

BEAUTIFUL, BUT ALSO POTENTIALLY INVASIVE

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Abstract

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Introduction of non-indigenous exotic species to new areas, where they may establish viable populations and become invasive, is a considerable problem in the protection of nature worldwide, as these species may alter the indigenous species population structure and potentially even decrease the biodiversity. The European fauna underwent through major negative changes on the continent and nowadays, it experiences another new treat, represented by the expanding aquarium pet trade, and with it, associated species (and disease) introductions. Exotic freshwater crustaceans are one of the taxa widely incorporated in the business, counting a remarkable number of species. Recent records of the exotic marbled crayfish or Marmorkrebs (*Procambarus fallax* f. *virginalis*) in German in open ecosystems in Slovakia pointed to human-mediated introductions associated with aquarium pet trade in the country. In this regard, a study of the aquarium pet trade both in expositions and shops and online was assessed. Several crustacean taxa are available both in pet trade exhibitions and online through the Internet. Altogether 26 different species were identified in the aquarium trade in Slovakia. These are *Procambarus fallax* f. *virginalis*, *P. clarkii*, *P. allenii*, *Cherax quadricarinatus*, *C. destructor*, *C. holthuisi*, *C. peknyi*, *Cambarellus patzcuarensis* and *C. diminutus* occurring in the aquarium pet trade in Slovakia ($n = 9$). *Procambarus fallax* f. *virginalis*, *P. clarkii* and *C. patzcuarensis* are the most common in this regard. There is also a quantity of other related taxa in the aquarium pet trade in Slovakia, mainly *Caridina* spp. ($n = 5$), *Neocaridina* spp. ($n = 4$), *Atyopsis moluccensis*, *Atya gabonensis*, *Arachnochium kulsiense* and several taxa of exotic crabs ($n = 5$) belonging to three different genera (*Cardiosoma*, *Geosesarma* and *Gecarcinus*) present. *Neocaridina davidi* is identified as the most frequent in this regard. As some of the species can become established and form viable populations in natural ecosystems in Europe, we alert the public to handle the animals responsibly and thus maintain and protect indigenous European fauna.

Key words: aquarium pet trade, Europe, exotic species, invasions, Slovakia.

Introduction

Global biodiversity is nowadays extremely challenged. Humankind has become a major factor negatively influencing the species richness, affecting nearly every ecosystem on earth. Negative factors associated with human actions can thus be divided into local (e.g. species introductions) and global (e.g. environmental pollution), although local ecosystem disturbances can dramati-

cally extend. One of the main causes of diversity declines are species introductions (Dudgeon et al., 2006). Holding of aquarium species has become very popular in Europe and nowadays is becoming increasingly attractive. There is a rich availability of species in the aquarium pet trade, with extending tendencies in the species assortment and perfection of the service (e.g. online shopping). Availability of ornamental species in the aquarium trade represents a major introduction pathway. Crustaceans in the aquarium trade are not an exception in this regard. Between the most common of the freshwater crayfish in the aquarium trade are mainly crayfish species as *Procambarus fallax* f. *virginalis* (marbled crayfish, also known as Marmorkrebs), *P. clarkii*, *P. alleni*, *Cherax quadricarinatus* and *C. destructor* (Holdich et al., 2009; Chucholl, 2013). This represents only a fraction compared to the general availability of exotic crayfish species in the aquarium trade, for example, counting some 120 different species in Germany (Chucholl, 2013). Recent research of the aquarium trade in Greece revealed availability of eight non-indigenous species, counting *Procambarus clarkii*, *P. alleni* and a few *Cherax* and *Cambarellus* species (Papavlasopoulou et al., 2014). Through online monitoring of the Marmorkrebs in the USA, Faulkes (2013) discovered the availability of the species in 28 American states and in 5 Canadian provinces and Ireland (Faulkes, 2015). In total, 27 crayfish species are advertised and marketed in Czech Republic (Patoka et al., 2014) and 28 different crustacean species are marketed in Turkey (Turkmen, Karadal, 2012). Although crayfish species become a subject of scientific interest, there is sparse data on the related taxa in the aquarium pet trade. To date, 17 non-indigenous crustacean species occur in the inland waters in Slovakia (Lipták, 2013). These species occur here as a consequence of introductions, shipping, aquaculture and interconnection of the waterways. The other front of introductions represents the aquarium pet trade. It is important to note that one-third of the 100 worst invasive species list created by the International Union for the Conservation of Nature are from aquarium pet trade (Padilla, Williams, 2004).

