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Australia's wish list of exotic pets: biosecurity and conservation implications of desired alien and illegal pet species

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Abstract

Globalisation of the live pet trade facilitates major pathways for the transport and introduction of invasive alien species across longer distances and at higher frequencies than previously possible. Moreover, the unsustainable trade of species is a major driver for the over-exploitation of wild populations. Australia minimises the biosecurity and conservation risk of the international pet trade by implementing highly stringent regulations on the live import and keeping of alien pets beyond its international CITES obligations. However, the public desire to possess prohibited alien pets has never been quantified and represents a number of species that could be acquired illegally or legally under different future legislative conditions. As such, highly desirable species represent an ongoing conservation threat and biosecurity risk via the pet-release invasion pathway.

We aimed to characterise the Australian desire for illegal alien pets and investigate potential sources of external information that can be utilised to predict future desire. Using public live import enquiry records from the Australian Commonwealth Department of Agriculture, Water and the Environment as a proxy for alien pet desire, we tested for differences in the proportion of species with threatened listings and records of invasions, after accounting for taxonomy. Additionally, we used a United States of America (U.S.) live imports dataset to infer pet demand in another Western market with less stringent regulations and determined whether species highly desired in Australia had higher U.S. trade demand than would be expected by chance.

The Australian public desire for alien pets is heavily and significantly biased towards species threatened with extinction, species popular in the U.S. trade and species with a history of successful invasions. Not only does this indicate the potential impacts of pet desire on invasion risk and the conservation of threatened species, but we also highlight the potential role of the U.S. trade as an effective predictor for Australian desire. Our research emphasises the value of novel datasets in building predictive capacity for improved biosecurity awareness.

Keywords
alien, invasive species, non-native, smuggling, wildlife trade

Introduction

Globalisation of trade and tourism has led to substantial changes in the international trade of live pets (Bush et al. 2014). Rapid information sharing, particularly via social media, has increased public awareness of traded species, potentially leading to subsequent increases in pet demand (Clarke et al. 2019; Kitson and Nekaris 2017). Additionally, the use of e-commerce platforms such as international classifieds has facilitated the acquisition of pets in greater numbers and from a greater diversity of regions than previously possible (Bergin et al. 2018; Morgan and Chng 2018; Siriwat et al. 2019), including species with highly restricted distributions (Shepherd et al. 2019). As such, the proliferation of the pet trade has the potential to exacerbate its existing detrimental impacts, including the over-exploitation of wildlife, the violation of animal welfare and both the transport and introduction of invasive alien species (IAS) via the pet-release pathway (Ashley et al. 2014; Auliya et al. 2016; Baker et al. 2013; Lockwood et al. 2019).

Australia has experienced an increased rate of IAS incursions over the last two decades, particularly from species prominent in the international pet trade, such as rose-ringed parakeets (*Psittacula krameri*), corn snakes (*Pantherophis guttatus*) and red-eared sliders (*Trachemys scripta elegans*) (Henderson et al. 2011; McFadden et al. 2017; Toomes et al. 2019; Vall-llosera et al. 2017). These trends are of concern for Australian biosecurity, as establishment success of IAS is dependent on propagule pressure, which is influenced by the number of individuals smuggled in and their probability of release/escape from captivity (Cassey et al. 2018; García-Díaz et al. 2015; Stringham and Lockwood 2018). Given the cost and difficulty of eradicating IAS from large landmasses (García-Díaz et al. 2017; Holmes et al. 2016; Jardine and Sanchirico 2018; Rout et al. 2014), the interception of IAS earlier in the invasion pathway is necessary for efficient management of biosecurity in Australia.

Australia implements wildlife trade restrictions beyond its' CITES obligations (Department of the Environment and Energy 2019). This stringent regulatory framework has played a major part in mitigating the threat of IAS to date, as highlighted by fewer IAS established in Australia compared with the U.S. (Capinha et al. 2017;

Smith et al. 2008; Strecker et al. 2011), a country with less stringent pet trading and keeping regulations (Eskew et al. 2019; Smith et al. 2017). However, a challenge associated with Australia's regulatory system is the lack of consistent surveillance of alien pets held, legally or otherwise, within Australia. There are a number of species that are not permitted for live import, yet are legal to domestically trade within Australia (Fredberg and McNeil 2010). Additional species have been acquired illegally, either from international smuggling or from domestic captive breeding (Toomes et al. 2019). Therefore, an unquantified proportion of pet keepers have the capacity to legally or illegally acquire desired pets if they are not accessible through importation. Anticipating which species are likely to be desired, acquirable and subsequently pose a biosecurity risk through deliberate/accidental releases, is essential to mitigating the cost of IAS.

