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Untangling the web: dynamics of Australia's online terrestrial invertebrate trade

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Abstract

The trade and keeping of exotic pets has serious implications for both biosecurity and biodiversity conservation. In Australia, the online trade of live invertebrates is an understudied and unregulated issue, with almost non-existent monitoring. It is uncertain what species are being traded, whether they are being identified correctly, and how they are being sourced (i.e., captive bred or wild harvested, native, or alien). Consequently, potential invasion risks and conservation concerns remain unknown. Here, we explored the online trade of terrestrial invertebrates in Australia across a range of publicly available e-commerce platforms. We detected 264 species of invertebrate traded, from 71 families and 168 genera over 12 months. The native *Extatosoma tiaratum* (giant prickly stick insect) was the most traded species, while the most popular families were Phasmatidae (stick insects), Formicidae (ants) and Theraphosidae (tarantulas). Three species are known to be invasive in Australia, while 87% of species traded were native. The conservation status of almost of the species (92%) listed in the invertebrate trade has not been evaluated. Exploring socio-demographic relationships, we found that human population density was positively correlated with the location of invertebrate sellers. Further, we found the classifieds website had lower prices in contrast to traditional online pet-stores (median of c. A$7 less). Finally, we did not observe a saturation in the number of species traded in our one-year study, exemplifying the need for large scale monitoring and risk assessments for Australia's online terrestrial invertebrate trade. We recommend continued surveillance of live invertebrate trade on e-commerce sites. Substantial changes to legislation and monitoring methods are required at a national level to control the vast number of invertebrates traded across the country, and to minimise the future risks of the invertebrate trade.

KEYWORDS
biosecurity, conservation, e-commerce, invasive species, terrestrial invertebrate, wildlife trade

INTRODUCTION

Biodiversity is increasingly threatened by the commercial exploitation and trade of wildlife (Cardoso et al. 2021). A major driver of the global wildlife trade is the consumer demand for rare and exotic pets (Bush et al. 2014). Wildlife trade has many adverse consequences, including overexploitation of wild populations, the introduction of alien species (through accidental pathways, or intentional release into the environment), and the spread of zoonotic diseases (Alacs & Georges 2008; 't Sas-Rolfes et al. 2019), in addition to a multitude of animal welfare and security issues (Wyatt et al. 2021). These issues are exacerbated when trade is

poorly regulated (Cardoso et al. 2021). The global wildlife trade is worth billions of dollars annually (Wilson-Wilde 2010) and encompasses both the legal and illicit commerce of tens-of-thousands of wildlife species (Bending 2015; Fukushima et al. 2021). The Internet has greatly facilitated the exotic pet trade, allowing for greater transnational advertisement and transport of traded species (Fink et al. 2021; Morcatty et al. 2021; Stringham et al. 2020). Previous research has found live animals traded across a vast range of online platforms, revealing the pervasiveness of the internet trade (Fink et al. 2021; Hernandez-Castro & Roberts 2015; Stringham et al. 2020). However, the majority of research, and subsequent conservation efforts, appear to be systematically biased towards vertebrates, leaving the trade of lesser charismatic species, such as invertebrates, widely unrecognised and under researched (Black et al. 2001; Cardoso, Borges, et al. 2011; Caldas et al. 2018; dos Santos et al. 2020).

In recent years the number of online vendors selling terrestrial invertebrates has increased globally (Kumschick et al. 2016). Despite this trend, there has been no investigation into the variety of terrestrial invertebrate species traded in Australia nor the potential biosecurity hazards associated with their release into the wild. Invasive invertebrates introduced through wildlife trade pose a direct threat to both native biodiversity and agriculture (Lockwood et al. 2019; Ricciardi 2015). To mitigate these threats, Australia invests heavily in biosecurity to prevent invasive hitchhiker species incursions (Bradshaw et al. 2021; Hoffmann & Broadhurst 2016). The Emergency Plant Pest Response Deed (EPPRD) responds to alien invertebrate incursions affecting plant industries, particularly the agriculture industry (Carnegie & Nahrung 2019). However, the extent to which the government and organisations are concerned about pet invertebrates is unclear, and there are significant deficiencies in Australia's biosecurity system with regard to domestic invertebrate trade.

While the conservation of vertebrate species is better studied, invertebrates may be suffering an even higher global extinction rate (Cardoso, Erwin, et al. 2011; Eisenhauer et al. 2019). This remains largely unacknowledged in contemporary policy and conservation management efforts (Eisenhauer et al. 2019). Poor taxonomic resolution and general lack of species distribution data are major impediments for researching the impact of trade on invertebrate populations. Declines of some Australian invertebrates have been documented over time (New & Yen 2013; Rix et al. 2017; Taylor et al. 2018; Yen 1995), with some notable long term case studies (Braby et al. 2021; Green et al. 2021; Kearney et al. 2021). However, the magnitude, geographical extent, and environmental impact for the vast majority of invertebrates is largely unknown. By understanding the diversity of invertebrate species traded in Australia and the drivers (i.e., consumer demand) behind this trade, we can gain a greater understanding of the risk factors (including overexploitation, introduction of exotic species, and spread of zoonotic disease) recipient environments and traded species are facing.

While studies have explored the trade of invertebrates in other countries (Caldas et al. 2018; Kumschick et al. 2016; Nelufule et al. 2020), no such investigation exists for Australia. All Australian States have some degree of legislation regarding the import and export of invertebrates across their borders (Braby 2018; Braby et al. 2021; Hoffmann & Broadhurst 2016) However, legislation varies between the Commonwealth (i.e., at a national level) and States and Territories (e.g., the number of species declared as pests and the level of penalties), reducing the credibility and effectiveness of conservation efforts (Braby 2018; Eisenhauer et al. 2019). Overall, the Australian legal system regulating domestic invertebrate trade is mostly non-existent, focusing exclusively on crop pests (Canyon et al. 2002; Yen 2010), and thus ignoring invertebrates traded as pets.

Here, we explore the diversity and scale of the Australian live terrestrial invertebrate trade and identify associated conservation and biosecurity risks. We extracted data from public online listings (i.e., advertisements) on e-commerce websites to develop a baseline understanding of the terrestrial invertebrate species traded online in Australia. We identified the trade of species with high conservation or biosecurity concern. Further, we tested for relationships between species traits and rate of trade. Finally, we explored market-level trends by investigating how the abundance and location of traded invertebrates correlate with factors that may influence the ability of traders to acquire and keep pets, namely human population density, and median annual income. Ultimately, our results can be used to improve current policies regarding the trade of invertebrates, by providing evidence of the key threats the online terrestrial invertebrate trade poses for Australian biosecurity and conservation.

