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Invasive Potential of Pet-Traded Pill-Box Crabs from Genus *Limnopilos*

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Abstract: The pet trade in aquatic animals is known to be one of the main sources of non-native species worldwide. Freshwater decapod crustaceans have increased in popularity as ornamentals in the last two decades. Freshwater crabs of the genus *Limnopilos* were discovered by hobby aquarists and introduced on the market in 2008. They are generally considered interesting additions to an aquarium, but information about their living requirements are scarce. Additionally, their invasive potential is not known. Here, we present a survey of the availability of *Limnopilos* crabs on the market in Europe and North America and analyzed the invasive potential of all species from the genus based on climate matching from a global perspective. The only species recorded in the pet trade is *L. naiyanetri,* but future introduction of other species is discussed. Certain tropical regions were identified as the most suitable for the potential establishment of *Limnopilos* crabs including the northern part of South America, and *L. microrhynchus* was evaluated as the highest risk species. In this pilot study, we also suggest some points to be answered regarding further improving the risk assessment and also recommend continuous monitoring of the market for ornamental decapods.

Keywords: aquarium; ornamental aquaculture; Decapoda; Brachyura; Hymenosomatidae; risk assessment; ecology; climate matching

1. Introduction

Biological invasions, a pervasive component of global change, are perceived as an increasing threat to biodiversity worldwide [1]. An important vector of non-indigenous species is the international trade in aquarium animals [2] and the popularity of this sector of aquaculture is growing annually [3–5]. Not only are fish popular pets in ornamental aquaculture, but decapod crustaceans have also become relatively commonly traded in the past two decades [6–8].

Numerous records of non-indigenous decapods introduced via the pet trade are known from various regions over the globe; for instance, crayfish such as redclaw *Cherax quadricarinatus* [9,10], marbled crayfish *Procambarus virginalis* [11,12], Mexican dwarf crayfish *Cambarellus patzcuarensis* [13], and freshwater shrimps such as the red cherry shrimp *Neocaridina davidi/heteropoda* [14–16] and Kaira river prawn *Macrobrachium dayanum* [15]. Generally, invasive decapod crustaceans can outcompete native species and alter habitats, and certain species serve as a vector of infectious diseases, especially

crayfish plague caused by the oomycete *Aphanomyces astaci*. The presence of this pathogen has been confirmed in ornamental crayfish, and in some cases, also in crabs and shrimps [17–19]. The sensitivity of the above-mentioned non-crayfish decapod hosts is currently under research.

There are several tens to hundreds of freshwater and land-dwelling crab species traded as ornamentals internationally (Radosta, O., pers. comm. 2019), but a detailed survey of the market is still lacking, with few reports on local trade [20–22]. Recently, the traded crab species have increased in number and are exported via the pet trade to Europe, East Asia, and the USA [23]. In 2008, the small crab *Limnopilos naiyanetri* was imported from Thailand to Germany and introduced to the market by the wholesaler Aquarium Glaser GmbH (see https://www.aquariumglaser.de/en/fish-archives/limnopilos-naiyanetri/). The genus *Limnopilos* (family Hymenosomatidae) was scientifically described in 1991 [24], later synonymized with genus *Hymenicoides* [25], and in 2007 resurrected as *Limnopilos* in light of the fact that several distinctive characters were identified [26]. Due to their tiny size (less than 1 cm in diameter), *Limnopilos* crabs are also called pill-box crabs, Thai micro crabs, or false spider crabs.

The genus *Limnopilos* is endemic to South-East Asia and includes three species: *L. microrhynchus*, *L. naiyanetri*, and *L. sumatranus*. *Limnopilos microrhynchus* has been described from eastern Kalimantan, Indonesian Borneo, and from Sabah, Malaysian Borneo [27]. The second mentioned species, *L. naiyanetri*, is native to Thailand, where the first individuals were found inhabiting the root systems of non-native water hyacinths [24,28]. The last species, *L. sumatranus*, is native to central Sumatra [26].