While it is important to consider Australia's acquisition of alien pets from the perspective of biosecurity risk, there are also potentially serious conservation implications. The unsustainable harvest and trade of species at rates exceeding their reproductive output can be a major driver of biodiversity loss (Mandimbihasina et al. 2020; Natusch and Lyons 2012; Siriwat and Nijman 2018; Shepherd 2010). Threatened species and those with low fecundity are especially susceptible to this threatening process, due to the effect of perceived rarity on market value (Holden and McDonald-Madden 2017; Siriwat et al. 2019). Even when captive breeding is established to supply a given market, harvesting can still take place in order to increase genetic diversity of captive populations from 'founder stock' (Brooks et al. 2010; Lyons and Natusch 2011) or to introduce a new subpopulation/breed/locality into the market with higher perceived value (Auliya et al. 2016). These issues are particularly apparent in illegal trade, as there are no licensing systems in place to promote sustainable practice. As such, the demand for and acquisition of alien pets within Australia may be contributing to a leading global threatening process.

Quantifying and characterising public demand for alien wildlife is extremely difficult given that the keeping of most alien pets in Australia is illegal or unregulated by any domestic permit system (Toomes et al. 2019). Specifically, to date, there has been no attempt to quantify or elucidate public preference for exotic alien pets. Here, we seek to generate insights about potential demand for alien vertebrates by analysing a novel dataset on the public 'desire' for alien species. We obtained records of anonymous public enquiries to the Australian Commonwealth Department of Agriculture, Water and the Environment (DAWE; formerly the Department of Environment and Energy) relating to the legality of importation of various alien taxa. We aimed to investigate whether species desired in Australia (i.e. species present in DAWE enquiries) were biased towards being threatened by extinction, as indicated by broader research on pet demand (Holden and McDonald-Madden 2017; Siriwat et al. 2019) or towards being invasive species elsewhere, which would indicate trade-related biosecurity risks (Toomes et al. 2019). Furthermore, we compared Australian desire with that of a Western nation with less stringent pet-keeping regulations (the U.S.) in order to identify a potential source of data to predict future desire. The U.S. plays a leading role in the

global exotic pet trade, importing millions of live animals annually to be kept as pets (Harfoot et al. 2018; Smith et al. 2009). Thus, we considered the species imported into the U.S. to represent the total diversity of traded pets and their quantity as a proxy for 'Western' demand for pets.

Methods

Australian phone enquiries

The Australian Department of Agriculture, Water and the Environment (DAWE) maintains a hotline for people to enquire about the legality of importing or owning a particular species in Australia. A DAWE policy officer answers and responds to the enquiry and records non-identifiable information about each request. The information recorded by the officer, if supplied by the caller, includes: (i) the date the enquiry occurred; (ii) the location of the enquirer (city or State/Territory); (iii) the species enquired about; (iv) the action (importing, keeping/owning, breeding); and (v) whether the action was for private or commercial reasons. We acquired this dataset for all enquires lodged from October 2017 to April 2019, which contained a total of 150 phone calls. We acknowledge that the sample size of this dataset is relatively small; however, as we are using the data to identify broad-scale biases, we assumed the data to be sufficiently representative of highly-desired alien pets. Moreover, as enquiries are free and anonymous, we assumed the set of anonymous callers to be an unbiased representation of pet keepers/traders with an interest in importing alien pets.

We categorised the stated use of the animal into six categories: (i) pet (private use); (ii) zoo (commercial use for display in a zoo/wildlife park); (iii) exhibitor (commercial use for exhibition/show); (iv) breeding pets (commercial use to breed as pet); (v) breeding food (commercial use to breed as food); (vi) other (not otherwise specified). If an enquirer specified multiple intended uses, all use types were recorded. We referenced species and common names against the Global Biodiversity Information Facility (GBIF 2019) to resolve species identification to the most specific possible taxonomic level. If multiple species were discussed in a single call, we recorded each species as an independent enquiry (n = 198). For our analyses, we only considered enquiries relating to vertebrate pets (n = 168). We categorised cartilaginous fishes (Chondrichthyes) and ray-finned fishes (Actinopterygii) into one clade (Fish).

U.S. imports of live animals

The U.S. maintains a database of imports/exports of live organisms and wildlife products, called the Law Enforcement Management Information System (LEMIS), which is maintained by the U.S. Fish and Wildlife Service (see Romagosa (2014) and Eskew

et al. (2019) for more details). We acquired the LEMIS dataset for records from 1999 to 2016. We excluded records of exported animals, records that did not specify the quantity of individuals imported, records that were not categorised as live imports and all non-vertebrate records. We only considered import records that were deemed relevant to the pet trade (i.e. commercial or personal use designation). This dataset resulted in 3083 species, resolved using GBIF. For analysis, we derived the popularity of each species in the U.S. import records by ranking the species by total number of individuals imported from 1999 to 2016.

