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Research Article

Non-native small mammal species in the South African pet trade

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Abstract

Non-native small mammals are amongst the most popular species traded as pets around the world. Some of these mammals have become invasive through various pet trade releases and escapees in most countries. In South Africa, several non-native small mammals have been introduced for pet trade purposes. We assessed the sale of non-native small mammals in South Africa from September 2018 to 2019 to determine their abundance and degree of trade online and in pet shops. A total of seven websites were recorded selling 2,681 individuals representing 24 species belonging to seven taxonomic orders. For physical pet shops, 19,391 individuals representing 16 species and seven orders were recorded from 122 pet shops. Rodents and primates were the most dominant groups in both online and pet shops. The most common small mammal species traded were the Norwegian rat *Rattus norvegicus*, the guinea pig *Cavia porcellus*, the European rabbit *Oryctolagus cuniculus* and the house mouse *Mus musculus*. Prices ranged from ZAR9.00 to ZAR12,000.00, with rodents offered at relatively low prices. The most abundant species traded were relatively cheap when compared with the least abundant species and CITES species were more expensive than non-CITES species. Species with high abundances traded at low prices and have a history of invasion through pet trade releases and escapes pose an invasion risk in South Africa. Therefore, their trade should be strictly regulated.

Key words: biological invasion, introduction pathways, pet shops, policy, online trade

Introduction

Non-native species have been deliberately and accidentally introduced around the world through different pathways (Hulme 2009; Mori et al. 2017; Lockwood et al. 2019). Examples of accidental introductions include hitch-hikers or contaminants of transported goods, while hunting, biocontrol, fishing and pet trade are considered as deliberate introductions (Keller et al. 2011; Britton and Orsi 2012; Faulkner et al. 2016; Ng et al. 2016; Carpio et al. 2020). The trade of non-native pets is one of the growing consumer trends for many societies around the world (Micheli 2014; Lockwood et al. 2019; Carpio et al. 2020; Shivambu et al. 2020a, b). The pet trade industry makes millions of dollars for the business owners, and it has been reported that the international legal trade in live non-native animals is worth ~ US$451.48 million (Durand et al. 2013; Robinson et al. 2015). For

example, the reptile pet trade industry in the UK is estimated to be worth ~ US$260.6 million, with a reported ~ 250,000 amphibians and reptiles bred for the pet trade industry every year (Herrel and van der Meijden 2014; Robinson et al. 2015). Small mammals, especially rodents, are increasingly becoming the most popular pets in the world (Ellis and Mori 2001; Grant et al. 2017). The American Veterinary Medical Association (AVMA) indicated that between 2007 and 2012, the number of households who keep rodents in the USA had increased by 11% (Lankau et al. 2017). An online search in the USA by Lankau et al. (2017) showed that rodents such as chinchillas (e.g. *Chinchilla chinchilla*, *C. lanigera*), hamsters (e.g. *Mesocricetus auratus*, *Crecetus grideus*, *Phodopus campbelli*, *P. roborovskii*), gerbils *Meriones unguiculatus*, guinea pigs *Cavia porcellus*, mice (e.g. *Mus musculus*, *M. musculus domesticus*), and rats (e.g. *Rattus norvegicus*) are sold on the internet and are listed on pet shop websites.

Online trade has been shown as an important pathway for non-native species invasions as traders can move different non-native pets relatively easily from one place to another (Kikillus et al. 2012; Mazza et al. 2015; Canlas et al. 2017; Shivambu et al. 2020c). Although trade bans can reduce movement and the risk of invasion (Cardador et al. 2017, 2019), studies have indicated that prohibited non-native pets continue to be sold via online portals, e.g. Faulkes (2018) indicated that prohibited crayfish species are sold online, and Siriwat and Nijman (2018) showed that prohibited otter species listed on the Convention on International Trade in Endangered Species (CITES) are largely sold online. In addition, the online trade offers almost any type of non-native pet species as opposed to the physical pet shops which are generally easier to regulate and are subject to inspection (Marano et al. 2007; Pasmans et al. 2017; Shivambu et al. 2020b). Increased usage and ease of access to the internet has contributed to the introductory pathways of invasions, however, the internet, as an invasion pathway has mostly been overlooked by policy-makers and researchers (Derraik and Phillips 2010; Martin and Coetzee 2011; Lenda et al. 2014; Mazza et al. 2015). Consequently, the sale of species through the internet may likely increase in the future as it has been indicated to increase the accessibility of a wide range of taxa (Gastañaga et al. 2010; Bush et al. 2014; Daut et al. 2015).

Most households with non-native pets obtain these from either breeders, rescue clubs, pet shops, and/or through online trade (Meenken 2012; Halsby et al. 2014; Stoakes 2014; Neville et al. 2019). Non-native small mammal species are also commonly traded via online portals and pet shops as feed for other non-native pets such as snakes, e.g. ball python *Python regius* and the red-tailed boa *Boa constrictor* (Cooper and Williams 2014; Kanagarajah et al. 2018). An increase in the trade of these non-native small mammal species as pets is of great concern for human and predator pets' health as most of these species are associated with zoonotic agents such as *Salmonella*, *Francisella tularensis*, monkeypox virus and *Yersinia pestis* (Inoue et al.

2009; Lankau et al. 2017; Kanagarajah et al. 2018). Some of the non-native small mammal species traded as pets pose a risk of becoming invasive if released or escape from captivity, e.g. the black-tailed prairie dog *Cynomys ludovicianus* in North Central Florida (Hardin et al. 2014) and Siberian chipmunks *Tamias sibiricus barberi* in Europe (Marsot et al. 2013; Mori et al. 2018).

