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Research Letters

Assessing the risk of invasion of species in the pet trade in Brazil

Clarissa Alves da Rosa[a,*], Rafael Zenni[b], Sílvia R. Ziller[c], Nelson de Almeida Curi[b], Marcelo Passamani[b]

[a] *Instituto Fauna Selvagem, Rua 3600, N° 232, 88330-248 Balneário Camboriú, Santa Catarina, Brazil*
[b] *Programa de Pós-Graduação em Ecologia Aplicada, Setor de Ecologia, Departamento de Biologia, Universidade Federal de Lavras, Campus Universitário, 37200-000 Lavras, Minas Gerais, Brazil*
[c] *Instituto Hórus de Desenvolvimento e Conservação Ambiental, Servidão Cobra Coral, 111 – Campeche, 88.063-513 Florianópolis, SC, Brazil*

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Biological invasions are a major concern for biodiversity conservation. The release and escape of pet animals are the main sources of mammal invasions. Identifying potential invaders before they are introduced is a key tool for preventing the spread and impact of invasive alien species. Among the tools available for screening potential invaders are risk analysis protocols, which can also be used to assess the risk of species introduced in the past and limit or ban their import or commerce. We aimed to identify potential invasive mammals in the pet trade by applying a risk analysis protocol adapted to Brazil. Six alien mammals sold as pets in Brazil resulted high invasion risk. Rodents resulted the highest risk values. In order to prevent the release of invasive species through the pet trade it is necessary to avoid new introductions based on risk analysis, to identify species pathways, and to combat animal trafficking.

Introduction

Invasive alien species are one of the major global threats for the conservation of biodiversity (Pyšek et al., 2012). The majority of invasive alien species in natural areas (Pyšek et al., 2012) are plants introduced for horticulture, forestry, or agriculture (Zenni, 2014). Similarly, many animal species were introduced for human use (e.g. food, labor, pets, hunting) and are now widespread (Long, 2003). Invasive alien species of both fauna and flora disrupt organism interactions and ecosystem processes (Blackwell, 2005; Clout and Russell, 2007) and are associated with more than half of the contemporary species extinctions worldwide (Doherty et al., 2016; Pyšek et al., 2012).

The most cost-effective way to avoid impacts of biological invasions is to prevent the introduction of species that have invasive potential, and, once they have been introduced, to prevent their release or escape from captivity or cultivation (IUCN, 2000). Risk analysis protocols are relevant tools used for screening potential invasive species which provide opportunities to avoid the introduction of high-risk species (Bomford, 2008; Nentwig et al., 2010; Parker et al., 1999). Invasive species risk assessments are often criticized for being incomplete, insufficient and/or ineffective (Simberloff, 2005). However, there are currently no other more cost-effective and precise method to identify potential risks, rank them, and support decision-making (Bueno et al., 2015; Lodge et al., 2015; Nentwig et al., 2010). Additionally, risk assessments have been shown to be over 85% accurate in detecting invasive species (Pheloung, 1995) and have been used with success to evaluate invasive plants for import in Australia (Keller et al., 2007), brown tree snake introductions to Hawaii (Burnett et al., 2012) and for reducing aquatic invasions from ballast water (Bailey et al., 2011). The protocols are based on species traits that have shown to be consistent predictors of biological invasion (National Research Council, 2002). The protocol may be adapted to different geographic realities, especially by adjusting climate similarities between the area of origin, other areas where the species is invasive, and the area of introduction (e.g. Bomford, 2008; Nentwig et al., 2010).

Species life-history traits (body mass, reproductive rate, diet, home range, and behavior) and characteristics of both the native and recipient habitats (resource diversity, presence of predators, competitors and parasites, and climate) complementarily drive invasion success or failure (Mooney et al., 2005; Prenter et al., 2004; Zenni and Nuñez, 2013). These traits act in all steps of the invasion process (transport, release/escape, establishment, and spread) with

* Corresponding author.
E-mail address: alvesrosa_c@hotmail.com (C.A. da Rosa).

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effects on survival and reproduction rates of invading populations (Blackburn et al., 2011; Zenni et al., 2016a). For instance, generalist species of mammals have high reproductive rates, wide physiological tolerance, and broad diet, having become successful invaders worldwide (Clout and Russell, 2007; Long, 2003).