Comparison datasets

We compared four metrics between species in DAWE enquiries and U.S. imports: (i) popularity in the trade; (ii) the proportion of threatened taxa; (iii) the proportion of taxa with international trade restrictions; and (iv) the proportion of species known to be invasive species elsewhere. To compare the proportion of threatened taxa, we matched each species from DAWE enquiries and LEMIS imports to their IUCN Red List designations: Data Deficient (DD), Least Concern (LC), Near Threatened (NT), Vulnerable (VU), Endangered (EN) and Critically Endangered (CR) (IUCN 2019). For the purpose of our analysis, we re-categorised the Red List designation into a binary variable: Not Threatened (LC and NT) and Threatened (VU, EN and CR). Species listed as "Data Deficient" were excluded from our analysis. We created a binary variable because we had small sample sizes for some IUCN designations. To compare proportions of trade-restricted taxa, we recorded whether species were listed in the Appendices of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) (UNEP-WCMC 2019). Finally, we used the Global Invasive Species Database (GISD) to determine if a species has a history of successful invasions (ISSG 2019). We supplemented this dataset to include species known to the authors as being considered invasive in peer-reviewed scientific literature, for example, established populations of Argentine black and white tegus (*Salvator merianae*) in Florida (Johnson et al. 2017). For enquiries involving hybrids, we took a conservative precautionary approach and categorised them as GISD-listed if at least one parent species has a history of invasions.

Analysis

We performed four analyses comparing the species in the phone enquiries with the species in exotic pet trade at large (i.e. species from U.S. imports). First, we compared the popularity (see *U.S. imports of live animals*) of the species in the phone enquiries to the overall popularity of species in the exotic pet trade at large. Next, we compared whether the proportion of threatened species (i.e. species listed in the IUCN Red List)

in the phone enquiries differs from the proportion of threatened species in the exotic pet trade at large. Then, we tested whether the proportion of species with trade restrictions (i.e. species listed in CITES appendix) in the phone enquiries differs from the proportion of species with trade restrictions in the exotic pet trade at large. Finally, we tested whether the proportion of species known to be invasive species elsewhere (whether or not in a GISD database) in the phone enquiries differs from the proportion of species known to be invasive species elsewhere in the exotic pet trade at large.

To test these hypotheses, we performed a series of empirical hypothesis tests (analogous to two-tailed t-tests but for ranked data; also known as bootstrap hypothesis testing) by randomly sampling from the U.S. imports dataset and comparing this to what was observed in the DAWE phone enquiries. To obtain the popularity of pets in the overall exotic pet trade, we uniformly randomly sampled species from the U.S. import records and calculated their collective median rank. To obtain the proportion of species threatened, with trade restrictions or invasive in the overall exotic pet trade, we randomly sampled species from the U.S. import records and recorded their collective proportions (respectively). The sample size of this sampling procedure was set to the total number of phone enquiries and was stratified by taxonomic class to account for taxonomic bias. For example, for the species popularity test, there was a total of 79 phone enquiries corresponding to species or subspecies, of which 42 enquiries were mammals (class Mammalia), 24 were birds (class Aves), 14 were reptiles (class Reptilia) and nine were fish (class Actinopterygii or Chondrichthyes). Therefore, for each iteration of sampling, we randomly sampled from the U.S. imports 42 mammals, 24 birds, 14 reptiles and nine fish. We repeated this sampling for 10,000 iterations for each analysis, with replacement. The sample size, stratified by taxonomic class, differed slightly for the proportion threatened (IUCN) test since some species are not yet evaluated by the IUCN or designated as Data Deficient and therefore excluded from analysis. We then compared the phone enquiry median rank or proportion (i.e. observed rank/proportion) with the resulting distribution of rank or proportions from sampling of the U.S. imports. P-values were calculated as the proportion of sampling iterations that were more extreme than the observed rank or proportion. For these analyses, we only considered taxa that were resolved to the taxonomic level of species (i.e. no genus, family etc.).

Results

Summary statistics

In total, there were 196 enquiries from 150 phone calls. Most enquiries were related to the private keeping of pets (n = 180), followed by breeding for food (n = 11; Fig. 1). Across all uses, there were 126 unique taxa (subspecies, species, genus, family etc.) and 84 unique species (including subspecies), of which 114 unique taxa and 73 unique species pertained to pet enquiries (Fig. 2a, b). Mammals received the most enquiries (n = 83) followed by birds (n = 27), then reptiles (n = 25; Fig. 3a). Carnivora was the order with the most en-

