was interpreted as meaning that temperature is not a constraint for the species survival (Britton et al. 2010). We calculated the temperature suitability in the EU (further referred to as TSEU) for each species as the percentage of meteorological stations with Climatch score ≥ 7.0 within the target area. Additionally, a paired *t*-test in R statistical software (R Development Core Team 2014) was employed to reveal differences between the warmest and coldest periods of the year for all analysed species of fish.

Assessment of invasiveness risk. To evaluate potential invasiveness, we employed the Freshwater Fish Invasiveness Screening Kit (FISK) (Copp et al. 2005b, Copp et al. 2009, Lawson et al. 2013) on species with TSEU exceeding 10% in the coldest quarter of the year. We used the 10% threshold of TSEU as demonstrative criterion based on qualified estimate of the obtained data for FISK. Information regarding the biology, ecology, biogeography, exploitation by humans, invasive history, and presence of ‘undesirable traits’ of each evaluated species were obtained through a review of the scientific literature (Nelson 2006, Froese and Pauly 2014).

RESULTS

In total, we credibly identified 1118 fish species representing 51 families in the EU aquarium fish trade. Thirty-three species belonging to 13 families were assessed as ‘very common’ due to their availability in large quantities through the entire season.

Traded aquarium fishes had three sources of origin:

- Domestic production within the EU;
- Farm production outside the EU; and
- Wild harvests in region of origin (Table 1).

The major suppliers outside the EU were located in South and south-east Asia (China, India, Indonesia, Malaysia, Singapore, Taiwan, Thailand, and Vietnam), South America (Brazil, Colombia, and Peru), Africa (Congo and Nigeria), and the Middle East (Israel). Only a single, very common species, *Chromobotia macracanthus* (Bleeker, 1852), endemic to Borneo and Sumatra (Indonesia), originated exclusively from wild harvest.

Table 1

List of the most traded ornamental fish species

Species	Family	Main origin	TSEU		FISK	
			Winter	Summer	Score	Category
<i>Carassius auratus</i> (Linnaeus, 1758)	Cyprinidae	D, O	95	73	26	high
<i>Corydoras paleatus</i> (Jenyns, 1842)	Callichthyidae	D	38	38	4	medium
<i>Poecilia latipinna</i> (Lesueur, 1821)	Poeciliidae	D, O	35	29	22	high
<i>Tanichthys albonubes</i> Lin, 1932	Cyprinidae	D, O	29	39	5.5	medium
<i>Clarias batrachus</i> (Linnaeus, 1758)	Clariidae	O	24	99	16.5	medium
<i>Poecilia sphenops</i> Valenciennes, 1846	Poeciliidae	D, O	20	98	20	high
<i>Trichopodus leerii</i> (Bleeker, 1852)	Osphronemidae	D	17	83	12	medium
<i>Trigonostigma heteromorpha</i> (Duncker, 1904)	Cyprinidae	D	16	91	1	medium
<i>Xiphophorus helleri</i> Heckel, 1848	Poeciliidae	D	15	78	21	high
<i>Trichogaster lalius</i> (Hamilton, 1822)	Osphronemidae	O	14	93	13	medium
<i>Danio rerio</i> (Hamilton, 1822)	Cyprinidae	D, O	14	93	4.5	medium
<i>Thorichthys meeki</i> Brind, 1918	Cichlidae	D	9	33		
<i>Astronotus ocellatus</i> (Agassiz, 1831)	Cichlidae	D, O	8	15		
<i>Xiphophorus maculatus</i> (Günther, 1866)	Poeciliidae	D, O	4	25		
<i>Gymnocorymbus ternetzi</i> (Boulenger, 1895)	Characidae	D	3	20		
<i>Trichopodus trichopterus</i> (Pallas, 1770)	Osphronemidae	D	2	51		
<i>Paracheirodon innesi</i> (Myers, 1936)	Characidae	D, O	2	30		
<i>Pangasianodon hypophthalmus</i> (Sauvage, 1878)	Pangasiidae	O	2	24		
<i>Epalzeorhynchus frenatum</i> (Fowler, 1934)	Cyprinidae	O	2	23		
<i>Pangio kuhlii</i> (Valenciennes, 1846)	Cobitidae	O	1	51		
<i>Balantiocheilus melanopterus</i> (Bleeker, 1850)	Cyprinidae	O	1	49		
<i>Puntius tetrazona</i> (Bleeker, 1855)	Cyprinidae	D	1	49		
<i>Megalechis thoracata</i> (Valenciennes, 1840)	Callichthyidae	D	1	33		
<i>Ancistrus dolichopterus</i> Kner, 1854	Loricariidae	D	1	30		
<i>Piaractus brachypomus</i> (Cuvier, 1818)	Characidae	O	1	30		
<i>Paracheirodon axelrodi</i> (Schultz, 1956)	Characidae	D	1	28		
<i>Gyrinocheilus aymonieri</i> (Tirant, 1883)	Gyrinocheilidae	O	1	15		
<i>Chromobotia macracanthus</i> (Bleeker, 1852)	Botiidae	F	0	31		
<i>Poecilia reticulata</i> Peters, 1859	Poeciliidae	D, O	0	30		
<i>Mikrogeophagus ramirezi</i> (Myers et Harry, 1948)	Cichlidae	D	0	27		
<i>Pterophyllum scalare</i> (Schultze, 1823)	Cichlidae	D	0	27		
<i>Synodontis nigriventris</i> David, 1936	Mochokidae	D, O	0	24		
<i>Betta splendens</i> Regan, 1910	Osphronemidae	O	0	3		