METHODS

We collected terrestrial invertebrate listings (i.e., advertisements) from two different categories of website: (i) a popular Australian classifieds website, and (ii) 23 Australian online pet stores. The classifieds website allows users to post their own listings of invertebrate pets, where on pet store websites, only the owner of the pet store can post invertebrate listings.

Classifieds website trade data

We collected online wildlife listings from a popular publicly viewable Australian classifieds website in an automated fashion (sensu Stringham et al. 2020). Data collection occurred weekly, over 12 months (July 2019–

July 2020). We extracted listings exclusively from the website category 'Other Pets', (there is no specific category for invertebrates on this website). We collected a total of 24 984 listings. Information associated with each listing included: (i) the date, (ii) the physical location (suburb and State), (iii) asking price, and (iv) a unique listing identification code (see Table 1 for full list of attributes). Our research was conducted under the Adelaide University Human Research Ethics Committee approval: Semi-automated monitoring of international online wildlife trade, No. H-2020-184. All personal data from listings were deidentified for analyses. We chose to keep the name of the website anonymous as it is considered good ethical practice (Hinsley et al. 2016).

The extracted listings encompassed a large variety of wildlife and non-wildlife products. Because our focus was restricted to terrestrial invertebrates traded as pets, we manually removed listings irrelevant to our study. These irrelevant listings included: (i) duplicate listings ($n = 525$); (ii) listings selling other non-target wildlife (e.g., guinea pigs and alpacas, $n = 22\,397$); (iii) listings that were not selling live animals (e.g., equipment such as terrariums, $n = 39$); and (iv) listings selling aquatic invertebrates (e.g., shrimp and aquatic snails, $n = 29$). We also removed listings selling invertebrates for commercial purposes, such as honey production (*Apis mellifera*, honeybees, $n = 102$) and feeder food for domestic pets (i.e., mealworms and crickets, $n = 11$). For each listing we recorded if the user was requesting an invertebrate species (i.e., 'wanted') or if they were selling. We removed wanted listings and focussed only on sales. This cleaning process resulted in a subset of 1701 listings selling terrestrial invertebrate pets. Some listings advertised more than one taxon ($n = 129$), and we split these instances into unique taxa-listing combinations for our dataset. The resulting dataset contained every terrestrial invertebrate taxa-listing combination for the purpose of pet trade on the classifieds website over a period of 12 months ($n = 2205$ unique rows selling a single invertebrate taxon).

We identified taxa advertised in each listing to the most specific rank possible (i.e., species and genus), using the title, images, and text description provided in the listing. Several invertebrates that lacked taxonomic knowledge or were poorly displayed in listing images could only be assigned to its genus ($n = 46$ distinct taxa), or coarser taxonomic levels ($n = 21$ distinct taxa). We standardised taxonomic names using Global Biodiversity Information Facility taxonomic database (hereafter, GBIF; GBIF 2021). We extracted and recorded upstream taxonomic information (i.e., order, class, family, and species name) for each taxon, using GBIF. Additionally, we obtained the IUCN Red List of Threatened Species status for each species (IUCN 2022).

Online pet stores

We conducted a snapshot survey (i.e., at one point in time, May 2021) of a range of Australian online pet stores using a systematic web search, involving three steps: (1) defining key search words to use; (2) conducting searches on Google Search Engine; and (3) collating and classifying the relevance of websites returned from the searches (Stringham et al. 2020). We created key words for search phrases ($n = 58$) from a combination of general invertebrate names (e.g., 'spiders', 'scorpions', 'ants', 'bugs', and 'insects') and trade terms (e.g., 'for sale', 'trade', 'buy online', and 'pet store') (see Table S1 for the full list of search terms). Using Google Search Engine, we recorded the first 10 websites displayed for each search term combination. From a total of 58 search term combinations, we obtained a list of 30 unique pet stores selling invertebrates. We did not consider websites that: exclusively sold feeder food (i.e., crickets and meal worms); did

TABLE 1 Variables recorded from each invertebrate listing on a prominent Australian classifieds website.

Variable name	Variable type	Format example	Explanation
Date posted	Date	27/09/2020	Date of when the listing was first posted to the website
Date recorded	Date	28/09/2020	Date of when the listing information was extracted from the website
Listing title	Text string	Tarantula Rubiseta: 80–90 mm female	Listing title chosen by the seller
Listing text	Text string	*Phlogius* 'Rubiseta'. Absolutely beautiful spider, vicious eater and very active. Comes with 20 × 20 reptile one enclosure.	Description chosen by the seller
Seller location	Text string	Penola, South Australia	Seller location listed on website
Postcode	Integer	5277	Postcode of seller location
Listing URL	Text string	https://www.classifieds/example.com.au	URL for the webpage containing the target listing
Image URL's	Text string	https://example.jpg	URLs for photo's seller uploaded to the listing
Listing price	Integer	A$350	The listed price of the item for sale in listing

not sell live invertebrates (e.g., preserved invertebrate specimens for collection); or did not provide information on invertebrates for sale (e.g., the buyer must visit their physical store to see what is for sale). This resulted in 23 websites that we then surveyed for terrestrial invertebrate trade. Due to COVID-19 and the distances between pet stores nationwide, it was not logistically feasible to compliment this research with physical visits to pet stores. Thus, all of our surveys were done over the internet. Over a period of 1 month in May 2021, we visited each website once and manually extracted all invertebrate listings. We recorded a total of 701 invertebrate listings. The variables extracted from each listing were the same as those extracted from the Australian classifieds website (Table 1). Likewise to the classifieds website, we identified each invertebrate to the most specific taxonomic rank possible (most commonly, species name), and collected upstream taxonomic information from GBIF (GBIF 2021). We obtained the IUCN Red List of Threatened Species status for each species. We did not sample across an entire year because preliminary investigation revealed that pet store listings are changed/updated far less often compared with classifieds.

Ancillary data

To investigate spatial patterns within invertebrate species distributions, and invertebrate seller characteristics, we collected: (i) species occurrence datasets from GBIF (GBIF 2021); (ii) Australian State suburb boundaries from the Australian Bureau of Statistics (ABS 2017); (iii) population estimates by Local Government Area, 2019 to 2020 (ABS 2021); and (iv) Total income by Local Government Areas, 2011–12 to 2017–18 (ABS 2020).

Species provenance

Using data from GBIF we assessed the occurrences of each species, outside Australia and within Australia (GBIF 2021). If a species had occurrences only within Australia, we assumed the species was native. Species with occurrences only outside Australia, and both within and outside of Australia were further researched ($n = 89$). For each of these species we conducted a short literature review on Google Scholar to assess the species distribution history, and cross-checked species occurrence data from the Atlas of Living Australia (ALA 2022).