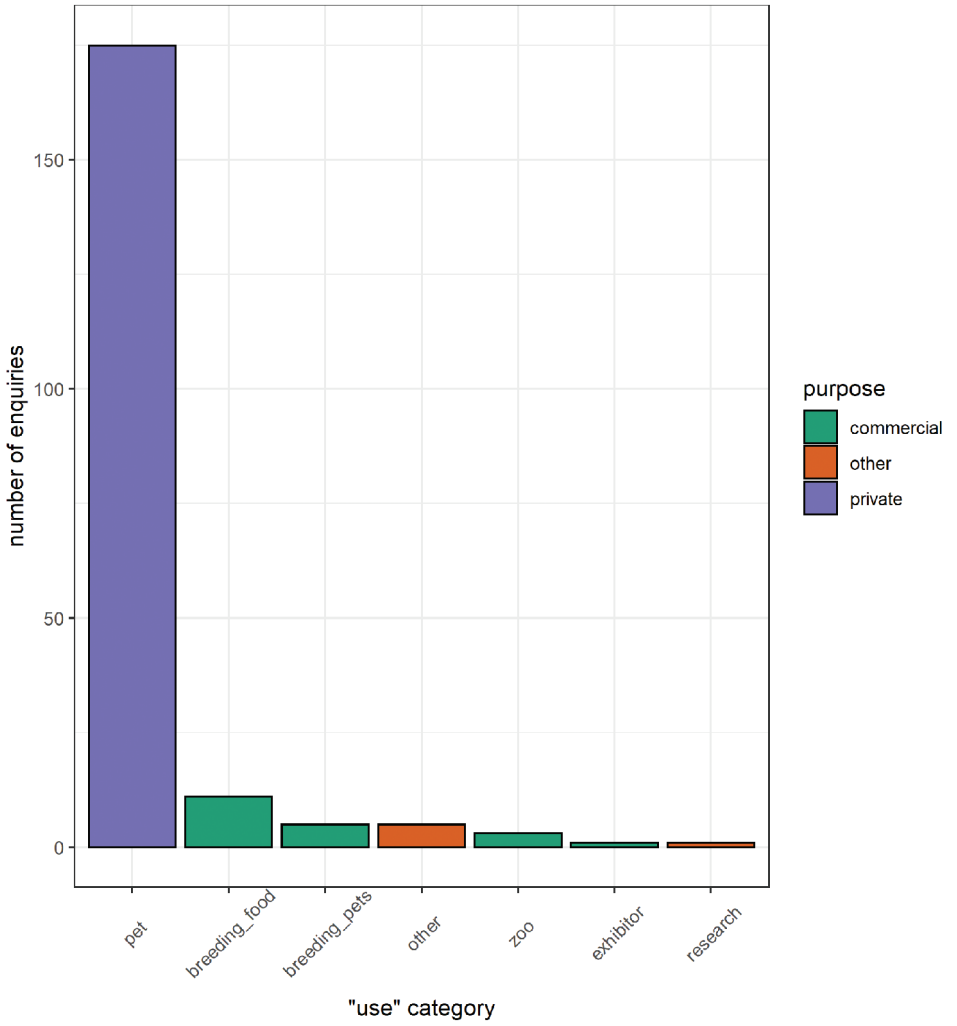

Figure 1. The stated use and purpose of public import enquiries recorded by the Australian Government Department of Agriculture, Water and the Environment. Use was categorised using enquiry notes (Pet = private use of the animal as a pet; breeding food = commercial use of the animal to be bred as food; breeding pets = commercial use of the animal to breed and sell as pets; zoo = commercial use for display in a zoo/wildlife park; exhibitor = commercial use for exhibitions/shows; research = use of the animal for scientific research; other = use not stated).

quiries, followed by parrots (Psittaciformes), then hedgehogs (Erinaceomorpha; Fig. 3b). Overall, the most enquired taxa were hedgehogs (Erinaceinae), fennec fox (*Vulpes zerda*), African grey parrot (*Psittacus erithacus*), monkeys (Simiiformes) and pygmy marmoset (*Cebuella pygmaea*; Fig. 3c). The two most commonly enquired non-vertebrate taxa were tarantula spiders (Theraphosidae, n = 14) and freshwater atyid shrimp (*Caridina*, n = 5). All remaining non-vertebrate taxa (n = 3) had a single enquiry each.