The illegal market of global pet trade is a worldwide source of alien species and a growing threat to biodiversity (e.g. Bermudez et al., 2014; García-Díaz et al., 2014; Petrossian et al., 2016). In Brazil, pet trade was the source of 70% of identified invasions by mammal species in the past 30 years due to intentional release or escape from breeding grounds (Rosa et al., 2017). The aim of our work was to distinguish potential mammal invaders in the Brazilian pet trade by using a risk analysis protocol adapted to Brazil.

Materials and methods

We searched the Internet for alien mammals for sale in Brazil to compile a list of species whose potential risk of invasion would be assessed. Searches with the terms "pet shop," "animais exóticos" (alien animals), "venda" (sale), and "loja" (store, shop) were carried out via Google. From 448 pet sellers obtained from search results we compiled a list of physical and virtual stores regularized to sell pets ($N = 23$), which we believe offer the main demands of pets in Brazil. We assessed the non-native mammals of Brazil sold as pets in each store and analyzed the species available from pet stores that have established (*sensu* Blackburn et al., 2011) alien and feral populations in any country according to Long (2003).

The risk analyses were conducted using the protocol adjusted to Brazil by the Horus Institute for Environmental Conservation and Development (Pereira and Ziller, 2011). The protocol, available in Portuguese and English, was provided at no cost by the Horus Institute upon request with instructions for use. Minor changes were made to the protocol from the Australian model (Bomford, 2008), which did not include climate matching, but does include a question on potential predation in the area of introduction. Although Brazilian ecosystems might include a wider range of potential predators, this question is nearly always negatively answered, as predation has not been found to be effective in controlling invasive populations.

The protocol is a 39 question scoring system that rates the risk of invasion based on species ecological and biological traits, history of introduction in other countries, potential impacts, and feasibility of control (Pereira and Ziller, 2011). We started gathering data by compiling the information provided by Long (2003), then extracted information from the ISI Web of Knowledge using species names as search terms. Because we were interested in all aspects of the biology and ecology of the species and because invasive alien species often change behavior in sites of introduction, information from studies in both native and alien environments where the species occur were considered. In total, we found 111 useful scientific papers (see Online Appendix A). Some questions of the protocol concern public policies, so we also sought information on Brazilian legislation (Ordinance IBAMA 93/1998 and Normative Instruction IBAMA 07/2015) and employees of governmental agencies. All risk analyses were conducted by the same assessor based on scientific evidence, avoiding bias created by personal expertise (Turbé et al., 2017).

A risk analysis is valid when at least 70% of the questions are answered in each of four sections in the protocol: (1) biological and ecological traits, (2) biogeographic features, (3) social and economic issues, and (4) characteristics that represent high risk (Online Appendix A). The final risk rating is calculated based on the scores attributed to each answer, which vary according to the relevance and consistency of each question/feature in contributing to invasion success. The final rating indicates the risk of a species becoming invasive if released in nature or in specific habitat types. The scale of values was maintained from the original protocol (Bomford, 2008). Questions are given different weight based on three levels of impact: high (5 points), medium (3 points) or low (1 point). These weights were set according to the potential competitive advantage of species traits if introduced in an ecosystem (e.g. species able to live in habitats with a wide spectrum of changes in temperature and/or humidity – question 4.03 – may have strong competitive advantage, so potential impact is considered high). The questions on "biogeographic aspects" are attributed high impact values because propagule pressure along with history of invasion, are the most consistent predictors of invasion to date (Lockwood et al., 2005). If one species is subjected to repeat introductions (question 5.01) the greater the propagule pressure (5 points) and the greater is the chance of establishment and invasion. If a species is already established in some other location (question 5.02) higher values are assigned (7 points). If the species has a history of invasion elsewhere (question 5.05), 10 points are added. Because mammals are generally successful invaders globally, they receive the highest risk score among terrestrial vertebrates (5.5 points). Overall risk can be rated as very low (total score below 11 points), low (total score between 11 and 32 points), moderate (total score 32 and 45 points), high (between 45 and 65 points) or very high (total score above 65 points to a maximum of 150 points) (Pereira and Ziller, 2011). More than 50 assessments were conducted to adjust the level of risk based on species already known to be invasive or unable to invade and previous evaluations of the protocol estimated a precision of 90% in correctly identifying species that have become invasive in Brazil and species that never established or invaded (Pereira and Ziller, 2011).