Limnopilos crabs have generally been poorly studied and detailed information about their biology, ecology, and ethology is not available including information about their reproduction. When their zoea larvae hatch, they apparently develop in fresh water (Ng P., pers. comm. 2019). Since these crabs are probably freshwater for their whole life cycle, they are attractive for hobby keeping. Even though they have attracted the attention of traders and keepers, the presented information about their life requirements is confused in many aspects (see https://www.fishkeeper.co.uk/databank/thai-micro-spider-crab).

The legislative regulations and restrictions focused on aquatic pets are ineffective in many cases [29]. Hence, the importance of preventing the new introduction of identified high-risk species is obvious. For this reason, we have decided to survey the availability of *Limnopilos* crabs on the market and analyze the invasive potential of all three species based on climate matching from a global perspective.

2. Materials and Methods

2.1. Data Collection

Information about *Limnopilos* crabs within the pet trade, their availability, and origin was collected between November 2018 and February 2019. In total, lists offered by online shops in various countries in North America and Europe, the main importers in ornamental aquarium species, were surveyed. The links were found using the standard search engine Google with "*Limnopilos*" or "Micro crab" as keywords and verified by email correspondence with the owners or live-stock managers.

2.2. Market Availability

Market availability was estimated for each species according to [30], using the following criteria: (i) "very rare"—species available only for a short period and in small quantities; (ii) "rare" species—available occasionally in small quantities; (iii) "common" species—available frequently in small quantities; and (iv) "very common" species—always available in large quantities. Although we are aware of the heuristic aspect of this method, it is applicable for a rough estimate of species availability in the market [31,32].

2.3. Species Determination

We obtained 20 live crabs from one wholesale facility for aquatic ornamental animals in Slovakia and 100 individuals from one wholesaler in the Czech Republic. The origin of crabs from Slovakia is

unclear and were most probably imported from Thailand, which is the verified origin for crabs obtained in the Czech Republic. Selected individuals were morphologically examined following characteristics such as the absence of rostrum and setose claws described in [24] and [26] as *L. naiyanetri*.

2.4. Climate Matching

Climate matching was modeled from a dataset of environmental layers and native range of *Limnopilos* crabs. Environmental layers were obtained from the WorldClim database (v.1.4; http://www.worldclim.org; [33]) with a spatial resolution of 2.5 arcmin (~1 km^2) and were assembled in DIVA-GIS (v.7.5.0; http://www.diva-gis.org; [34]) to the ASCII format for use with the MaxEnt algorithm (v.3.4.1; https://biodiversityinformatics.amnh.org/open_source/maxent; [35]). MaxEnt is a maximum entropy model well-suited for species distribution mapping [36,37]. The model describes a continuous probability surface of habitat suitability in the target area. The final set of bioclimatic predictors comprised the mean diurnal temperature range (BIO2), isothermality (BIO3), temperature seasonality (BIO4), temperature annual range (BIO7), and mean temperature of the wettest, driest, warmest, and coldest quarter of the year (BIO8-11). The native range of the evaluated species was obtained from validated published records (five locations for *L. microrhynchus*, eight locations for *L. naiyanetri*, and seven locations for *L. sumatranus*). Even if all known localities with the native occurrence of the species were included in the analysis, it must be noted that the amount of data (five to eight points) was relatively low and thus the results must be perceived as a preliminary study. Additionally, MaxEnt calculates a threshold value at each run. As the cumulative output, a continuous map was generated for each evaluated species. This map output allows for a fine distinction to be made between the modeled suitability of different areas for the evaluated species.

3. Results

We found just one pet-traded species of *Limnopilos* crabs: *L. naiyanetri*; its determination was verified morphologically. This species was common (available frequently in small quantities) in Germany and rare on the market (occasionally available in small quantities) in the following countries: Belgium, Canada, Czech Republic, Denmark, France, Greece, Hungary, Italy, Netherlands, Poland, Romania, Serbia, Slovakia, Spain, Sweden, Ukraine, United Kingdom, and the USA. The size class of the marketed crabs was less than 1 cm in carapace width.