In Brazil, da Rosa et al. (2017) indicated that 70% of identified non-native mammal species became invasive because of deliberate release or escape from breeding facilities. Most of the escaped or released pet mammal species are associated with negative impacts (Shivambu et al. 2020c), for example, the sugar glider *Petaurus breviceps* in Tasmania has been reported to negatively impact biodiversity by preying on tree cavity-nesting birds (Stojanovic et al. 2017; Campbell et al. 2018). It has been reported that most of the non-native species which become invasive are those that have relatively high availability, easy to breed in captivity and sold at generally low prices in the pet trade (van Wilgen et al. 2010; Stringham and Lockwood 2018; Lockwood et al. 2019). Non-native small mammal species are generally considered easy to care for, relatively cheap to maintain and are inexpensive pets to purchase (Quesenberry and Carpenter 2011; Sirois 2016).

In South Africa, non-native small mammal species such as the Norwegian rat and house mouse are sold as companion pets (Maligana et al. 2020). However, the role of the pet trade as an introduction pathway for most of the non-native small mammals has not been thoroughly evaluated across South Africa, and few species are regulated under the National Environmental Management: Biodiversity Act (NEM:BA) (DEA 2016). Species such as the Norwegian rat, house mouse and European rabbit *Oryctolagus cuniculus* are listed under NEM:BA as category 1b for off-shore islands. According to this regulation, these three species may not be owned, imported into South Africa, moved, sold and given as a gift only in the South African off-shore islands. There is currently no regulation that prevents the selling, importing or breeding of these three species in mainland South Africa. Additionally, the eastern grey squirrel *Sciurus carolinensis* is listed under category 1a in KwaZulu-Natal Province and category 3 in other provinces (DEA 2016). Category 1a prohibits a species from being imported, possessed, bred, moved, sold, and accepted as a gift, while category 3 does not prohibit and requires a permit for trade. Although listed, these four species are established in South Africa and its off-shore islands (Picker and Griffiths 2017; Measey et al. 2020). Additionally, little is currently known about which non-native small mammal species are sold nor their trade volume. There is also a paucity of information on how trade in non-native small mammal species sold in South Africa varies between online portals and physical pet shops. In our present study, we, therefore, aimed to 1) determine which non-native small mammal species were sold in South Africa, including

their relative abundance and richness in the online and pet shop trade; 2) determine invasion history and introduction pathways for these small mammal species; 3) determine their prices in the two trade platforms; and 4) investigate if the price is determined by species availability, IUCN (International Union for Conservation of Nature) conservation, CITES status, and invasion status. We predicted that online trade would offer more non-native small mammal species than pet shops as online trade is poorly regulated and there is typically lower compliance with existing regulations, and so any type of non-native pet can be easily sold (Marano et al. 2007; Pasmans et al. 2017). We further predicted that rarer species would be offered at relatively high prices than other species. For example, CITES-listed species were predicted to be more expensive compared with other species, and least concern species were predicted to be cheaper compared with other species.

Materials and methods

Pet shops

We located the geographical locations of physical pet shops that sold non-native small mammal species in the provinces of South Africa (Figure 1), by identifying them through Google maps and Google earth. We also searched the South African pet shop directory (http://www.pet-shops.co.za/Manual/locate-petshop-in-south-africa.html) and the South African Pet Traders Association website (http://www.sapettraders.co.za/membership-2016/) for any listed physical pet shops. We collated a database of all physical pet shops present in South Africa and created a heatmap to indicate their distribution using ArcGIS version 10.4 (Environmental Systems Research Institute 2018, Figure 1). We found most of these pet shops located within shopping centres in the city centres and towns near major cities (Figure 1).

Each pet shop was visited once in September 2018, December 2018, April 2019, and June 2019 to find if there were any new species advertised that we could not have recorded in previous sampling. This was done because pet shops are likely to import different animals in different seasons from various countries, as reported in Shiau et al. (2006) and Faulkes (2015). Pet shops which were not open in September 2018 were surveyed in September 2019. In total, each pet shop was visited four times. We excluded all the pet shops which only sold pet products from our pet shop list and surveyed those pet shops which sold live non-native animals. We conducted general observations in each pet shop to record the following in a database: 1) date of visit; 2) province where pet shop was situated; 3) common and scientific names of each of the small mammal species available for sale; 4) number and age class (juvenile, adult) of individuals of each recorded species; and 5) displayed price for each recorded small mammal species. An opportunistic survey was conducted to get information about