Results

Eight mammal species available for purchase on the Internet matched our search criteria, however two species already assessed are the European polecat *Mustela putorius* (Eurasia) and the wild rabbit *Oryctolagus cuniculus* (Europe) (Horus Institute, 2017). Risk analyses were carried out for six species: hedgehog *Erinaceus europaeus* (Eurasia), skunk *Mephitis mephitis* (North America), gerbil *Meriones unguiculatus* (Eastern Asia), sugar glider *Petaurus breviceps* (Australia-Indonesia), chipmunk *Tamias sibiricus* (Asia) and stoat *Mustela ermine* (Eurasia and North America). The results of the assessments for all six species resulted in very high risk of invasion, with rodents assessments generating the highest scores (Table 1). The biogeographical features generated the same value of risk (27 points) for all species (Table 2).

The ecological and biological traits (e.g. high reproductive capacity, generalist feeding habits, and wide tolerance to temperature variation and human-modified habitats) of herbivorous and omnivorous species (hedgehogs, sugar glider, chipmunk and gerbil) summed 30–35 points, representing more than 30% of the final score in the risk analysis of each species (Table 2). Characteristics

Table 1
Risk analysis of mammal species sold by pet shops in Brazil that are potential invasive species in the country. Potential risk is divided into five categories: very low (values less than 11 points), low (values between 11 and 32 points), moderate (values between 32 and 45 points), high (between 45 and 65 points) and very high (values above 65 points and a maximum of 150 points) (Pereira and Ziller, 2011).

Species	Questions answered	Points	Risk analysis	Source
Erinaceus europaeus	34	81.5	Very high	Our work
Tamias sibiricus	33	82.5	Very high	Our work
Meriones unguiculatus	34	88.5	Very high	Our work
Petaurus breviceps	34	71	Very high	Our work
Mephitis mephitis	31	79	Very high	Our work
Mustela erminea	31	73	Very high	Our work

Table 2
Point values for each of the four sections of traits in the risk analysis protocol for the species assessed.

	Erinaceus europaeus	*Tamias sibiricus*	*Meriones unguiculatus*	*Petaurus breviceps*	*Mephitis mephitis*	*Mustela erminea*
Biological and ecological traits						
Reproductive mechanisms	13	13	18	13	3	8
Food group	4	5.5	6.5	3.5	5	4
Ecological interactions	5.5	5.5	2.5	5.5	4.5	6.5
Habitat	8	8	8	8	11	8.5
Total	30.5	32	35	30	23.5	27
Biogeographic features						
Occurrence	27	27	27	27	27	27
Total	27	27	27	27	27	27
Social and economic features						
Economic importance of the taxon	6	6	11	1	6	1
Risk to people	1	1	1	1	5.5	2.5
Total	7	7	12	2	11.5	3.5
Characteristics that represent high risk						
Contamination by pathogens and parasites	5.5	5	5	5	10	5.5
Attributes of persistence	13.5	13.5	9	9	9	12
Social actors involved	3.5	3.5	6	3.5	3.5	3.5
Total	22.5	22	20	17.5	22.5	21

that represent high risk (disease transmission to native animals and high control costs) accounted for additional 17.5–28 points for each of these species. Besides, the main risk value for hedgehog and chipmunk in social and economic features was history of unintentional release (5 points for each species). The sugar glider resulted the lowest risk rating among all the species assessed. Social and economic traits (human interest in pets and risk of zoonosis transmission) contributed only two points to the final score, while no record of unintentional release was found for this species (Table 2).

The final score of carnivorous species was mostly represented by ecological and biological traits related to carnivore habit (predation and competition with native species and high capacity for displacing other animals), as well as to a wide tolerance to temperature fluctuations and human-modified habitats, which account for 23.4–27 points of the total score of each species. The characteristics that represent high risk (risk of disease transmission to native animals and difficulty of control) added between 20.5 and 28 points for each species. There are indications that skunk have high potential for social and economic impacts, which added 11.5 points for the species (Table 2).