The current study is the first and to date the only study referring to exotic crustacean species in the aquarium pet trade in Slovakia, with a hint for the regulation and control of introduction.

Material and methods

Various aquarium expositions orientated to the pet trade in Slovakia were inspected from September 2013 to June 2014. In addition, major pet markets were examined for crustaceans along the same time period. Decapods were identified in the aquarium containers at the exhibitions by visual observation. The same identification procedure was applied in the pet markets. Additional information on the availability of exotic crustaceans in the country was assessed through the Internet. Each exhibitionist, pet shop or insertion on the Internet was classified as presence and frequency was assessed from the total number of subjects containing exotic crustaceans in their assortment. The data were then sectioned to compare the availability, the frequency and the species spectrum found in expositions and shops, with the species availability, the frequency and the species spectrum identified on the Internet. Thirty subjects (market exhibitionists and pet shops) and 117 insertions on the Internet were identified and evaluated.

Results

Three North American freshwater crayfish species belonging to genus *Procambarus* (Cambaridae), two dwarf crayfish species of the genus *Cambarellus* (Cambaridae) and four species of Australian genus *Cherax* (Parastacidae) were identified in the aquarium trade in Slovakia, counting together nine different species. Five species of exotic crabs belonging to three genera (*Cardisoma*, *Geo-*

Table 1. The exotic species identified in the Slovak aquarium pet trade in 2013–2014.

Species	Authority	Common name	Trade name in SK	Family	Native origin	Introductions known
Freshwater crayfish						
<i>Procambarus jallax</i> f. <i>virginialis</i>	Hagen, 1870	Marbled crayfish	Rak mrnavoraný	Cambaridae	South-Eastern United States	Yes
<i>Procambarus clarkii</i>	Girard, 1852	Red swamp crayfish	Rak červený	Cambaridae	South-Eastern United States	Yes
<i>Procambarus allenii</i>	Paxon, 1884	Florida crayfish	Rak modrý	Cambaridae	South-Eastern United States	Yes
<i>Cherax quadricarinatus</i>	von Martens, 1868	Red claw crayfish	Rak modrý	Parastacidae	Northern Australia, Papua New Guinea	Yes
<i>Cherax destructor</i>	Clark, 1936	Yabby	Rak modrý	Parastacidae	Papua New Guinea	Yes
<i>Cherax holthuisi</i>	Lukhamp and Pekny, 2006	New Guinea crayfish	NA	Parastacidae	Papua New Guinea	Unknown
<i>Cherax peknyi</i>	Lukhamp and Herbert, 2008	Zebra crayfish	Rak zebra	Parastacidae	Papua New Guinea	Unknown
<i>Cambarellus patzcuarensis</i>	Villalobos, 1943	Dwarf orange crayfish	Rak mexický	Cambaridae	Central Mexico	Unknown
<i>Cambarellus dhimutus</i>	Hobbs, 1945	Least crayfish	NA	Cambaridae	Southern United States	Unknown
Freshwater crabs						
<i>Cardisoma armatum</i>	Herklotz, 1851	Rainbow crab	NA	Gecarcinidae	Western Africa	Unknown
<i>Geosesarma notophorum</i>	Peter and Cheryl, 1995	Mandarin crab	NA	Grapsidae	Indonesia	Unknown
<i>Geosesarma bogorensis</i>	Boti, 1970	Vamp crab	NA	Grapsidae	Indonesia	Unknown
<i>Gecarcinus quadratus</i>	de Saussure, 1853	Halloween crab	NA	Gecarcinidae	Central America	Unknown
<i>Gecarcinus ruricola</i>	Linnaeus, 1758	American land crab	NA	Gecarcinidae	Caribbeans	Unknown
Freshwater shrimp						
<i>Atyopsis moluccensis</i>	De Haan, 1849	Bamboo shrimp	NA	Atyidae	Malaysia	Unknown
<i>Atya gabonensis</i>	Giebel, 1875	Vampire shrimp	NA	Atyidae	West Africa	Unknown
<i>Anachochium kulstense</i>	Jayachandran, Lal Mohan and Raji, 2007	NA	NA	Palaemonidae	India	Unknown
<i>Caridina babaulti</i>	Bouvier, 1918	Green shrimp	NA	Atyidae	Little Asia	Unknown
<i>Caridina brevia</i>	N.K. Ng and Cai, 2000	Bumble bee shrimp	NA	Atyidae	Small stream near Zhapu Village	Unknown
<i>Caridina cantonensis</i>	Yu, 1938	Crystal red	NA	Atyidae	Southern China	Unknown
<i>Caridina multidentata</i>	Simpson, 1860	Amama shrimp	Krevetka japonská	Atyidae	East Asia	Unknown
<i>Caridina propinqua</i>	De Man, 1908	Mandarin shrimp	mandarinlová	Atyidae	Peninsular Malaysia, Singapore, Brunei	Unknown
<i>Neocaridina davidi</i>	Bouvier, 1904	Red cherry	NA	Atyidae	East and central China	Yes
<i>Neocaridina denticulata</i>	De Haan, 1844	Green neon shrimp	NA	Atyidae	East Asia	Unknown
<i>Neocaridina palmata</i>	Shen, 1948	NA	NA	Atyidae	Southern China	Unknown
<i>Neocaridina zhongjiaoensis</i>	Cai, 1996	White pearl, Blue pearl	NA	Atyidae	Human and Guangdong provinces (China)	Unknown