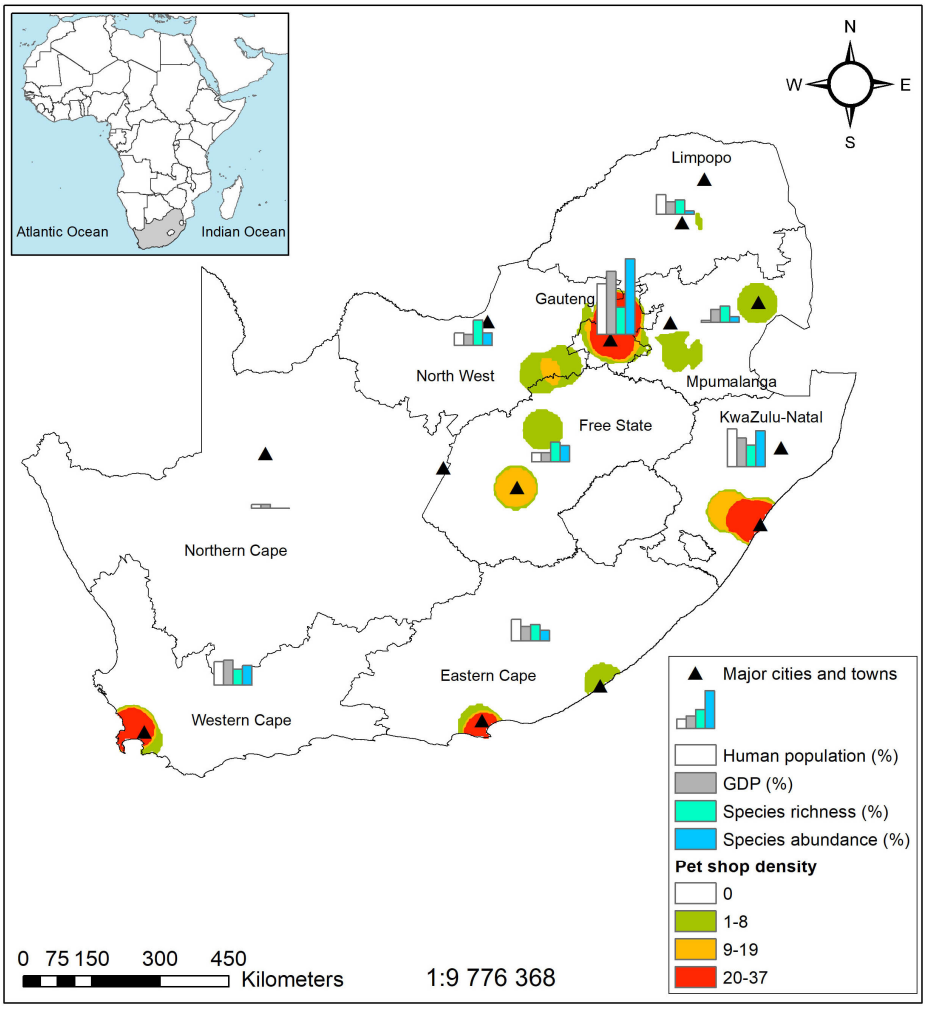

Figure 1. Heatmap summarising the distribution of physical pet shops surveyed between September 2018 to September 2019 in South Africa. The bar chart indicates the relative percentage of the total human population and gross domestic product (GDP) of the country, species richness and abundance for non-native small mammals available for sale in the pet trade.

the species of small mammals traded. The owners or workers were asked general questions, including how often they receive new livestock from their suppliers and how long individual species last in the store before they are purchased. This was done to minimise duplication of the pet shop dataset. Additionally, if the same individual species was still not purchased on our follow up visit, we did not record that species. This was often the case for rare species such as ferrets *Mustela putorious furo*, sugar gliders and primates. Most of the small mammal species were displayed with their common names only, but in some of the pet shops, scientific names were also provided (Supplementary material Figure S1). Some of the pet shop owners were experienced breeders and some zoologists; this made the process to identify the species easier. We obtained human ethic approval to conduct the surveys by the University of KwaZulu-Natal, Humanities and Social Research Ethics Committee (Permit number: HSS/0908/018D).

Online small mammal species trade

We conducted an online assessment of small mammal species between September 2018 and September 2019. We collated information on the small mammal pet species listed for sale in Facebook and South African advertising websites (Figure S2). Search terms such as "small mammals for sale", "mammals for sale" and "non-native pets" were used. We further expanded the searches by using the common name of each species, e.g. "rats, mice, ferret, chinchilla, fennec fox, kinkajou, tenrec, rabbit, guinea pig, degu, sugar glider, and hamster or monkey for sale". We checked the sales four times each month within a year to establish if there were any new listings on the adverting websites and Facebook. We also recorded the following for any small mammal species sold online: 1) the date of the advertisement; 2) the province where the species was sold from; 3) the name of the small mammal species traded; 4) the number and age class (juvenile, adult) of individuals of each species available for sale; and 5) the price of each recorded individual. All the non-native small mammal species available for sale in the online trade were mainly sold under their common names and not scientific names (Figure S2). We, therefore, identified all the taxa to species level using personal experience and where necessary identification guides were used (Turner 2004; Petter and Desbordes 2013; Couzens et al. 2017; Kingdon 2019). To minimise duplication for the online dataset, we compared the photographs posted by different advertisers and in different regions of advertisement, as advertisers can post the same individuals using different advertising websites. Again, some advertising websites allow for the advertisement to be active for two months, so we were able to notice if the advertisement was repeated or new. Advertisements without pictures were excluded in this study as it was not possible to identify the species. For Facebook, we differentiated the advertisements by checking different users and different animal images posted. Again, on Facebook sites, only 5,000 pictures can be displayed at a time, and older ones are automatically removed when new images are received (Iqbal 2016).