In general, reproductive traits (capacity to reproduce twice or more in a year and capacity to produce a large number of offspring in each reproductive cycle) and wide habitat tolerance (ability to live in environments with great variation of physical attributes) were the main biological and ecological traits that accounted for the scores of the sugar glider and rodents (hedgehog, chipmunk and gerbil). The high potential of unintentional introductions due to escape from breeding grounds, the potential harm to public health, and social and economic traits also contributed to the high scores of rodents. In the carnivore risk analyses, food group (carnivore) and ecological interactions (predation and competition with native species) were the biological and ecological traits that best represented risk scores. The detailed risk analyses and corresponding references are available as part of the article online (Appendix A).

Discussion

The six mammal species assessed, sold as pets in Brazil, carry traits that confer them high potential to invade natural and human-modified habitats. Consequently, all species represent a potential threat to the conservation of biodiversity and ecosystems. Six new species were added to the list of 21 species (32% of all species assessed) with very high risk of becoming invasive in Brazil (Horus Institute, 2017). In our risk analyses we used information available in the scientific literature to avoid the bias of expert opinion (Turbé et al., 2017). However, we found few papers on invasive populations for half the species (skunk, gerbil, sugar glider and hedgehog), and scarce information is available about their introduction, establishment and control. Our inferences had therefore to be drawn from information from the species native range, not from areas where they are invasive, which tend to be more informative of their behavior once introduced to new environments. The species analyzed are taxonomically similar (mammals), already have a history of invasion in Australia, New Zealand, North America and Europe (e.g. England, France, German), and are widely traded as pets (Long, 2003). Therefore, we inevitably selected species with similar biogeographical aspects and characteristics that represent high risk. The same traits that render species valuable for captivity and breeding are often associated with invasive potential (Zenni et al., 2016a).

In most cases, tolerance to ecological variations and history of release by humans accounted for most of the high risk scores in a wide range of risk analyses (e.g. Bomford, 2003; Nentwig et al., 2010). Carnivorous and rodents display some of the highest potential to generate environmental impact (Nentwig et al., 2010). Our list of high risk non-native mammals shows a high overlap with lists of the worst invasive species in Europe and Australia, mainly due to human interest for pets, history of negative impacts in invaded environments, high reproductive capacity and high habitat and feeding plasticity (Bomford, 2003; GISD, 2015a,b; Mallick and Driessen, 2010; NNSS, 2011a,b). The skunk was the only species considered of moderate risk of invasion in Europe (NNSS, 2011a,b), while the assessment indicates high risk in Brazil. We were not able to find other risk analyses of the gerbil. One risk analysis of the sugar glider with low risk results was found for Tasmania (Mallick and Driessen, 2010). The protocol used in this analysis places high value on the potential impact alien species may have on native species while making no reference to economic impacts (Mallick and Driessen, 2010). However, because economic impacts caused by mammals tend to be more prominent than environmental impacts (Clout and Russell, 2007), the protocol applied to Tasmania is more conservative than others. Thus, species considered of high risk in other places (Bomford, 2003) received low risk ratings in Tasmania (Mallick and Driessen, 2010).

It is important to consider that unsuccessful introductions are more common than successful ones (Zenni and Nuñez, 2013) and that species will become invasive only after surpassing environmental barriers for survival, reproduction and spread (Blackburn et al., 2011). The geographical barriers of the six species assessed in this study have already been conquered, as they are already present in Brazil. Their high risk ratings suggest that if they pass the second environmental barrier (intentional or unintentional release from captivity), they carry the required biological and ecological characteristics to overcome the following three barriers (survival, reproduction and spread) and invade (Blackburn et al., 2011).

While there are records of occurrence of the gerbil, stoat and sugar glider in tropical and subtropical environments in their native and invaded ranges, the chipmunk, hedgehog and skunk are native to temperate areas and, until now, exclusively invasive in temperate regions with cold climates (Long, 2003). The climate may therefore be a limiting factor for the establishment of these species in most Brazilian ecosystems. However, the south and southeast of Brazil include areas of temperate climate with forest and grassland ecosystems which may be susceptible to invasion. In Brazil, the six alien mammals assessed may be a threat in fragmented natural areas because they are generalist species invading areas where native species populations are weakened by fragmentation and loss of top predators (Galetti et al., 2009) and where invasive plants spread rapidly and contribute to habitat degradation (Williams et al., 2016).