Table 2. The availability and frequency of the identified species in the Slovak aquarium pet trade in 2013–2014 (0.0–0.25 very rare, 0.25–0.50 rare, 0.50–0.75 common, 0.75–1.0 very common).

Species	Online availability	Expositions and shops availability	Total availability	Online frequency	Status	Expositions and shops frequency	Status	Total frequency
Freshwater crayfish								
<i>Procambarus fallax</i> f. <i>virginalis</i>	26	9	35	0.22	Very rare	0.3	Rare	0.238
<i>Procambarus clarkii</i>	7	9	16	0.06	Very rare	0.3	Rare	0.109
<i>Procambarus alleni</i>	1	2	3	0.009	Very rare	0.067	Very rare	0.02
<i>Cherax quadricarinatus</i>	4	1	5	0.034	Very rare	0.033	Very rare	0.034
<i>Cherax destructor</i>	NA	1	1	0	Not available	0.033	Very rare	0.007
<i>Cherax holthuisi</i>	1	NA	1	0.009	Very rare	0	Not available	0.007
<i>Cherax peknyi</i>	NA	1	1	0	Not available	0.033	Very rare	0.007
<i>Cambarellus patzcuarensis</i>	8	13	21	0.068	Very rare	0.433	Rare	0.143
<i>Cambarellus diminutus</i>	3	7	10	0.026	Very rare	0.233	Very rare	0.068
Freshwater crabs								
<i>Cardisoma armatum</i>	1	1	2	0.009	Very rare	0.033	Very rare	0.014
<i>Geosesarma notophorum</i>	2	1	3	0.017	Very rare	0.033	Very rare	0.02
<i>Geosesarma bogorensis</i>	NA	1	1	0	Not available	0.033	Very rare	0.007
<i>Gecarcinus quadratus</i>	NA	1	1	0	Not available	0.033	Very rare	0.007
<i>Gecarcinus ruricola</i>	NA	1	1	0	Not available	0.033	Very rare	0.007
Freshwater shrimp								
<i>Atyopsis moluccensis</i>	2	8	10	0.017	Very rare	0.267	Rare	0.068
<i>Atya gabonensis</i>	1	2	3	0.009	Very rare	0.067	Very rare	0.02
<i>Arachnoidium kuldsense</i>	1	NA	1	0.009	Very rare	0	Not available	0.007
<i>Caridina babaulti</i>	2	NA	2	0.017	Very rare	0	Not available	0.014
<i>Caridina breviata</i>	1	NA	1	0.009	Very rare	0	Not available	0.007
<i>Caridina cantonensis</i>	8	9	17	0.068	Very rare	0.30	Rare	0.116
<i>Caridina multidentata</i>	1	8	9	0.009	Very rare	0.267	Rare	0.061
<i>Caridina propinqua</i>	NA	1	1	0	Not available	0.033	Very rare	0.007
<i>Neocaridina davidi</i>	36	19	55	0.308	Rare	0.633	Common	0.374
<i>Neocaridina denticulata</i>	2	NA	2	0.017	Very rare	0	Not available	0.014
<i>Neocaridina palmata</i>	3	1	4	0.026	Very rare	0.033	Very rare	0.027
<i>Neocaridina zhangjiajiensis</i>	1	7	8	0.009	Very rare	0.233	Very rare	0.054