Data analyses

All data were analysed using R statistical software (version 3.4.4, R Core Team 2018). We averaged the number of species sold for both online and pet shop trade respectively to determine the most abundant species, the species richness and abundance per province. We used the Mann-Whitney U test to compare the species abundance based on pairs of replicates in online trade and pet shops. The Kolmogorov-Smirnov normality test was used to determine if data were normally distributed, independent, and identical. As a result, we found that the data were not normally distributed. We, therefore, used a Kruskal-Wallis test by ranks to determine which species was abundant and used a Mann-Whitney pairwise test with

Bonferroni p values adjusted at 0.01 to determine the differences between the groups. We examined the relationship between the number of individuals of each species and their overall price using linear regression with the Pearson correlation test. The data for linear regression was log-transformed to reduce the highly skewed distributed data to normal. Linear regression models were used to determine the relationship between each variable (species number, CITES-listed, IUCN status, non-invasive and invasive in South Africa and elsewhere) and price. The Akaike Information Criterion (AIC) was used to identify the model with the greatest explanatory power. We used the Kruskal-Wallis test by ranks and the Mann-Whitney pairwise tests to determine the price differences between CITES and Non-CITES listed species, between the different IUCN statuses and invasion status.

Results

We found a total of 122 physical pet shops selling 19,391 individuals representing 16 non-native small mammal species and seven online advertising websites selling 2,681 individuals representing 24 species (Table S1). Only one native species, the southern multimammate mouse *Mastomys coucha* was recorded, but this rodent was excluded from further analyses. We found out that there were no additional new species in the pet shops during follow-up visit. However, for online sampling, a total of 10 new species were recorded during the follow-up searches (Table S2). The recorded species belonged to seven orders, with Rodentia being the most dominant order representing more than 40% of all species for sale (ten species) in both online platforms and pet shops (Table S2). The second-largest group was the primates, which represented 29% (seven species) of species for sale in the online trade and 12% (two species) of the species for sale in the pet shop trade. Carnivores contributed 13% (three species) of the online trade compared with 6% (one species) of the pet shop trade (Table S2). The other remaining groups, including the Eulipotyphla, Afrosoricida, Lagomorpha and Diprotodontia together contributed 4% of online trade and 6% of the pet shop trade (Table S2). Most of the online advertisements were recorded from Gauteng Province (number of adverting websites (n) = 7), KwaZulu-Natal Province (n = 7) and Western Cape Province (n = 6), followed by the Eastern Cape Province (n = 4), and Mpumalanga Province (n = 4) (Table S1). The Free State Province (n = 3), North West Province (n = 3), Northern Cape Province (n = 3) and Limpopo Province (n = 2) had the least number of websites advertising non-native small mammal species per province (Table S1). The provinces with the highest numbers of pet shops were Gauteng Province (number of pet shops (n) = 37), KwaZulu-Natal Province (n = 27), and the Western Cape Province (n = 20) (Table S1). Some provinces such as Limpopo (n = 3) and Northern Cape Province (n = 2) had only a few pet shops selling non-native

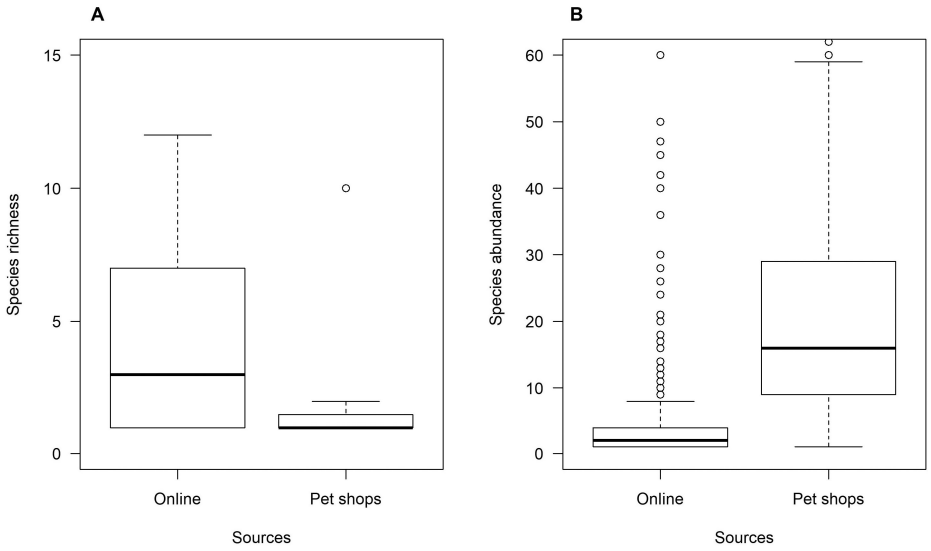

Figure 2. Non-native small mammal species sold in South Africa from September 2018 to September 2019 where (A) shows the mean number of species available in the online trade (max = 24 species) and pet shops (max = 16), and (B) shows their mean abundance in online trade (total abundance = 2,681) and pet shop (total abundance = 19,391).

small mammal species (Table S1, Figure 1). In terms of online trade per province, Gauteng Province recorded a total of 1,160 individuals representing 24 species (Table S1). This was followed by KwaZulu-Natal Province, which recorded 800 individuals (n = 15 species) and the Western Cape Province, which recorded 421 individuals (n = 11 species) (Table S1). Other provinces recorded less than 200 individuals for sale, with the Eastern Cape and Mpumalanga Provinces representing 11 species each and other provinces representing less than six species (Table S1).

In terms of numbers in physical pet shops per province, Gauteng Province recorded the highest number of individuals, i.e. 8,199 representing 15 species. This was followed by KwaZulu-Natal Province which recorded 3,946 individuals (n = 12 species), the Western Cape Province with 2,191 individuals (n = 9), and North West Province with 1,393 individuals (n = 14) (Table S1). Free State, Eastern Cape, Mpumalanga, and Limpopo Provinces recorded less than ten small mammal species represented by 1,644, 1,043, 578 and 387 individuals, respectively (Table S1). We did not record any small mammal species for sale in the Northern Cape Province physical pet shops (Table S1).