The chipmunk is considered to have growing potential for high impact in Europe due to recent releases related to the pet trade, therefore deserving careful monitoring in Brazil. Wide habitat tolerance, high dispersal capacity and competition with native animals are the traits that rate the chipmunk as moderate to extreme risk of invasion in Europe (D'hondt et al., 2015; GISD, 2015a; O'Rourke et al., 2014), where it is rapidly spreading (Nentwig et al., 2010). The stoat was rated as extreme risk species worldwide owing to a carnivore diet, which places native animals at risk, and climate matching with areas of susceptible native species or communities (Bomford, 2003; Csurhes and Markula, 2010). In addition, all species assessed can be vectors of important zoonoses and diseases that may affect humans, native species and livestock. Examples are toxoplasmosis (e.g. stoat, skunk), lyme disease (e.g. hedgehog, chipmunk), listeriosis (e.g. sugar glider), and rat bite fever (e.g. gerbil) (Bonnet et al., 2015; Burrells et al., 2013; Dubey and Jones, 2008; Gaastra et al., 2009; Krawczyket et al., 2015; Nichols et al., 2015).

Some introduced species defined as domestic in Brazilian legislation (Ordinance IBAMA 93/1998) can be either be commercialized without restrictions or are regulated by specific legislation. Any other native or alien species only can be commercialized and maintained as a pet with a specific permit, and are required to be identified (by a chip or other mechanism) and castrated (Ordinance IBAMA 93/1998 and 163/1998). The species that we evaluated can be found in both regulated and non-regulated stores, so animals for sale on the Internet also derive from illegal trafficking. Because wildlife trade is a global problem, it is internationally regulated by the Convention on the International Trade in Endangered Species 1975 (CITES); however with the increasing demand for exotic pets worldwide (Chan et al., 2015), law enforcement and policies that regulate wildlife trade and decrease both the supply and demand of wildlife goods can benefit the conservation of wildlife (Sutherland et al., 2014). To reduce the supply of exotic pets, legislation and actions to combat animal trafficking need to be enforced, while actions at the community level can provide economic alternatives to wildlife trade by engaging local communities in solutions that decrease illegal activities while benefitting wildlife conservation (e.g., payments for ecosystem services, and jobs as community guards) (Cooney et al., 2016). Public support is very important for the success of animal management efforts (Hulme et al., 2009). Species that are regulated and prohibited for maintenance as pets are less preferred by pet enthusiasts (Moorhouse et al., 2016). Although there is national legislation to protect animals (Law on Environmental Crimes 9605/1998), there is a lack of control and strategies to combat animal trafficking in Brazil. Other efforts for avoid animal trafficking are part of academic projects or non-governmental organizations such as RENCTAS (National Network for Combatting Animal Trafficking).

Although legislation and policy on invasive alien species in Brazil have improved in the past ten years (Zenni et al., 2016b), a national policy addressing pet trafficking and invasive species is urgently needed to support the implementation of existing tools that can help prevent further introductions of pet species that may become invasive. Many alien species of high risk of invasion are also species of economic and personal value, leading to conflicts of interest (Lodge et al., 2015). Thus, management decisions need to consider all points of view in order to settle differences between stakeholders with different agendas (Nentwig et al., 2010). Risk analysis is a useful tool that provides insight and clear information for decision-making based on a framework that takes potential benefits and impacts into account. An ideal risk analysis should be quick to process and highly accurate so that many species can be assessed while offering reliable results to indicate true impacts of invasive alien species (Lodge et al., 2015; Turbé et al., 2017). Besides, the analyses need to be transparent and structurally flexible to easily allow inclusions of new information when available, especially for taxa that are not very well studied. It can be used to deny requested introductions, but can also help to define relevant preventative measures for safer pet management (e.g. sale of sterile specimens to avoid reproduction and owner identification by subcutaneous chips, and containment).

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.pecon.2017.09.005.

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