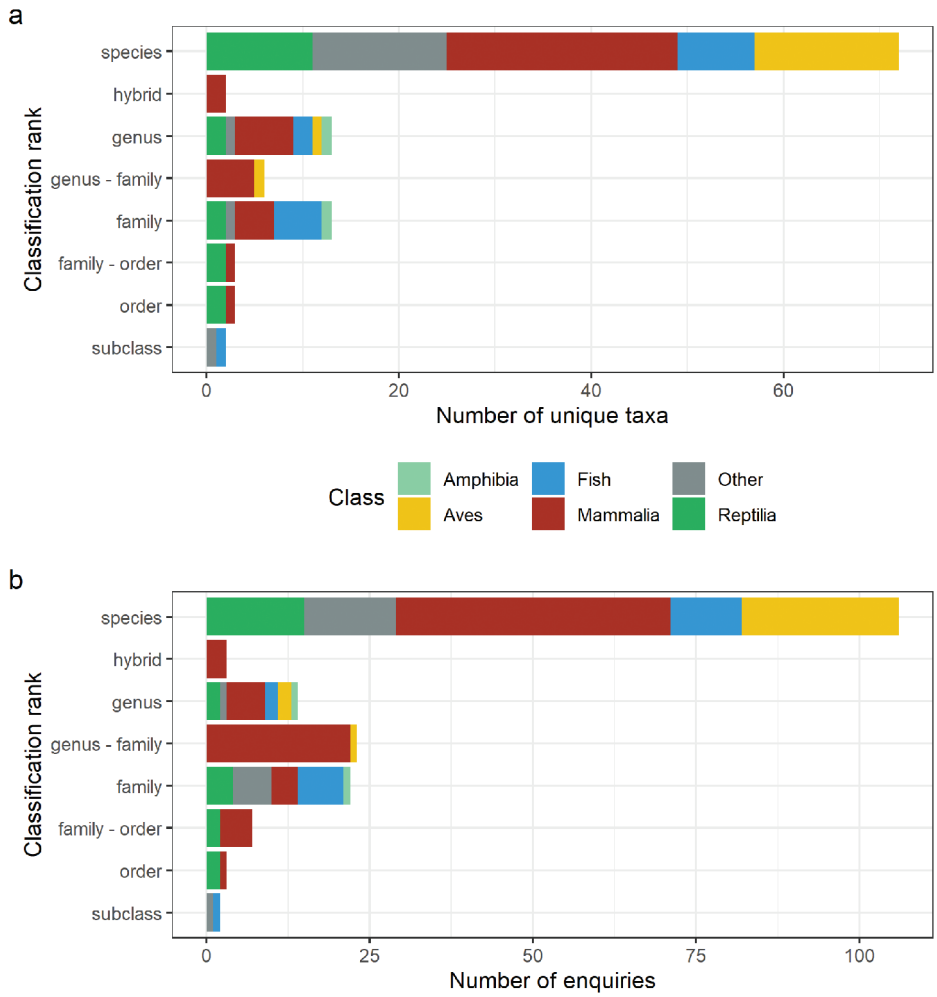

Figure 2. The number of unique taxa (**a**) and total enquiries (**b**) according to taxonomic classification rank for enquiries relating the private use of keeping or importing pets. We resolved the species or common names mentioned by the enquirers to the most specific possible taxonomic rank. Here, species refers to both species and subspecies. Genus – family corresponds to taxonomic ranks in between genus and family (i.e. tribe, subfamily) and family – order corresponds to taxonomic ranks in between family and order (i.e. infra-order). Colours correspond to the taxonomic class, where fish includes Chondrichthyes and Actinopterygii. Other taxonomic class refers to taxa not in vertebrate (Vertebrata) classes.

Comparative analysis

We found that enquired species were more popular than expected by chance compared to species in the U.S. exotic pet trade (p = 0.007, Fig. 4a). We found that the proportion of enquired species threatened by extinction (IUCN listed) is higher than the