D = domestic production in EU, O = farm production outside EU, F = wild harvest in region of origin; TSEU = temperature suitability in the EU [%], FISK = Freshwater Fish Invasiveness Screening Kit; The dashed line separates the fish with more than 10% TSEU.

Evaluation of temperature suitability with target area.

When comparing all 33 fishes classified as very common, the warmest period of the year in the target area showed a stronger climate match with the source area (paired *t*-test, $t = 6.98$, $P < 0.0001$). The particular temperature suitability for each species in the warmest and coldest periods of the year within the target area is given in Table 1.

Assessment of invasiveness risk. FISK scoring divided the 11 species evaluated with the highest TSEU in winter (over 10%) into seven species representing medium risk for the EU and four species bearing high risk (Table 1). Fishes of the family Cyprinidae occurred most frequently among all evaluated taxa (seven species), but the majority of high-risk fishes belonged to the family Poeciliidae (three species).

Of all the evaluated fishes, the highest risk score was obtained by *Carassius auratus* (Linnaeus, 1758) from family Cyprinidae, commonly known as goldfish.

DISCUSSION

In total, we identified 1118 traded freshwater aquarium fish species, a number which is slightly higher than that published by Livengood and Chapman (2007), who recognized 1100 species. Our findings emphasize the importance of the Czech Republic as a distribution hub for the aquarium fish trade. Although not all of the fish are continuously present in the Czech Republic, they can be imported upon customer request and redistributed to other European countries.

Gozlan et al. (2010) has suggested that the survival and spread of the majority of aquarium fishes is unlikely throughout the EU due to their ecological and physiological requirements, as they mostly come from tropical or subtropical climates. This was undoubtedly proven by the test of 33 fish species classified as very common on the market. Only 13 species displayed TSEU exceeding 10%.

Within the territory of the EU, such locations are apparently situated in southern European countries. Only one species, *Carassius auratus* (family Cyprinidae), which is tolerant to cold water (Rixon et al. 2005, Kottelat and Freyhof 2007), had TSEU of at least 95% in winter. Traded varieties of goldfish clearly form a genetically monophyletic lineage (Rylková et al. 2010), therefore we analysed *C. auratus* sensu stricto separately from other representatives of the *C. auratus* complex (sensu Takada et al. 2010). The area of lower Yangtze River in China, which is considered as the only source of *C. auratus* for domestication (Rylková et al. 2010, Wang et al. 2013) was used for comparison of climate conditions between the target area (EU) and the region of origin. In contrast van der Veer and Nentwig (2014) in their evaluation used *Carassius auratus* and *Carassius gibelio* (Bloch, 1782) together.