Characteristics of the most popular species

We identified the top 20 most traded species (i.e., species that featured in the greatest number of listings) from both types of e-commerce platform (Table S2). We collected characteristics for each species that we hypothesised are likely to influence either: (i) an invertebrate buyer's (i.e., consumer) preference; (ii) the price of an individual species; or (iii) conservation and biosecurity concerns associated with the species. These variables were: (i) conservation status (from IUCN red list of threatened species; IUCN 2022); (ii); a species capacity of delivering a painful bite/sting to humans, and if the bite/sting can be fatal, and (iii) if handling the species is not recommended (Table S3). To collect this information, we searched peer-reviewed literature on Google Scholar, using search terms including the species scientific or common name, and words describing invertebrate traits (e.g., venomous) or relating to pet keeping practices (e.g., handling). We acquired information on pet keeping practices of species from hobbyist knowledge from websites and online forums. Additionally, we acquired data from GBIF, Atlas of Living Australia, and IUCN's red list of threaten species (ALA 2022; GBIF 2021; IUCN 2022).

Analysis

To test the influence of human population density by km^2 (population estimates by LGA 2019 to 2020), and average annual income (Total income by LGA, 2011–2012 to 2017–2018), on the occupancy of invertebrate sellers in Local Government Areas (LGA) across Australia, we performed a logistic regression, using a generalised linear model (GLM) with a logit link function and binomial distribution. We set the response variable as the presence of advertisements of invertebrates in a suburb (from our online surveys) and the explanatory variables as human population density and annual income. We tested for over dispersion of data using the 'pchisq' function (R package *stats*, R Core Team 2021). We $\log_{10}$ transformed median income and population density values prior to analyses, to satisfy GLM assumptions of normally distributed residuals.

We tested whether the prices of invertebrates on the classifieds website were different to the prices of invertebrates in online pet stores. First, we calculated price-per-unit by dividing the listing price by the number of individuals listed for sale. We then calculated price differences per species as the mean species price-per-unit on the classifieds website, minus the mean species price-per-unit from pet stores. To ensure sufficient data was available for comparison, we used a subset of species that were featured in three or more listings on both online platforms. This equated to a total of 27 species sold on both classifieds and online pet stores with sufficient data. We constructed a linear regression model to investigate the overall difference between pet store and classifieds website prices (i.e., all species together). Additionally, we tested for differences in prices at the species level, using one linear regression per species (27 models), with the explanatory variable as 'platform type', and response variable as 'price-per-unit'. Finally, we performed a paired

sample Wilcoxon test, to compare the distribution of price differences on the classifieds website and online pet stores.

We performed all statistical analyses, modelling and data summaries in the R software environment for graphical and statistical computing, version 4.0.5 (R Core Team 2021). All upstream taxonomic information was collected from GBIF, using the 'classification' function from the *taxize* package (Chamberlain et al. 2020). We produced a species accumulation curve, using the 'speccum' function from the *vegan* package (Oksanen et al. 2020) Within the *tidyverse* collection of packages, version 1.3.0, we used the package *dplyr* to assist with data manipulation (Wickham et al. 2021) and *ggplot2* to create most of the graphics (Wickham 2016). The *performance* package was used to evaluate the performance of the GLM's (Lüdecke et al. 2021).

RESULTS

From the 25 685 online listings investigated (24 984 from the classifieds website and 701 from online pet stores), we identified a total of 264 distinct invertebrate species. We identified over two-thirds of listings to the taxonomic level of species (68% on the classifieds website, 69% in pet stores, Table 2). From the remaining 704 listings selling invertebrates, we identified 94 to genus, 23 to family, six to order and three to class.

Invertebrate species diversity

Public classifieds website

From July 2019 to July 2020, 1701 listings trading terrestrial invertebrates were published on an Australian popular classifieds website. To account for listings selling multiple species of invertebrates, several listings were split into multiple rows (one for each unique taxa-listing combination), resulting in 2205 rows selling a single invertebrate taxon. From these listings, we identified 145 distinct invertebrate species ($n = 1761$ listings). These species derived from 58 families, 21 orders, and seven classes (Table S2).

The cumulative number of species recorded on the classifieds website increased through time, and never reached an asymptomatic plateau (Figure 1).

Species abundance and composition differed between invertebrate orders (Figure 2). The order with the greatest number of listings was Phasmatodea, followed by orders Hymenoptera and Araneae. The order Hymenoptera contained the greatest number of species traded, followed by Araneae (Figure 2b).

The taxonomic composition of classifieds listings was dominated by stick insects (family Phasmatidae), ants (family Formicidae), scorpions (families Hormuridae, Bothriuridae, Buthidae, and Scorpionidae) and tarantulas (family Theraphosidae). Stick insects had the greatest number of classifieds listings (22.5% of listings). Ants accounted for more species than any other family (41 species) and were advertised in 21.6% of all classifieds listings (Table 3).

On the classifieds website, the top 10 most popular species (by number of listings) accounted for 44% of all listings, and *Extatosoma tiaratum* (giant prickly stick insect) was the most common species traded (Figure 3). When compared with the top 10 most popular species sold in online pet stores (Figure 4), five invertebrate species were ranked in the top 10 across both e-commerce platforms.

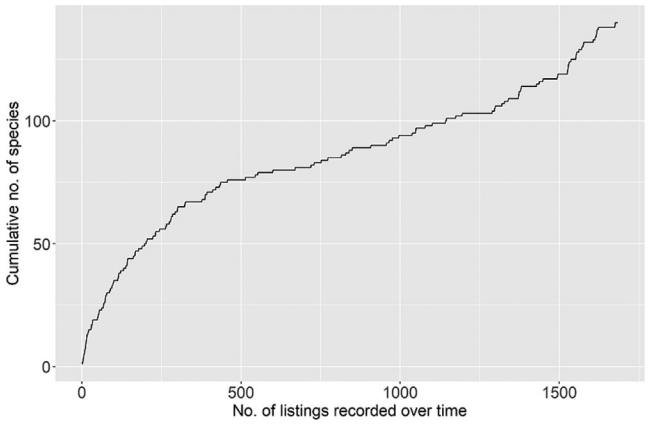

FIGURE 1 Species accumulation curve for invertebrate listings collected from the public classifieds website, representing the total cumulative number of species identified over time as listings were collected from the website.

TABLE 2 Distinct number of taxa identified to taxonomic levels and the total number of listings identified to each taxonomic level.