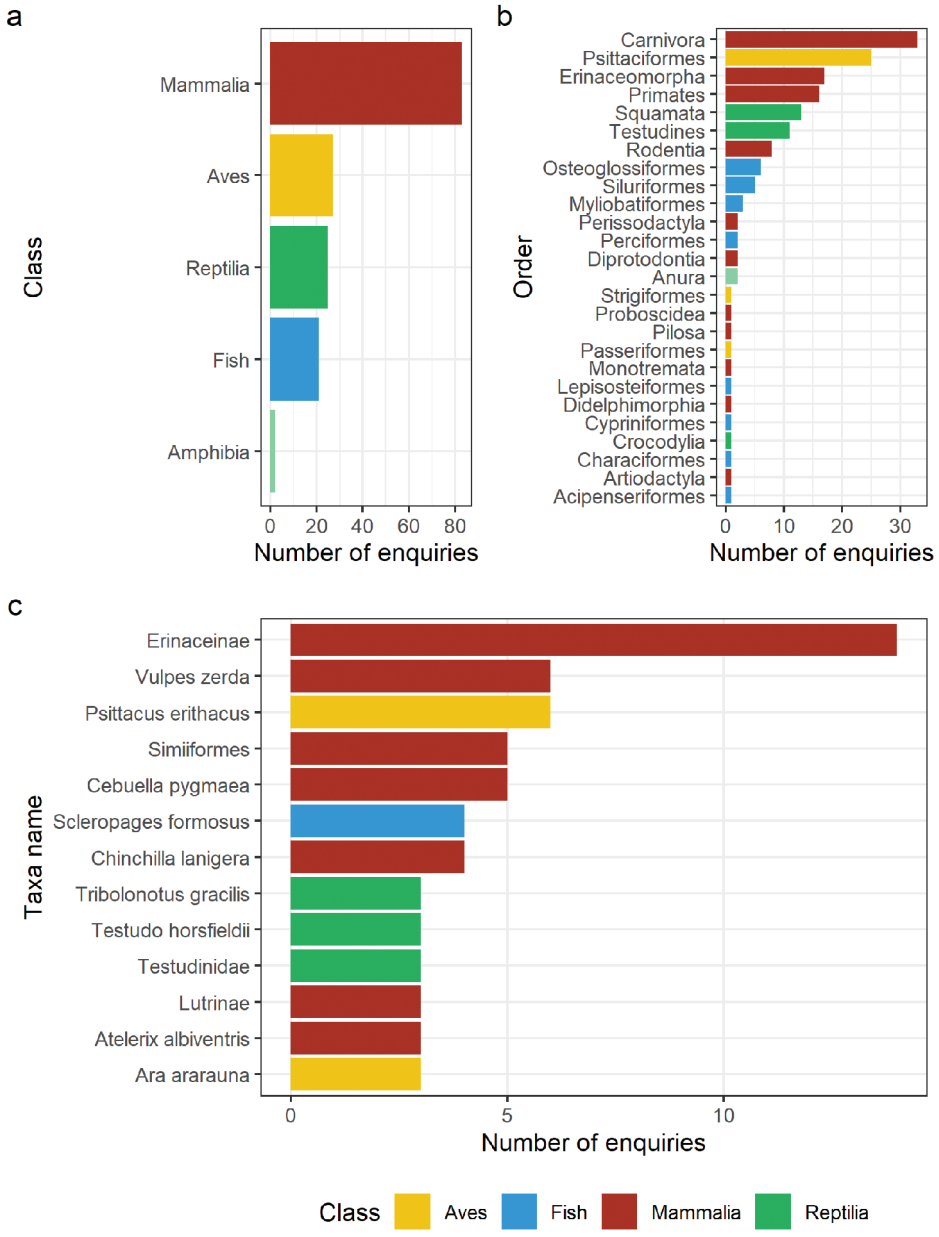

Figure 3. The number of enquiries by taxonomic class (**a**) and order (**b**) and highest taxa specified (**c**), excluding invertebrates. The subfamily Erinaceinae includes hedgehogs, *Vulpes zerda* is the fennec fox, *Psittacus erithacus* is the African grey parrot, order Simiiformes refers to monkeys, *Cebuella pygmaea* is the pygmy marmoset, *Scelropages formosus* is the Asian arowana, *Chinchilla lanigera* is the long-tailed chinchilla, *Tribolonotus gracilis* is the red-eyed crocodile skink, *Testudo horsfieldii* is the Russian tortoise, the family Testudinidae includes tortoises, the family Lutrinae include otters, *Atelerix albiventris* is the four-toed hedgehog and *Ara ararauna* is the blue-and-yellow macaw.