sesarma and *Gecarcinus*) were identified. Freshwater shrimp species were represented by 12 different species belonging to five genera (*Atyopsis*, *Atya*, *Arachnochium*, *Caridina* and *Neocaridina*). Altogether 26 species (Table 1) are identified in the aquarium trade in Slovakia, from which *Procambarus fallax* f. *virginalis*, *Cambarellus patzuarensis* and *Neocaridina davidi* are the most common. Altogether, 21 different species were identified in expositions and pet shops together, and 20 species were recorded online on the Internet (Table 2). Except crustaceans, a vast number of other potentially invasive taxa (e.g. molluscs) were observed at each exhibition and pet shop. Although there is a high selection of species both found online or in expositions and shops (Fig. 1), there is much higher frequency of the species available through the expositions and pet shops (Fig. 2). This is mainly because online availability is most commonly oriented to just one species, where one insertion represents a single species.

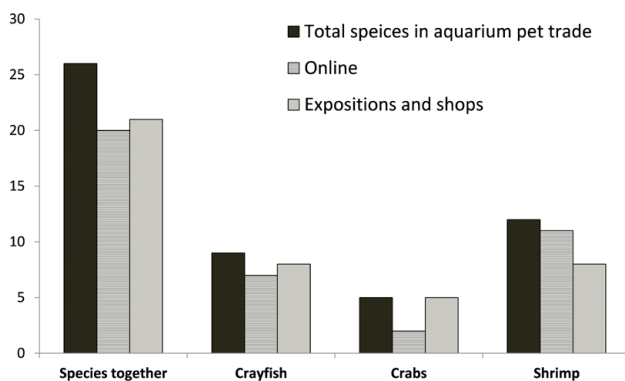


Fig. 1. The overview of species, which have occurred in the aquarium pet trade in Slovakia in 2013–2014.

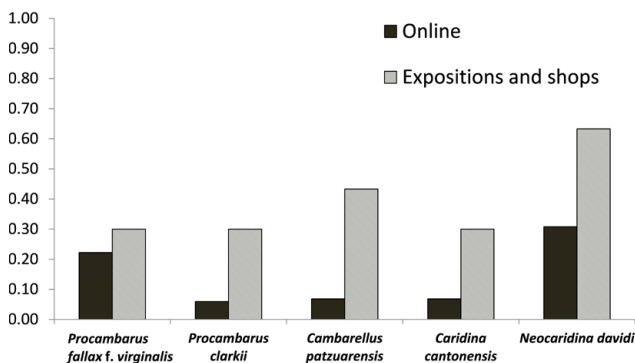


Fig. 2. The frequency of the most available species in the aquarium pet trade in Slovakia in 2013–2014.

Discussion

There is a considerable number of exotic (and potentially invasive) species that are identified in the aquarium pet trade in Slovakia. This potential species invasiveness and disease introduction highlights the reverence of deliberate introductions mediated through the owners and breeders. Owners of these exotic species must pay special attention as they represent a high likely introduction pathway. Occasional releases of exotic species should not be practiced or encouraged. Managing this problem by dissemination of relevant information should be one of the priorities in order to prevent deliberate introductions of exotics. Regulation through the legislation still remains incomplete. In this regard, education on the matter should be promoted by the legislation

binding the provider and the appropriate ministry. A law should be enacted to introduce obligatory educational programmes by specialists to ornamental species providers to further educate the aquarium enthusiast.

There are already several records of releases of the non-indigenous crayfish species associated with the aquarium trade discovered in Europe. The first record of the marbled crayfish originates in Germany, where the specimen was found near the Rhine River in 2003 (Marten et al., 2004). Further records of the species came from Saxony (Germany) at a lowland brook belonging to the Elbe River basin in 2009 (Martin et al., 2010) and the lake Moosweiher near Freiburg (upper Rhine catchment) (Chucholl, Pfeiffer, 2010). Currently, there are 16 records of marbled crayfish in Europe, with the majority of records from Germany (Chucholl et al., 2012; Bohman et al., 2013).