In terms of species richness in the online and pet shop trade, we found no significant difference between the number of species traded online compared with pet shops (Mann-Whitney U test, U = 20; P = 0.56; Figure 2a). The overall species abundance available for online trade was significantly lower than the overall species abundance in the pet shops (Mann-Whitney U test, U = 39869, P = 2,46e−165; Figure 2b).

We found that there was a significant difference in the number of each of the small mammal species available for sale online (Kruskal-Wallis X^2 = 59.46; df = 23; P = 6,28e−05; Figure 3a). The mean number of European

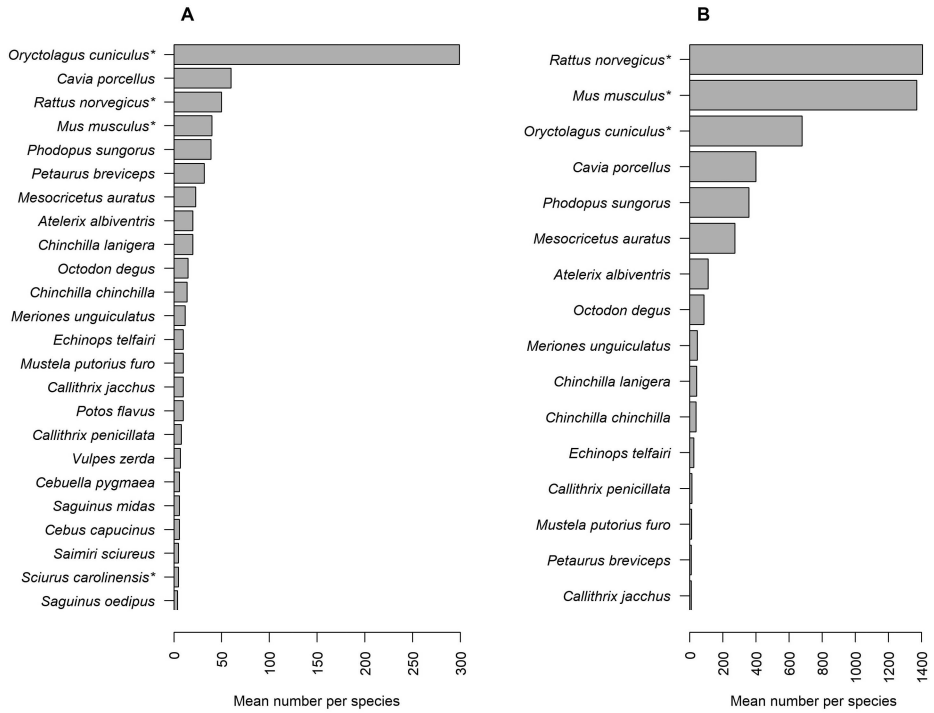

Figure 3. The mean number of the recorded small mammal species advertised for sale in South African a) online trade and b) pet shops between September 2018 and September 2019. An asterisk (*) indicates established non-native species in South Africa.

rabbits for sale online was significantly higher than the mean number for the other 23 species (Figure 3a). Species such as the Norwegian rat, the house mouse, the guinea pig, the dwarf hamster *Phodopus sungros,* and the sugar glider also had a significantly higher mean number available for sale than the other species (Figure 3a). The least available species were the common squirrel monkey *Saimiri sciurus*, eastern grey squirrel, and cotton-top tamarin *Saguinus oedipus* (Figure 3a).

There was a significant difference in the number of individuals of each non-native small mammal species sold in the physical pet shops (Kruskal-Wallis X^2 = 62.67; df = 16; P = 0.0084; Figure 3b). The most abundant species for sale in terms of mean number included the Norwegian rat, the house mouse and the European rabbit (Figure 3b). Guinea pigs, dwarf hamsters, and golden hamsters were also common species in terms of numbers in the pet shops (Figure 3b). The least common species in the pet shops included the black tufted-ear marmoset, the ferret, the sugar glider, and the common marmoset (Figure 3b). Eight species which were recorded in the online trade but not in the pet shops included the pygmy marmoset *Cebuella pygmaea*, the red-handed tamarin *Saguinus midas*, the cotton-top tamarin, the common squirrel monkey, the eastern grey squirrel, the white-faced capuchin *Cebus capucinus*, the fennec fox *Vulpes zerda*, and the kinkajou *Potos flavus* (Figure 3). The conservation status of about 67% (number of species (n) = 16) of small mammals traded was the least concern, 13% (n = 3) of the species are listed as endangered, and 8% (n = 2) are listed as vulnerable to extinction and not evaluated. Only one species (4%)

was listed as critically endangered (Table S2). Furthermore, we found that 54% (n = 13) of small mammal species were not listed on CITES, and this included mostly rodent species (39%; n = 10). In contrast, most primate species were listed on CITES (Table S2). Nine species have established feral populations in most countries (Table S3). Of these, only four, including the Norwegian rat, house mouse, European rabbit and eastern grey squirrel were recorded as established in South Africa (Figure 3a, b; Table S3). The introduction pathway for these species included pet trade, ornamentation, farming, hunting and stowaways (Table S3).