Climatic conditions, here represented by various temperature predictors, do not appear to constrain the spread of *Limnopilos* crabs in certain tropical regions if they are introduced. The most adaptable species seems to be *L. microrhynchos*, followed by *L. naiyanetri*; *L. sumatranus* was evaluated as the least adaptable species. The most suitable regions for the potential establishment of *L. microrhynchus* were identified as northern South America with a part of the Amazon River Basin and part of Southeast Asia, with a lesser extent in a dozen kilometer band taking in part of the coast of south India and Sri Lanka, around the Red Sea (in Eritrea and Saudi Arabia), and the Gulf of Guinea (Figure 1).

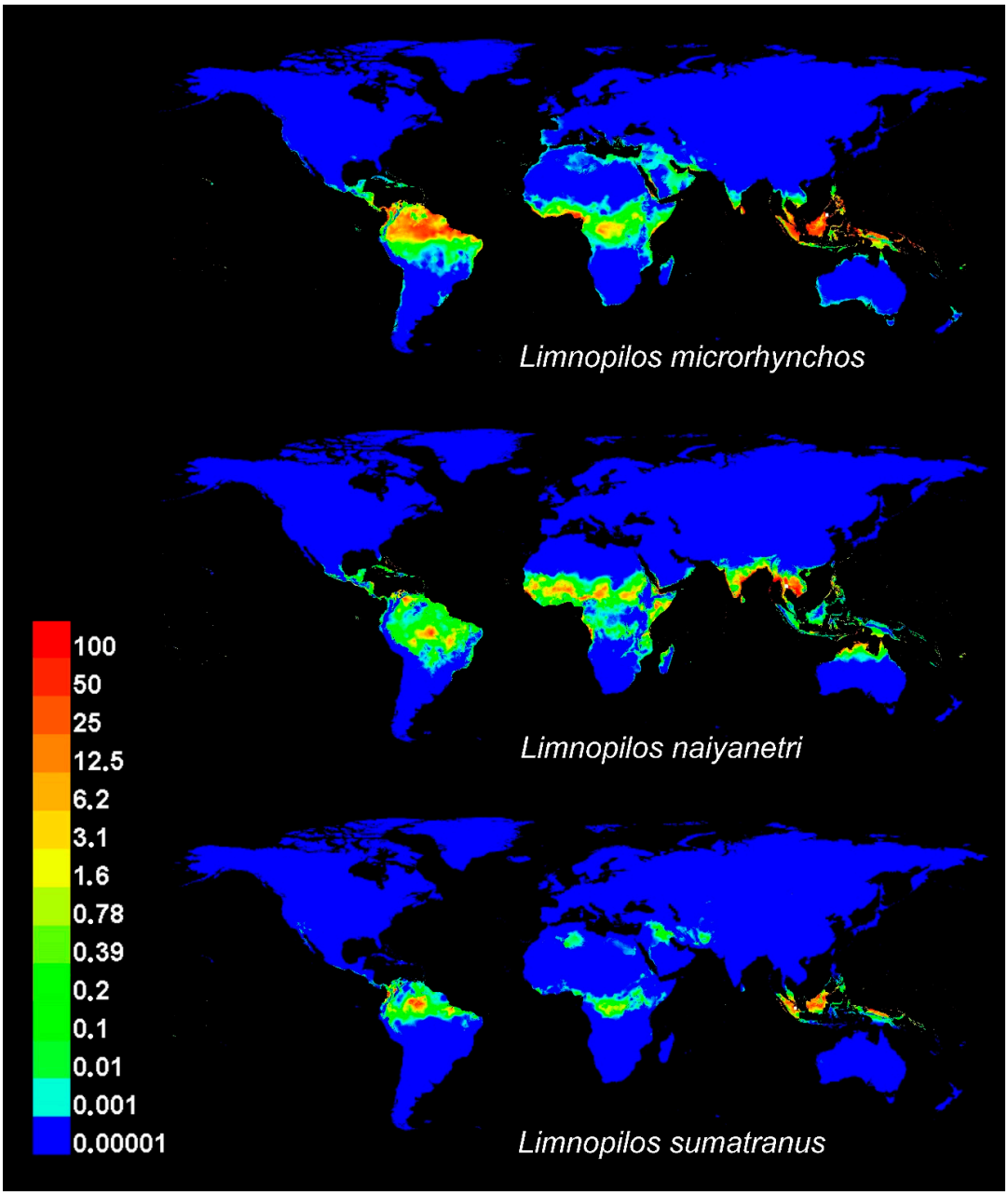

Figure 1. Worldwide environmental suitability for *Limnopilos* crabs (*L. microrhynchus*, *L. naiyanetri*, and *L. sumatranus*) based on environmental predictors in the MaxEnt model. Suitability is shown in different colors representing the percentage value, with red indicating the highest probability of establishment (100%).