Highest level of identification	Distinct taxa identified (classifieds)	Number of listings (classifieds)	Distinct taxa identified (pet stores)	Number of listings (pet store)
Species	145	1761	201	427
Subspecies	1	5	0	0
Genus	46	343	71	224
Family	13	61	12	31
Order	5	15	3	4
Class	3	15	1	6

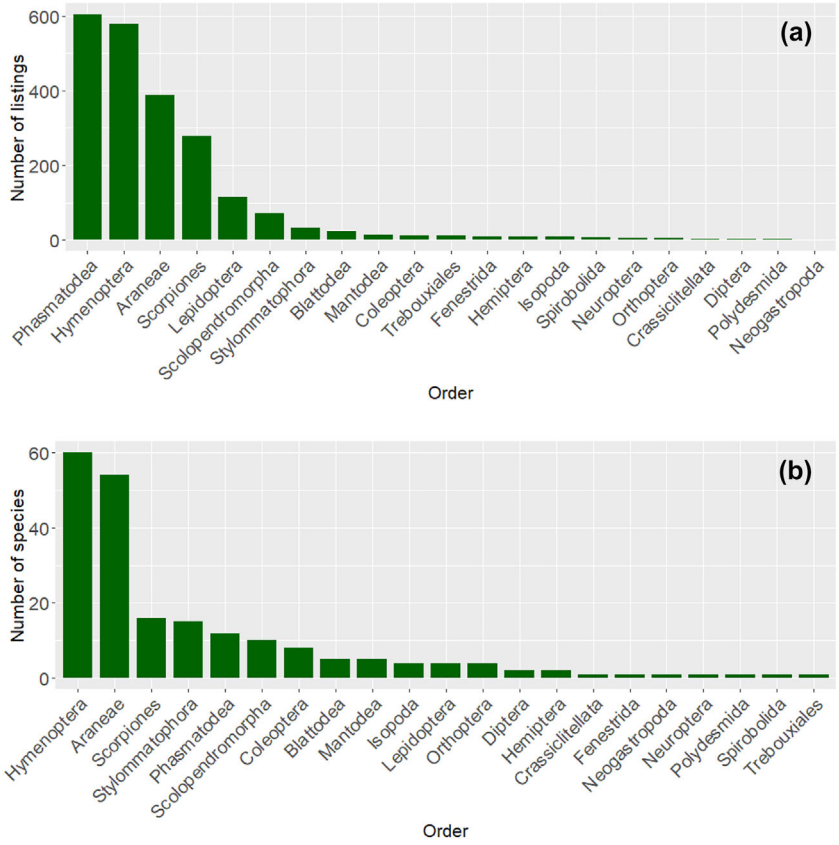

FIGURE 2 (a) Total number of invertebrate orders traded on the classifieds website. (b) Total number of species within each invertebrate order traded on the classifieds website.

TABLE 3 Invertebrate taxa featuring in the greatest numbers of listings on the public classifieds website and in online pet stores.

Scientific name	Common name	Taxonomic rank	Number of listings	Number of species	Percentage of all listings
Public classifieds website					
Phasmatodea	Stick insects	Order	497	12	22.5%
Formicidae	Ants	Family	477	41	21.6%
Scorpiones	Scorpions	Order	278	14	12.6%
Theraphosidae	Tarantulas	Family	202	4	9.2%
Online pet stores					
Phasmatodea	Stick insects	Order	39	13	5.6%
Scorpiones	Scorpions	Order	70	16	10%
Formicidae	Ants	Family	133	42	19%
Theraphosidae	Tarantulas	Family	102	3	14.6%

Online pet stores

From our manual collection of invertebrate sales from 23 online pet stores, we identified 201 distinct invertebrate species. These species derived from 71 distinct families, 21 orders, and six classes.

Overall, the composition and abundances of species traded in pet stores was similar to those traded on the classifieds website (Table 3). The composition of pet store listings was dominated by stick insects, ants, scorpions and tarantulas. At the family level, ants (with 42 species) were advertised in 19.0% of all online listings (Table 3).

The top 10 most popular species in online pet stores (by number of listings) accounted for 12.84% of all listings. Just as on the classifieds website, *Exatosoma tiaratum* was the most common species traded (Tables 3 and 4).

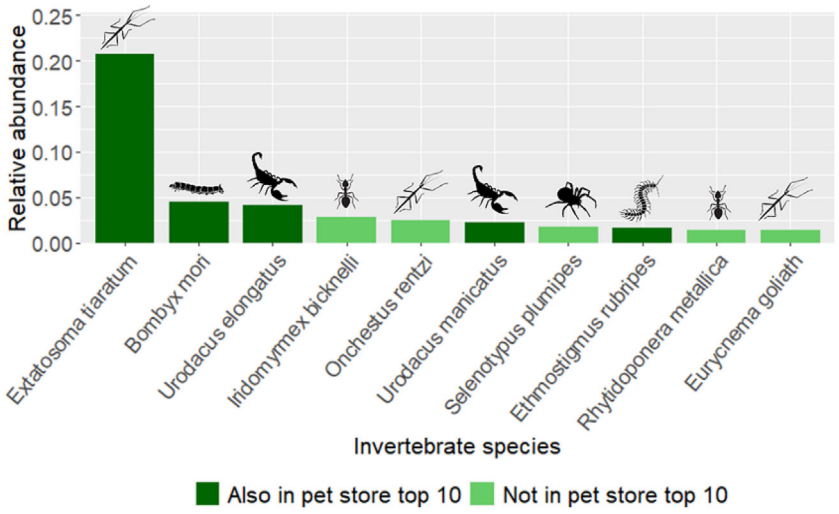

FIGURE 3 Bar graph of the top 10 most popular invertebrate species on the classifieds website by proportion of total listings, and those that also feature in the top 10 most popular species in online pet stores.

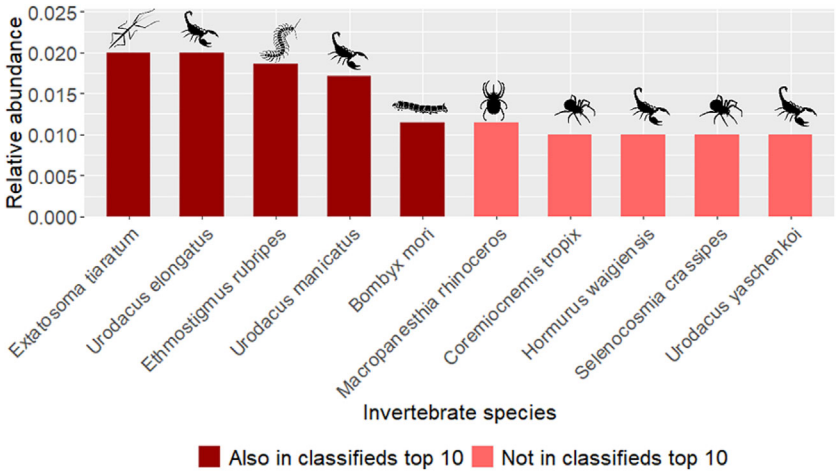

FIGURE 4 The top 10 most popular invertebrate species in online pet stores, and those that also feature in the top 10 most popular species on the Australian classifieds website. Note that *Urodacus elongatus* (Flinders Ranges scorpion) has the same relative abundance in online pet stores as *Exatosoma tiaratum* (giant prickly stick insect), the overall most traded species online.