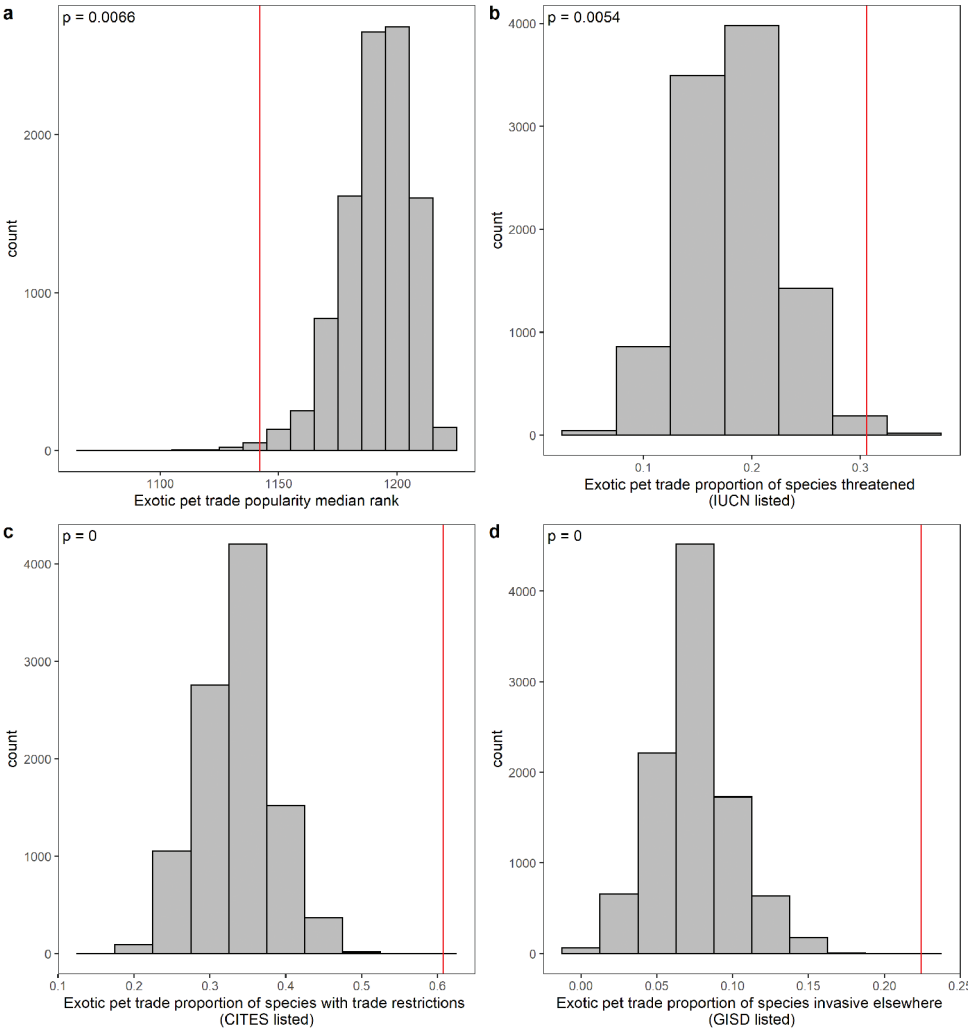

Figure 4. Empirical hypothesis tests comparing: (**a**) enquired species popularity; (**b**) proportion of threatened species; (**c**) proportion of international trade-restricted species; and (**d**) proportion of invasive species, to the overall exotic pet trade. Each histogram represents 10,000 iterations of random sampling from the U.S. Fish and Wildlife imports dataset from 1999–2016 (representative of the Western exotic pet trade), stratified by taxonomic class. Red lines correspond to the 'observed' median rank or proportion from the enquired species. P-values are calculated as the proportion of sampling iterations that fall to the left or right of the observed rank or proportion. Non-vertebrate taxa were not included in these analyses.

proportion in overall pet trade (p = 0.005, Fig. 4b). Additionally, we found that the proportion of enquired species with trade restrictions (CITES listed) is higher than the proportion in overall pet trade (p < 0.005, Fig. 4c). Finally, we found that the proportion of enquired species that are invasive species elsewhere (GISD listed) is higher than the proportion found in overall pet trade (p < 0.005, Fig. 4d).

Discussion

Australia imposes strict legislation to prevent the importation of alien vertebrate species (Henderson and Bomford 2011), yet the continual rise in illegally smuggled pets suggests that biosecurity efforts are being undermined (Toomes et al. 2019). Here, we characterised the attributes of desirable alien species. In the absence of direct information on which illegal alien species are most desirable, our approach serves as a reasonable first step to identify the characteristics of species that can be a future and conservation biosecurity threat. We revealed that the Australian desire for illegal alien pets is biased towards species threatened with extinction, species with global trade restrictions in place, species with a history of successful invasions and species frequently imported into the U.S., a western market with less stringent pet-trade regulations. In addition, we show a taxonomic bias towards a desire for mammal species. This knowledge is easily interpretable and can be used to anticipate future trends in illegal animal imports and to focus biosecurity surveillance efforts.

Our findings that desired species were more likely to be IUCN-listed and CITES-listed compared to overall trade are consistent with the Anthropogenic Allee Effect, a process in which the trade and harvest of a species increases with rarity due to its effect on perceived value (Courchamp et al. 2006; Holden and McDonald-Madden 2017). Specifically, our results show a bias towards CITES-listed primates, some of which have previously been seized from illegal captivity in Australia, such as the pygmy marmoset (*Cebuella pygmaea*) (Toomes et al. 2019). In Thailand, Siriwat et al. (2019) found a high number of primates for sale in various social media groups, as well as price-rarity dynamics consistent with the Anthropogenic Allee Effect.