The mean price per small mammal species available for sale in the present study ranged from ZAR9.00 to ZAR12,000.00 (Table S2). The least expensive species for both the online trade and pet shops were rodent species which ranged between ZAR9.00 and ZAR250.00 (Table S2). These included species such as house mice, Norwegian rats, dwarf hamsters, golden hamsters, common degus *Octodon degus*, Mongolian gerbils *Meriones unguiculatus,* and guinea pigs (Table S2). Species which cost more than ZAR1,000.00 included domesticated ferrets, sugar gliders, chinchillas, kinkajous and eastern grey squirrels (Table S2). The most expensive species recorded were the primates, as they cost more than ZAR3,000.00 each (Table S2). Nonetheless, red-handed tamarin was the most expensive of all species, and it is listed as critically endangered under CITES Appendix I (Table S2). For species such as chinchillas, domesticated ferrets and lesser hedgehog tenrecs, the mean online prices were lower than the pet shops prices (Table S2). Overall, least concern species such as the Norwegian rat and house mouse were sold at relatively low prices compared with the other small mammal species (Table S2). There were no significant differences in the mean price of non-native small mammal species sold online compared with pet shops (Mann-Whitney U test, U = 108; P = 0.22). Small mammal species abundance and retail prices for both online (r^2 = −0.58; P = 2.2e−16) and physical pet shops (r^2 = −0.12; P = 2.2e−16; Figure 4) showed a negative linear relationship, with the least abundant species (number of individuals available for sale) sold at relatively high prices compared with abundant species (Figure 4).

When comparing the mean prices of small mammal pets according to their conservation status, there was a significant difference between the means for online sales (Kruskal-Wallis X^2 = 45.70; df = 4; P = 2.73e−09; Figure S3a). Furthermore, critically endangered species were offered at relatively higher prices when compared with the other species status categories (Mann-Whitney pairwise test; P < 0.001, Bonferroni corrected p values; Figure S3a). For pet shops, there was a significant difference on the mean prices of the small mammal species on sale between conservation status (Kruskal-Wallis X^2 = 82.25; df = 3; P = 1e−17; Figure S3b). Again, CITES-listed species were offered at higher prices when compared with non-CITES species (Figure S1c, d). The mean price of species listed on CITES

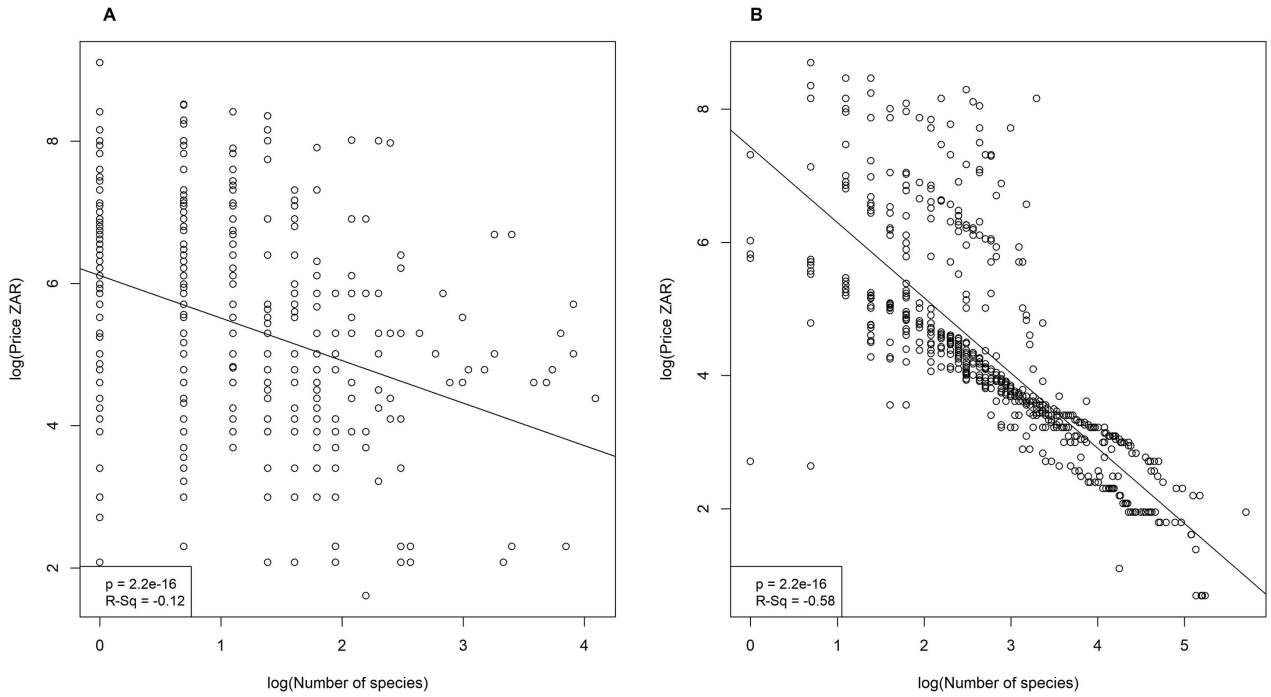

Figure 4. The relationship between log price and log number of non-native small mammal species recorded in the current study in a) pet shops and b) online trade in South Africa.