Species provenance

Of the 264 species traded, we found that 230 species were native to Australia (87%). In contrast, we identified 34 alien species; non-native to Australia. Further, three of these species are invasive in Australia: (i) Asian tramp snail (*Bradybaena similaris*), (ii) African big-headed ant (*Pheidole megacephala*), and (iii) white garden snail/Mediterranean snail (*Theba pisana*). Our reviews of the Atlas of living Australia and peer-reviewed literature revealed that five of the 34 alien species were intentionally introduced to Australia as biocontrol agents for agricultural practices (ALA 2022).

Species conservation status

Almost none of the traded terrestrial invertebrate species have been assessed by IUCN (92%; 243 species unassessed). Seventeen species are categorised as Least Concern, one as Data Deficient, two as Near Threatened (*Ctenomorpha gargantua* and *Phyllium monteithi*), and one as Endangered (*Thersites mitchellae*) (see Table S4). Of the 21 IUCN assessed species, 15 are stick insects, and three are snails. Additionally, IUCN recorded eight species as 'not utilised' within wildlife trade. This indicates that there is no current knowledge on the trade of these species, despite our evidence of them in the Australian trade (IUCN 2022).

TABLE 4 Top 20 most listed invertebrate species on a public classifieds website and in online pet stores.

Scientific name	Common name	No. of listings
Extatosoma tiaratum	Giant prickly stick insect	481
Bombyx mori	Silkworm	111
Urodacus elongatus	Flinders Ranges scorpion	109
Iridomyrmex bicknelli	Rainbow ant, black pavement ant	66
Urodacus manicatus	Black rock scorpion	63
Onchestus rentzi	Crown stick insect	60
Hormurus waigiensis	Rainforest scorpion	55
Ethmostigmus rubripes	Australasian giant centipede	50
Selenotypus plumipes	Australian feather leg tarantula	40
Rhytidoponera metallica	Green head ant	38
Eurycnema goliath	Goliath stick insect	36
Iridomyrmex purpureus	Meat ant	32
Camponotus consobrinus	Banded sugar ant	31
Myrmecia pyriformis	Bull ant, inch ant	31
Atrax robustus	Sydney funnel-web spider	25
Sipyloidea larryi	Cyclone Larry stick insect	25
urodacus yaschenkoi	Desert scorpion	24
Lychas marmoreus	Marbled scorpion	24
Selenocosmia stirlingi	Barking spider, whistling spider	21
Selenocosmia crassipes	Queensland whistling tarantula, barking spider, bird-eating tarantula	20

Popular species characteristics

From examining the 20 most popular species of invertebrates traded (Table 4), we found that a large proportion are potentially dangerous to humans, where 15 species (75%) have records of delivering a painful bite, and/or, are not recommended for handling. Further, one species is considered potentially lethal to humans (Sydney funnel web spider: *Atrax robustus*). Only four of the top 20 species were evaluated by IUCN (*Eurycnema goliath*, *Extatosoma tiaratum*, *Onchestus rentzi* and *Sipyloidea larryi*); being all Phasmatodea and categorised as Least Concern.

Seller and market characteristics

The 2205 classifieds listings were published by 813 individual sellers, from 583 different suburbs (of 15 353 Australian suburbs (ABS 2017)). The greatest number of listings came from sellers in New South Wales (Figure 5a). At the taxonomic level of order, Victoria and New South Wales traded a more diverse range of invertebrates than other States (Figure 5b).

The greatest number of Australian online pet stores were in Victoria ($n = 8$), and Queensland ($n = 7$) (Figure 6a). However, the greatest number of invertebrate listings came from South Australian online pet stores (19.12% of listings). Queensland pet stores advertised a more diverse range of invertebrate orders than other States (Figure 6b). Fourteen of the online pet stores (60.86%) were located within capital cities. We found no online pet stores in the Northern Territory.

For the classifieds website, our results from the generalised linear model ($R^2 = 0.480611$) indicated that suburbs with higher population densities (people per km^2) were statistically more likely to contain invertebrate traders (effect size [± standard error] = 0.61562 ± 0.05337, z score = 11.535, p-value = 2.06e-10). There was no significant relationship between median annual income and invertebrate seller locations (effect size = −0.89740 ± 0.71457, z score = −1.256, p-value = 0.209).

A paired samples Wilcoxon test revealed prices were significantly higher in pet stores compared with the classifieds website ($V = 50$, p-value < 0.005), with a median price difference of A$7.44 for the same species (Figure 7). When comparing the price-per-unit for individual species with three or more listings on both e-commerce platforms ($n = 27$), eight species were significantly more expensive in pet stores than on the classifieds website, and the remaining species showed no individual statistical difference (Table S5).

DISCUSSION

The trade of any wildlife can pose genuine conservation and biosecurity risks, including invertebrates. Here, we