In addition to conservation indicators, we found that desired species were much more likely to be invasive than expected by chance. Unlike the Anthropogenic Allee Effect, we are not aware of any study that shows a correlation between desirability of a species and their invasion status. This novel finding is of great concern for biosecurity agencies because it suggests that a filtering process is occurring where illegally smuggled animals may already be "pre-selected" to have the characteristics that are correlated with invasive species. For instance, traits closely associated with successful invasions include high fecundity and broad climatic tolerances (Herrel and van der Meijden 2014; Capellini et al. 2015; Howeth et al. 2016). In addition, the most desired taxa (mammals and birds) are considered 'charismatic', meaning people prefer them due to their appearance, behaviour or function (Beeves et al. 2019). These charismatic taxa may present an additional challenge to biosecurity because, if they become introduced or established, the general public may oppose eradication efforts (e.g. free-roaming horses in Australia, monk parakeets in the U.S. (Crowley et al. 2017; Knight 2019; Pruett-Jones et al. 2012)). Some examples of enquired species, which have yet to be detected in Australia but have established invasive species elsewhere, include the Argentine black and white tegus (*S. merianae*) (Johnson et al. 2017) and raccoon dogs (*Nyctereutes procyonoides*) (Kauhala and Kowalczyk 2011), representing potential future biosecurity risks for Australia. However, we emphasise that the probability of establishment of alien

species, as well as the scale of potential impacts, should be considered alongside public desire in determining high-priority biosecurity threats (Bacher et al. 2018; Blackburn et al. 2014; Bomford et al. 2009; Cassey et al. 2014; Davidson et al. 2016).

Our analysis relied on information collected in the style of a self-selecting survey from people interested in acquiring alien species, particularly pets. This does not necessarily represent actual intentions to illegally acquire alien pets and it remains unknown how desirability and introduction efforts are correlated. Given the records of illegally smuggled animals and illegally kept pets in Australia (Toomes et al. 2019), it is clear that there are people in Australia intent on acquiring illegal-alien pets. Whether the enquirers' desired pets are aligned with people who illegally acquire pets has not been tested. Therefore, one future avenue of research would be to interview people involved in the illicit trade. However, this is a problem with illegal activities in general; it is difficult to acquire information as people are unwilling to disclose or admit to illicit actions (Gnambs and Kaspar 2015). Following survey methodologies developed in the field of criminology may be useful to acquire information about the species in the illicit trade and the motives behind the want to acquire these species (Kleck and Roberts 2012). Similarly, these methods could be used to contact existing Australian wildlife breeders/traders and acquire a list of desired species that would be traded if legalised. Such a dataset would provide a representative sample of Australian wildlife traders and would help verify the extent to which anonymous enquiries are representative.

The legislative framework surrounding the import of alien pets, to which our enquiry data pertain, has a number of shortcomings that need to be addressed in order for the threat of alien imports to be reduced. In particular, there are discrepancies between what can be legally imported into Australia and what can be legally kept in domestic captivity as part of the national permitted list (Part 13A of the EPBC 1999) or State/Territory legislation. A large number of species are not permitted for live import, yet possession of live individuals within Australia is not necessarily a prosecutable offence unless evidence can be provided that the individuals have an illegal origin (Ciavaglia et al. 2015). Such evidence, requiring forensic analysis of provenance (e.g. Campbell et al. (2019)) is rarely available and costly to acquire. Thus, the purportedly captive-bred trade of species which potentially pose high biosecurity risks to Australia and which potentially originated from illegal import, continues unabated. We recommend renewed priority in addressing this legislative gap, including a national audit of alien species currently traded, in order to increase synergy between permitted imports and legal captive keeping.

Using U.S. import frequency, we have demonstrated that Australian import enquiries are heavily biased towards species popular in an overseas western market. The underlying process behind this observation deserves more investigation. We hypothesise that both U.S. legal trade and Australian demand for alien pets are driven by the same underlying processes, facilitated by the emergent role of social media in providing access to and awareness of available pets (Clarke et al. 2019; Harrington et al. 2019; Kitson and Nekaris 2017). Under this hypothesis, DAWE enquiries would represent a random sample of desire for species in the U.S. trade weighted by their popularity. This suggests the U.S. import data may have considerable utility for Australian biosecurity in predict-

ing species that are likely to either be illegally present yet undetected, or arrive illegally in the short-term future. This is exemplified by the fact that the vast majority (98.7%) of the 75 alien reptile species detected in Australia are present in the U.S. trade (Toomes et al. 2019). Further research aims to test these hypotheses with a comparative analysis between U.S. imports and the interception records collated by Toomes et al. (2019).

Conclusions

Invasive alien species have the potential to be introduced into Australia despite substantial investment in border and post-border biosecurity. We characterised a subset of domestic desire for alien pets via public import enquiries and identified several biases pertinent to both biosecurity and the conservation of threatened species. Specifically, desired species are more likely to be threatened by extinction and be invasive species elsewhere compared to species in the overall pet trade. Moreover, we emphasise the need for modifications to Australia's live import list in order to maintain relevance with a rapidly changing international pet trade. Finally, the utility of the U.S. pet demand as a predictor of Australian desire for alien pets needs to be investigated further and for other regional pet markets, in order to foster greater biosecurity preparedness.

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