The red swamp crayfish *Procambarus clarkii* is considered an old non-indigenous invasive crayfish species (Holdich et al., 2009). The species is already widely distributed in some regions of Europe, mainly in its western parts. Spain and Portugal are the most widely colonised. Except this distributional concentration, the species occur in France, Italy, Germany, United Kingdom, Belgium, the Netherlands, Austria and Switzerland (Holdich et al., 2009). The red swamp crayfish was first introduced in Europe in 1973 in Spain in an attempt to enhance the commercial production of crayfish. Intentional releases of the species continued further, and reached even the Azores, Canaries and Hawaii (Souty-Grosset et al., 2006; Gherardi, 2006). The species is currently listed in the top 100 worst invasive species in Europe (Delivering Alien Invasive Species Inventories for Europe, 2010). Even though the species is considered to be restricted to warmer waters, *P. clarkii* flourish in the colder climates at higher altitudes equally successfully (Chucholl, 2011).

Except these, several additional crayfish species occur in the wild. *Cherax destructor* occurs at one site in central Italy, with established sustaining population, discovered in 2008 (Scalici et al., 2009) and *Orconectes immunis* occurs in Germany from Strasbourg to Mannheim in the Rhine River, discovered in the mid-1990s (Schrumpf et al., 2013). There are also *Cherax quadricarinatus*, *Orconectes juvenilis*, *O. virilis*, and *Procambarus acutus* populations present in the ecosystems of Europe (Kouba et al., 2014).

North American crayfish species are well known crayfish plague carriers (Söderhall, Cerenius, 1999). Recent studies reported the crayfish plague pathogen in nine different crayfish species in the aquarium pet trade (Mrugała et al., 2015). The crayfish plague pathogen was even detected in wild marbled crayfish populations in Germany (Keller et al., 2014). North American crayfish species thus represent a potential for disease entry pathway into Europe.

Although freshwater crayfish species successfully established viable population under European climatic conditions, still, data on the occurrence of other related crustacean taxa in the wilderness or urbanised areas of Europe remains absent. So far, there is no record of such presence documented, although thermally polluted waters are suggested to support their occurrence. There is only one record of the occurrence of the exotic freshwater shrimp in the European wild, located in Germany. The species was identified as *Neocaridina davidi* occurring in Gillbach and Erft river and *Macrobrachium dayanum* found in Gillbach River, located west of Cologne City in North Rhine-Westphalia in 2012 (Klotz et al., 2013). Due to low water temperature tolerance of *N. davidi*, there is a hypothesis it could extend further in the region and even reach the Rhine River in the future. Recent research postulated evidence that freshwater shrimp (Svoboda et al., 2014a) and crab (Svoboda et al., 2014b) species can also become crayfish plague carriers, which suggest a

possible new transmission pathway of the zoospore of this disease. Schrimpf et al. (2014) already confirmed that Chinese mitten crab (*Eriocheir sinensis*), a highly migratory species penetrating freshwaters up to a distance of several hundred kilometres, serves as a vector of crayfish plague pathogen, transmitting the disease to susceptible noble crayfish (*Astacus astacus*). Thus, freshwater shrimps and crabs in the aquarium trade should also be considered as potential crayfish plague reservoirs and handled with care also.

Exotic aquarium pet trade species have a high introduction risk and represents a new risk factor for nature. This new risk is enhanced by the ever increasing assortment of exotics in the aquarium pet trade and absence of its control and regulation. Areas with higher density of the human population, with higher gross domestic product and growing socio-economic aspects are the introduction risk hotspots (Perdikaris et al., 2012; Chucholl, 2014). The aquarium species selected are easy to breed, favour the common conditions of aquariums and thus, are generally more tolerant, increasing the chances of an establishment when introduced. As the species tolerance to general conditions increases, it increases the possibility to establish a viable reproducing population (if introduced to favourable conditions) and potentially expand in its new environment. Introduction of the marbled crayfish in Slovakia is a good example to introductions mediated *via* the aquarium enthusiast. And Slovakia is, we believe, another of the countries in centre of these potentially troubling events of the ever-changing nature and consequences of human impact.

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