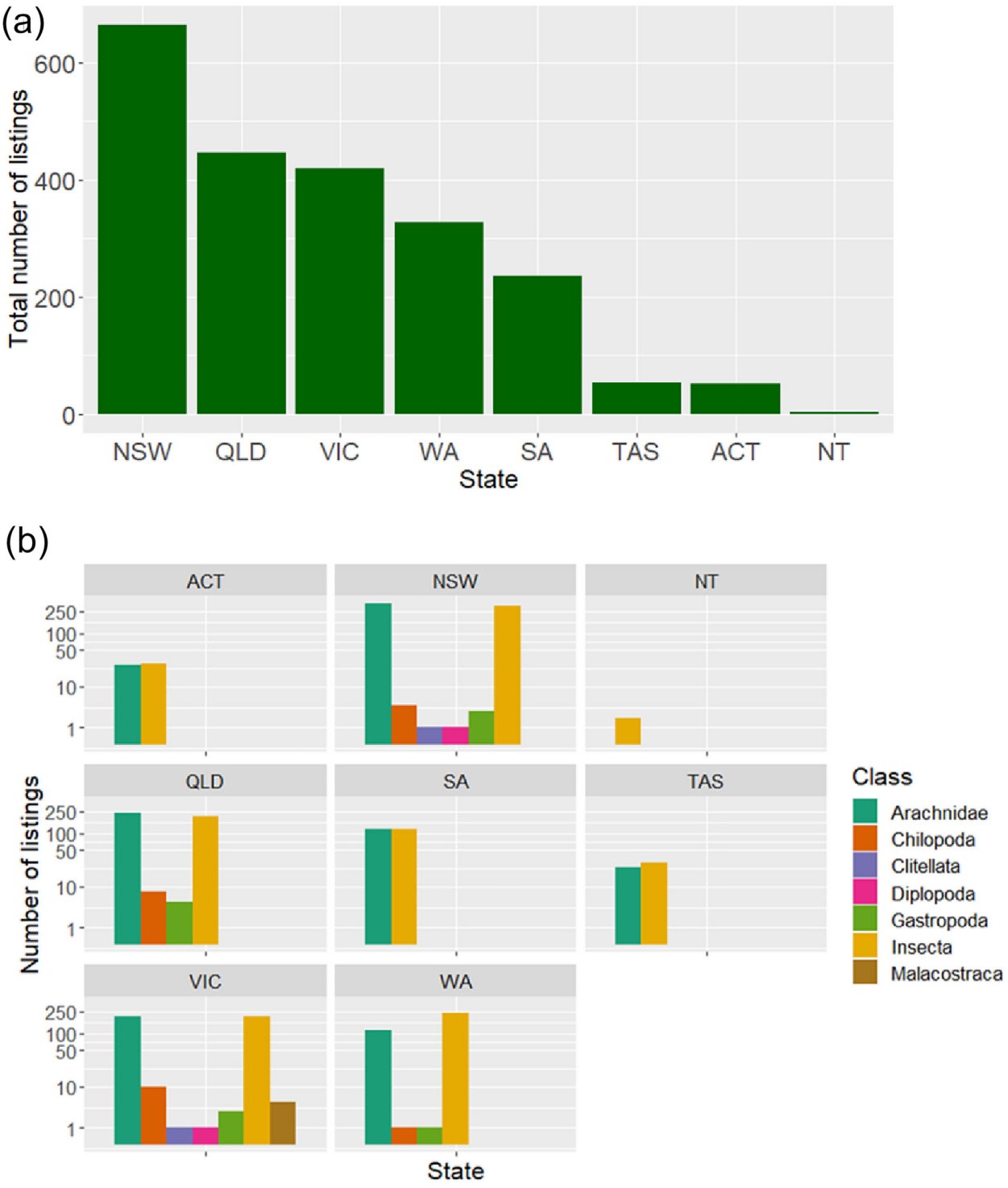

FIGURE 5 (a) Total number of invertebrate listings per State on the classifieds website, (b) classes of invertebrate for sale per State. *Note*: the *Y* axes are transformed to display less abundant classes.

identified 264 terrestrial invertebrate species being traded online in Australia; some in large quantities (>100 listings). It seems likely, from our species accumulation curve (Figure 1), that many more species are being traded online than identified in our one-year study. We identified three species known to be invasive in Australia, which are an immediate biosecurity risk as they are being traded outside their current distribution. For the rest of the species, biosecurity and conservation risks are still largely unknown. Understanding the drivers of consumer

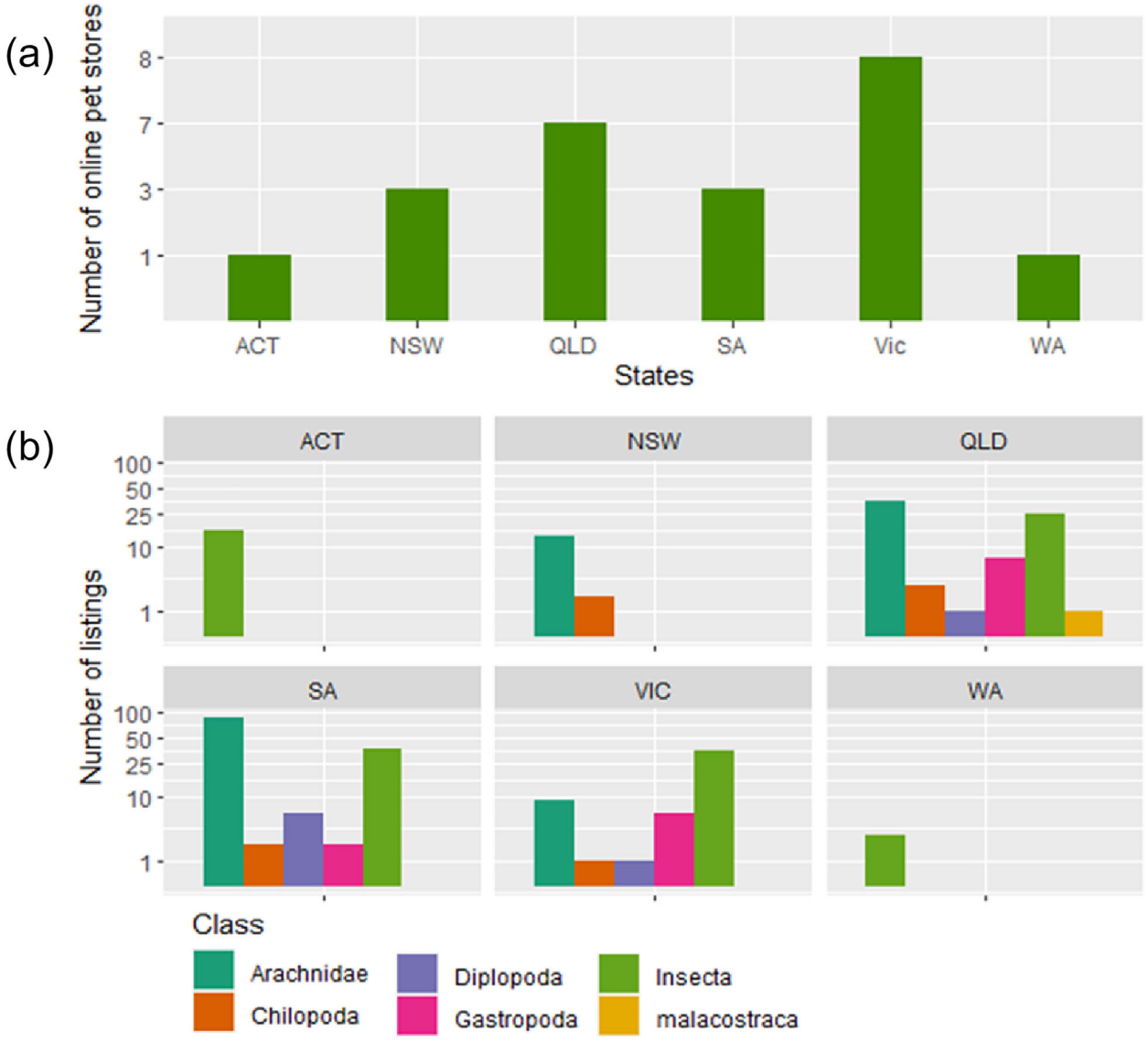

FIGURE 6 (a) Total number of invertebrate listings per State on online pet stores. (b) The classes of invertebrate each listing features. *Y* axis are $\log_{10}$ transformed to display less abundant classes.

demand for invertebrates will help inform biosecurity regulations, as well as addressing the potential threat of over exploitation of wild populations.

