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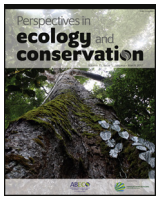

Research Letters

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

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ABSTRACT

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

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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

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