under Appendix I, II, III and non-CITES were significantly different for online sales (Kruskal-Wallis X^2 = 173.2; df = 3; P = 2.78e−37; Figure S3c). Appendix II and III species were offered at higher prices compared with Appendix I and non-CITES species (Figure S3c). For prices in pet shops, the mean price of species listed on CITES under Appendix I, II, and non-CITES were significantly different (Kruskal-Wallis X^2 = 97.3; df = 2; P = 7.30e−22; Figure S3d). Appendix II species were offered at higher prices compared with Appendix I and non-CITES species (Figure S1d). However, when comparing the mean price of Appendix I and non-CITES species, it was found that CITES Appendix I species were offered at higher prices than non-CITES species (Figure S3d). In terms of invasion status, mean prices for species known to be invasive elsewhere were sold at significantly higher prices when compared with non-invasive and invasive species in South Africa for both online (Kruskal-Wallis X^2 = 218; df = 2; P = 3.676e−48) and pet shops (Kruskal-Wallis X^2 = 113.5; df = 2; P = 2.253e−25) (Figure S3e, f). For online trade, the model showed that price was determined by CITES-listed species (Appendix I), non-CITES, IUCN-listed species (Vulnerable, Least Concern and Endangered), and by all categories for invasion status (invasive elsewhere, invasive in South Africa, and non-invasive) (Table S4). Species listed in CITES Appendix I, non-CITES, IUCN least concern and endangered determined the price for pet shop. Price was also determined by all invasion categories for species sold in the pet shops (Table S4).

Discussion

We found that three South African provinces, namely Gauteng, KwaZulu-Natal, and the Western Cape, had the highest number of pet shops and online websites selling non-native small mammal species. These three provinces represent South Africa's most fast-growing economies, and their cities are more populated compared with other provinces (STATS SA 2019). It has been indicated that an increase in non-native pets is linked to human population growth and economic status (Shepherd et al. 2007; Smith et al. 2017). Furthermore, the pet trade is likely to play a role in the economies of these provinces. However, it has been indicated that a growing human population lead to increased demand for non-native pets (Bush et al. 2014; Lockwood et al. 2019). Consequently, this may pose an invasion risk particularly for species with very high demand and popular, e.g. the Norwegian rat, house mouse, European rabbit, and guinea pig. In Japan, the common raccoon *Procyon lotor* became a popular pet, and as a result, it has established feral populations because of accidental escapes and intentional releases (Macdonald et al. 2017). In addition, Gauteng, KwaZulu-Natal, and Western Cape Provinces are at higher risk of becoming invaded given that most of the pet shops are situated in urban areas with high human density (see Banha et al. 2017 and Filz et al. 2018). Although KwaZulu-Natal and Western Cape Provinces had the most pet shops and recorded more number of individuals, the number of species offered for sale was lower compared with that in the North West Province, although the latter had relatively few pet shops. This suggests that the number of pet shops is not directly related to species richness. In terms of invasion risk, all the provinces are likely to be invaded despite their species abundance as invasions are also linked to the type of a species, its reproductive success, lack of predators, broad diet, and ability to tolerate wide climate ranges (Lockwood et al. 2019; Maceda-Veiga et al. 2019; Moraes et al. 2019)

In some of the provinces, we found that more non-native small mammal species were recorded in online trade than in the pet shops, which indicated that most of the sellers in these provinces were private. Online trade offered higher species richness, but lower abundance than the pet shops, even though statistical analysis indicated that there were no significant differences in species richness and abundance between the two sources of trade. This difference could be explained by that new species were recorded during the follow-up searches in online trade, while no additional species were found during the pet shop revisit. The relatively low species richness in the pet shops could also be explained by increased use of the internet (Gastañaga et al. 2010). In addition, the online trade is generally fast, species can be delivered directly to homes, easily accessed by more people than pet shops and it is difficult to regulate making it easy for the traders to sell illegal pets (Marano et al. 2007; Alacs and Georges 2008; Musing et al. 2015; Pasmans et al. 2017). Previous studies indicated that species sold in large volume are

most likely to be intentionally released into the wild as opposed to those traded at low volume (Holmberg et al. 2015; Stringham and Lockwood 2018). In the present study, the most abundant species in the pet shops and online trade were European rabbits, Norwegian rat, house mouse, hamsters, and guinea pig. This showed that these mammal species are traded in relatively large quantities in South Africa and are more likely to increase in their numbers which may lead to intentional release or escape. A study in the Netherlands also found that more rodents were traded online compared with other mammals (Westbroek 2014). Almost all the pet shops were selling these species in South Africa, and this may explain their abundance. Most rodents such as the Norwegian rat and house mouse breed throughout the year and often give birth to more than five litters (Gomez et al. 2008; Modlinska and Pisula 2020). This made them abundant throughout the study period, and as a result, the high reproductive rate leads to the successful establishment of species in the wild (Teixeira et al. 2015; Moraes et al. 2019). We found that the sugar glider was abundant in online trade but not common in pet shops. This suggests that sugar gliders in South Africa are mostly sold by private sellers or breeders rather than pet shops. This species may pose invasion risk in South Africa, given that they quickly escape enclosures and became invasive in Tasmania, Australia, through accidental escapes (Heinsohn 2004).

In our study, we found a negative relationship between price and species abundance; however, the regression coefficient (r^2) was low in pet shops but not for the online trade. This relationship is also more likely to be determined by other factors such as breed type, coat colour, and life span. Therefore, this warrant further investigation as documented in Su et al. (2015). In addition, our results were similar to the results of other studies where it was found that price was the most important factor that determines species availability in the pet trade, e.g. in Taiwan (Su et al. 2015), Australia (Vall-llosera and Cassey 2017) and Thailand (Siriwat and Nijman 2018; Siriwat et al. 2019). All these studies showed that the most abundant pet species were cheaper, traded in higher volumes and always available for purchase. Previous studies indicated that species traded in large volumes and cheaper are more likely to be released into the wild (Stringham and Lockwood 2018). Species such as the Norwegian rat, house mouse, European rabbit, and guinea pig are likely to be released, establish and cause impacts as they were traded at a low price and as the price was found to be an important predictor for species with invasive history elsewhere, established in South Africa and non-invasive. The first three species and the eastern grey squirrel are regarded as invasives in South Africa, its off-shore islands and elsewhere (Table S3). These species are expected to cause severe impacts, particularly socio-economic (i.e. agricultural production and human infrastructure) (Hagen and Kumschick 2018; Shivambu et al. 2020c; Zengeya et al. 2020). Species traded at low volume, and higher prices may also establish feral populations and cause impacts. For example, the eastern