Alien invasive invertebrates, released in even small numbers, could potentially become established in Australia through suitable environmental matching and difficulty detecting them at initially low densities (Gippet et al. 2019). We identified 34 non-native species, and three species already invasive to Australia: The African big-head (*Pheidole megacephala*), *the Asian tramp snail* (*Bradybaena similaris*), and the white Italian snail (*Theba pisana*).

Pheidole megacephala is currently one of six invasive ant species present in Australia and is listed in the worst 100 pests in the world (Lach & Thomas 2008; Lowe et al. 2000). This species is one of the most significant pest invertebrates in Australia, with serious ecological, agricultural and social impacts, and a long history of management (Hoffmann et al. 2017). Additionally, *Bradybaena similaris* poses a serious risk to human health, with the ability to serve as an intermediate host for rat lungworm (*Angiostrongylus cantonensis*) (Serniotti et al. 2019), whereas *Theba pisana* is a significant agricultural pest, contaminating harvest and soiling farming equipment (Blacket et al. 2016). Both snails and ants are proficient hitchhiker organisms, due to their concealment, ability to live off minimal food and small body-size (Patoka et al. 2020). In 2017 and 2018 Australia's National Border Surveillance Program identified 42 pests of environmental concern- most of which were snails (23.8%) and ants (16.6%) (DAWE 2021). Fortunately, within this project no newly emerging invasive alien species were

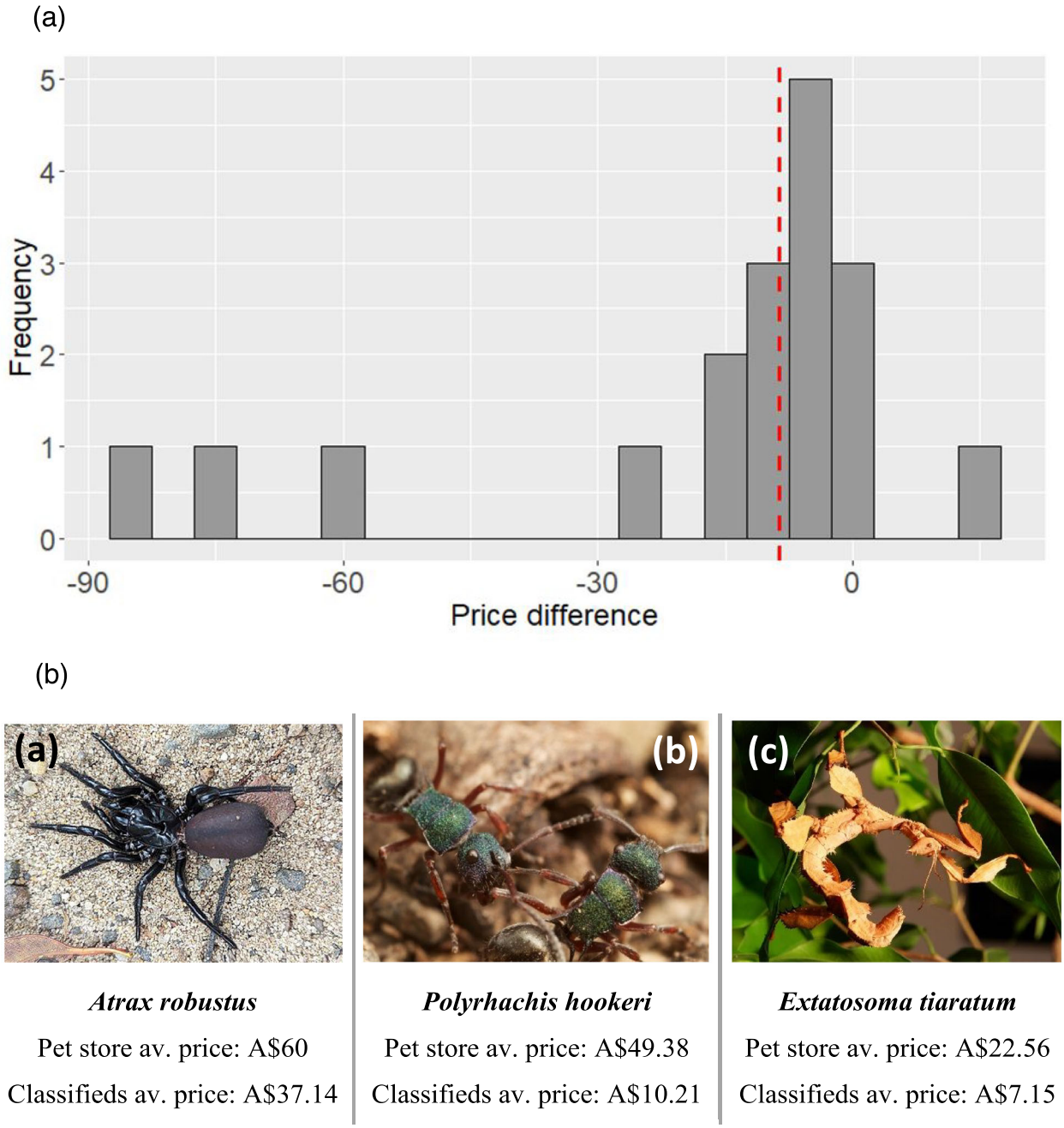

FIGURE 7 (a) Histogram of mean species price-per-unit differences (AUD) between classifieds and online pet stores (classifieds price minus pet store price, i.e., negative price difference indicates that classifieds species are less expensive). Median value of −7.442 is represented by the red line. (b) Examples of species with large price differences on the two e-commerce platforms. Photo credits: (a) Rosie Steinberg, (b) Ajay Narendra, (c) Stephan Höhne.

detected (i.e., those never recorded in Australia before), but without comprehensive knowledge on each species and in the absence of risk assessments, their potential to become invasive is generally unknown. Additionally, we found the above species to be traded outside of their current distribution in Australia which will potentially facilitate the spread and establishment of these invasive species in new areas and States.