Although the probability of freshwater aquarium fishes being established within the EU is relatively low, their survival during summer is likely (Elvira and Almodóvar 2001, Ellis 2006). Our results show that during the warmest period of the year, aquarium fish are not very much affected by temperature over most of the territory of the EU (Table 1). Twenty-six species out of 33 evaluated showed TSEU of at least 25% in summer, and 8 species had summer TSEU of at least 70%. This may be conducive to short-term survival in natural habitats where aquarium fishes are released by hobby keepers. This finding supports concerns as to possible transfer of novel pathogens into the native fish assemblage through uncontrolled release of infected aquarium fish. This is most likely to happen in areas of high human population density, where higher propagule pressure could be expected (Copp et al. 2005b, Kalous et al. 2013). Go and Whittington (2006) already presented that ornamental gouramis from Southeast Asia are the source of megalocytivirus (Family Iridoviridae) causing losses on native *Maccullochella peelii* (Mitchell, 1838) in Australia.

Human-mediated introduction of pathogens into new areas is recognized as one of the most important factors driving disease emergence in wildlife populations (Daszak et al. 2001). Not much attention has been devoted to possible disease and/or parasite transfer from introduced aquarium fish to local native fishes in Europe even though the problem has already been noted by Peeler et al. (2011).

The presented list of 33 aquarium fish species could be used as a starting point for examining the pathogen control process.

The risk assessment is meaningful only for species with considerable propagule pressure and which may survive winter in the target area. Duggan et al. 2006 proved the existence of the relations between frequency of occurrence of aquarium fishes in shops and likelihood of their introduction and establishment. We therefore evaluated 11 of the most traded aquarium fish species having TSEU of at least 10%. The fishes evaluated as medium risk are: South American catfish, *Corydoras paleatus* (Jenyns, 1842), with the second highest TSEU, reaching 38% in winter, but so far with no records in the wild; south Asian catfish, *Clarias batrachus* (Linnaeus, 1758), with TSEU reaching 24%, already found in England but only in chan-

nels sustained by the heated waters from a power station or dead due to temperature intolerance (Zięba et al. 2010); as well as three cyprinids: *Danio rerio* (Hamilton, 1822); *Tanichthys albonubes* Lin, 1932; and *Trigonostigma heteromorpha* (Duncker, 1904); and two gouramis: *Trichogaster lalius* (Hamilton, 1822) and *Trichopodus leerii* (Bleeker, 1852), with TSEU exceeding 10%.

The highest FISK score among the most common aquarium fishes was obtained by *Carassius auratus*. The evaluation of this fish by FISK as high risk is in accordance with observed reproduction of the species in open waters, e.g., in England and the Iberian Peninsula (Copp et al. 2005c, Ribeiro et al. 2008). Three high-risk species belonged to the family Poeciliidae. *Poecilia latipinna* (Lesueur, 1821) has already been introduced and established in Greece (Papavlasopoulou et al. 2013). In contrast, *Poecilia sphenops* Valenciennes, 1846 has been established only in thermal water springs in Hungary and Romania (Petrescu-Mag et al. 2008), which could reflect its higher temperature demands (see Table 1). The same seems to apply for *Xiphophorus helleri* Heckel, 1848, which is occasionally recorded in Slovakia but is probably not established there (Májsky 2000, Koščo et al. 2010). Interestingly, *Poecilia reticulata* Peters, 1859, which was introduced and established in some regions of Spain (Elvira and Almodóvar 2001), was evaluated by our model as having 0% TSEU, probably pointing to some weaknesses in our approach. While we compared the air temperatures of source and target areas, these do not completely reflect water temperatures (Britton et al. 2010). In addition, the temperature suitability of particular species might not be completely explained by the minimum and maximum air temperatures of the region of origin (Tojo et al. 2010). In any case, several prediction models, including FISK, are based on the same climate data (Bomford 2008, Henderson et al. 2011).

It might be advisable to test also the climate data of regions where fish have been introduced and established, but this approach discriminates against species that have not yet been established outside of their regions of origin or in places which do not correspond to their minimum or maximum temperature suitability. Unfortunately, the scientific literature also lacks information regarding the minimum survival temperature for the majority of aquarium fishes as either adults or larvae. Such information could play an important role in any risk assessment model.

The aforementioned weaknesses notwithstanding, this is the first comprehensive assessment of potential risks of aquarium fish species within the territory of the EU. More detailed studies are needed to evaluate risks within specific areas, where more precise data on water temperature and propagule pressure are available. Although the risk potential of the most traded fishes in the EU seems to be not alarming, attention should nevertheless be directed to the possibility of novel pathogen transfer to native aquatic biota as an important aspect of regulating the aquarium fish trade.

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