grey squirrel which was sold at a higher price is regarded as an established species through pet release and escapes in South Africa and other countries (Long 2003; Huynh et al. 2010; Measey et al. 2020). In addition, species such as the domesticated ferret, common marmoset, black tufted-ear marmoset, common squirrel monkey, and sugar glider may pose an invasion risk despise their trade volume and price given that they have established feral populations through pet trade releases and escapes in other countries (Svihla 1936; Long 2003; Heinsohn 2004; Rylands and Mendes 2008; Rylands et al. 2008; Camarotti et al. 2015; da Rosa et al. 2017; Table S3). Some of these expensive species may show aggressive behaviour leading to intentional release, e.g. domesticated ferrets and primates may attack owners (Hitchcock 1994; Favoretto et al. 2001; Soulsbury et al. 2009).

Some of the CITES-listed and protected IUCN species were expensive and not as abundant in our study. Su et al. (2015) and Siriwat et al. (2019) also found that species listed on CITES and those that are protected were expensive when compared with non-CITES and unprotected species. Most of the CITES-listed and protected species are primates (e.g. pygmy marmoset), and these were the second most traded group in the present study. This group has been reported to be the second most introduced species, mainly for the pet trade and research experiments (Bush et al. 2014; Carpio et al. 2020). Still, there is no legislation preventing them from being traded in South Africa, and news reports indicated that this country imports and also exports these primates, especially to Asia (Macleod 2012). Species such as the European rabbit and golden hamster are non-CITES but listed as endangered and vulnerable to extinction. These species are also cheap and traded at large volume; as a result, they may be overexploited in their native ranges and may pose an invasion risk in areas where they are traded, this is the case for the European rabbit.

Recommendations and conclusions

Based on the results obtained from the present study, we recommend that the non-native pet trade in South Africa is regularly monitored. Priority should be given to species with high availability, sold at low prices, and known to be invasive through pet release and escapes, e.g. the European rabbit, house mouse, Norwegian rat, eastern grey squirrel, sugar glider, and ferret. These species have also been found to pose either potential high environmental and socio-economic impact (Shivambu et al. 2020c). We, therefore, recommend that detailed risk analysis (see Kumschick et al. 2020) and species distribution modelling for all non-native mammal species traded be conducted as part of rapid screening. Species currently not included in the national list of non-native and invasive species (i.e. National Environmental Management: Biodiversity Act, 2004 (NEM:BA)) as described in Moshobane et al. (2019) should be included. Pet shop owners should be advised to provide flyers which explain the importance of not giving away the species or releasing them into the wild as many of

these species have been reported to have established in the wild in other countries through the pet trade (da Rosa et al. 2017; Stojanovic et al. 2017; Campbell et al. 2018). Individual hobbyists who keep or breed any of these pets must be encouraged to apply for a permit (as described in DEA 2014), and if they are buying a potential problematic species, such as the sugar glider or ferret, the males should be castrated. South Africa should have one regulation which applies to all the provinces as each province currently has its own legislation, and people can buy species that are prohibited in their provinces from other provinces where the desired species are not prohibited. Pet shop owners should be prohibited from breeding more animals because this may increase the population of the species leading to unintentional escapes and intentional releases if the species are not selling well. The online trade is highly unregulated, especially social media, where any non-native species are sold despite their prohibited status. The trade of the non-native small mammal species is relatively large in South Africa as different species are sold in different provinces. Given this, we recommend stricter law enforcement on online sales. Species sold at low prices, non-CITES, listed as vulnerable or endangered and that pose a risk of becoming invasive should be protected from trade to prevent extinction and invasion risk.

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Supplementary material

The following supplementary material is available for this article:

Table S1. The total number of online websites, number of non-native small mammal species recorded, and the total abundance of species available online and in pet shops recorded per province in South Africa between September 2018 and 2019.
Table S2. Small mammal species advertised for sale in pet shops and online platforms in South Africa between September 2018 and September 2019.
Table S3. Non-native small mammals reported being invasive elsewhere and in South Africa. Introduction pathway is the pathway in which the species were introduced, and references are provided.
Table S4. The regression models for each predictor variable showing the relationship between the log-transformed price and number of non-native small mammal species traded as pets in South Africa.
Figure S1. Examples of non-native and native small mammal species sold as pets in South Africa. Pictures were taken from different pet shops in the present study (©photograph N Shivambu).
Figure S2. Examples of non-native small mammal species sold as pets in South Africa. Pictures were taken from different advertising websites in the present study (©photograph Gumtree, PublicAds).
Figure S3. Mean prices for 24 small mammal pets in South Africa based on conservation status, CITES and invasion status for online (a, c, and e) and pet shops (b, d, and f). Letters i, ii, and iii indicate CITES-listed Appendices. For invasion status, "Elsewhere" = invasive elsewhere and "SA" = invasive in South Africa. Same letters indicate significant differences between the groups based on Mann-Whitney pairwise test; $P < 0.001$, Bonferroni corrected p values.