4. Discussion and Conclusions

The climate matching analysis showed the potential risk of the establishment of *Limnopilos* crabs at new localities outside their native range, with the highest probability in parts of South America and Southeast Asia. Of all three scientifically described species of *Limnopilos* crabs, we found just *L. naiyanetri* to be offered for sale as an ornamental creature via the pet trade. It is traded in numerous European countries as well as in the USA and Canada, but is usually not frequently available and stocked in pet shops and wholesalers, with the exception of the German market. This species is not as adaptable as its congener, *L. microrhynchos*, which is currently not pet-traded.

Species of the family Hymenosomatidae are the smallest freshwater crabs on the world [38]. *Limnopilos* crabs are traded in tiny sizes and can be easily overlooked and their accidental release with waste water from aquaria is possible (especially when there are high densities in the tank). Moreover, these crabs have been found hidden among floating water hyacinths (*Eichhornia crassipes*) [28]. Since this plant is known to serve as a medium for the translocation of various animal taxa via ornamental aquaculture [39], one can expect that unintentional translocation by this pathway is possible. It follows that the risk of the introduction of pet-traded *Limnopilos* crabs does exist.

One of the most susceptible regions for the potential establishment of *Limnopilos* crabs is the northern part of Brazil, a country with a well-developed trade in ornamental aquatic species. This fact should be of concern to local wildlife managers and policymakers. Even if this country has a prominent place in global biodiversity, covering a huge diversity of biomes and species, the Brazilian government has initiated activities that threaten biodiversity and entire ecosystems [40]. Among others, their legislation supports the production and trade of numerous ornamental freshwater species despite their nativeness [29]. Although no *Limnopilos* crabs have been recorded as traded in Brazil, their future introduction on the market cannot be excluded due to the high popularity and the increasing economic importance of this sector of aquaculture there.

All three species are native to countries that are among the main suppliers of ornamental freshwater species in the world. Although *L. naiyanetri* is currently the only found pet-traded species from the genus, exploitation of both *L. microrhynchus* and *L. sumatranus* for ornamental purposes is also likely. Both species have native ranges within Indonesian territory. Since Indonesia has been identified as one of the leading suppliers of ornamental freshwater crustaceans [7], we assume that the increasing popularity of *Limnopilos* crabs in hobby keeping will lead to field harvesting and the subsequent advertising of yet unexploited species for sale. The species identification is not easy even for crustacean experts (see the key to the species in [29]). Due to this fact and in line with previously identified behavior of traders who frequently advertise ornamental species under misnomers, names of other species, outdated names, or only by commercial names [30,41], species misidentification is likely if and when *L. microrhynchus* and *L. sumatranus* are introduced on the market.

To improve the risk assessment, we suggest that at least the following three queries are considered and answered: (i) Are there any symbionts? Nothing is known about the biota associated with *Limnopilos* crabs, but tiny symbionts such as rotifers and temnocephalidans are known to be transported via the pet trade associated with their decapod hosts [42]; (ii) Are *Limnopilos* crabs truly freshwater? *Limnopilos* crabs release free-moving larvae, and these larvae apparently develop in freshwaters, but this assumption must be confirmed; and (iii) Are *Limnopilos* crabs sensitive or resistant to crayfish plague? There are also three possible scenarios: they are either sensitive to this disease; they are resistant vectors of the pathogen; or they are resistant and do not serve as vectors of the pathogen. Further experiments are needed to test these hypotheses.

All traded *Limnopilos* crabs, despite their trade names, should be brought to the attention of wildlife managers and other stakeholders in the regions evaluated as suitable for their establishment, and detailed risk assessments from local perspectives are recommended together with subsequent monitoring of the market for ornamental decapods. For the increasing reliability of the analyses, a further survey of the native range of *Limnopilos* crabs is crucial.

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