The IUCN's Red List of threatened species is arguably the most useful tool for identifying species threatened with extinction. The Red List guides conservation efforts and funding, influences policy and environmental regulation, and assists with priority setting for land protection (Cardoso, Borges, et al. 2011). However, consistent with previous research (Cardoso, Borges, et al. 2011; dos Santos et al. 2020; Karam-Gemael et al. 2020), our

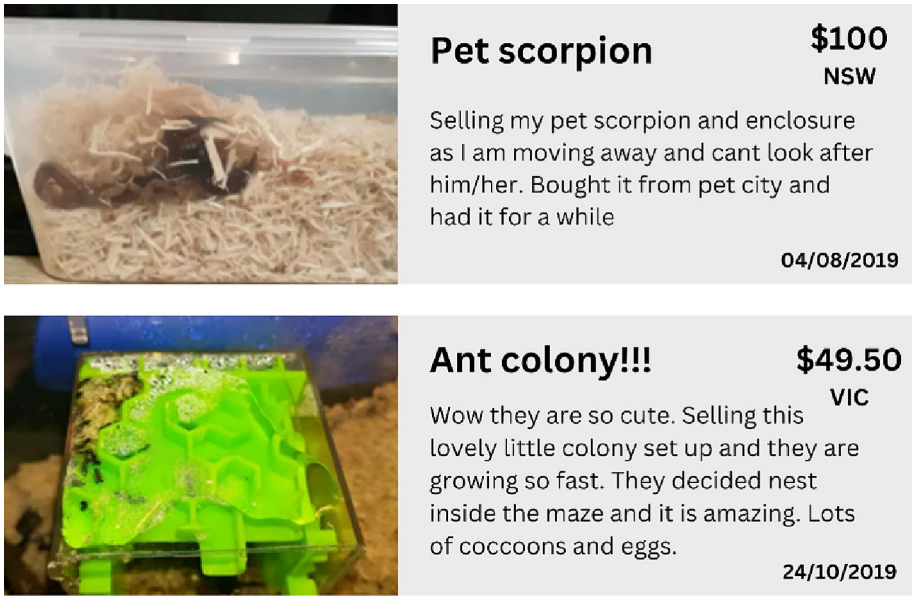

FIGURE 8 Reconstructed examples of classifieds listings with vague descriptions and poor-quality images.

findings showed a dramatic bias against invertebrates and a lack of baseline taxonomic knowledge. Specifically, almost all the species we found traded (92%) have not been evaluated by IUCN. Of the species that have been assessed, 71.4% are stick insects, showing a bias towards the order Phasmatodea. Furthermore, IUCN recorded eight of the traded species as 'Not Utilised' within the wildlife trade. Evidently, our findings contradict this, further emphasising the need to understand the role invertebrates play within the wildlife trade, and to develop baseline taxonomic knowledge of the invertebrate species traded.

The majority of invertebrate species traded online were native to Australia (230 species, 86.8%). Basic knowledge gaps regarding their distribution, life history and husbandry means the potential impact of wild harvesting on their populations is unknown. An added concern is that we do not know how these species were sourced (i.e., captive bred or wild harvested) because there is no regulations for sellers to reveal this information, and thus, it is seldom provided. While our analysis pertains mostly to native Australian species, many of these invertebrates are being sold within Australia, but outside of their native ranges, and can therefore still pose a biosecurity risk (Guo & Ricklefs 2010). For example, we found that the Flinders Ranges scorpion (*Urodacus elongatus*), which is endemic to South Australia, was traded in several other States. Therefore, we suggest the conservation risks of harvesting these species are evaluated, alongside the risk of them becoming established (and invasive) elsewhere.

Australia has one of the strongest pre-border biosecurity systems globally (Jarrett et al. 2020), with very few organisms permitted for import or export (Alacs & Georges 2008). Nevertheless, the biosecurity system does not mitigate 100% of the risk, and attempts to subvert the system still exist. For instance, in 2003 1000 Lord Howe Island Stag beetles were seized at Sydney Airport (Leggatt 2003), and in 2017 a man was caught attempting to smuggle over 4000 Australian native invertebrates on a flight out of Perth (Young 2017). The potential for export of endemic Australian species to markets in Asia, Europe and North America is of great concern for the country's biodiversity (Alacs & Georges 2008; Heinrich et al. 2021; Linacre 2021). Likewise, while Australia implements national protection for the export of native species, there is little regulation for the trade of wildlife across Australia's domestic borders. Given the aforementioned biosecurity and conservation risks, legislation on the trade of invertebrates within Australia should be urgently reviewed.

Wildlife consumer demand is highly complex, and an extensive body of literature on pet vertebrates demonstrates that particular species traits can influence a person's attitude towards a species, and their willingness to purchase it (Mohanty & Measey 2019; Scheffers et al. 2019; Toomes et al. 2021). Understanding the drivers for the demand of terrestrial invertebrates is imperative for identifying species at risk of becoming introduced and invasive in Australia, and for protecting Australia's rarer, endemic species. Within the online markets we explored, there was a greater abundance of the four invertebrate taxa, stick insects, ants, scorpions, and tarantulas; which are also commonly traded in other countries. Stick insects are generally safe to handle, relatively easy to keep as pets, fast breeders and aesthetically pleasing to observe (Nxumalo & Pacini-Ketchabaw 2017). However, ants, scorpions and tarantulas have the reputation of being dangerous, harmful, and often frightening

(Eisenhauer et al. 2019). Many species traded online are capable of inflicting pain to humans (i.e., bites and stings), and likewise, many of these species are not recommended for handling and can even be lethal to humans. From our research, it appears that both charismatic and dangerous traits of a species may influence invertebrate buyer preference. We recommend further research on consumer preferences focussed on invertebrates to better elucidate these relationships and mitigate risks of trade.

We found that every Australian State had records of selling invertebrates, yet the distribution of invertebrate species varied across States and differed between the two different e-commerce platforms. Population density showed a positive correlation with invertebrate trade, with the majority of invertebrate sellers located within or surrounding capital cities. One potential explanation for this correlation is that invertebrates are generally small-bodied and easy to keep in limited spaces (within small, easily maintained vivariums), which can make them ideal pets for higher density urban living.

We found no correlation between household income and the location of invertebrate sellers. This suggests that associated costs may not be a limiting factor for the acquisition of invertebrate pets in Australia. Other studies found similar results in different exotic pet markets: household income was not significantly associated with bird-keeping in Indonesia (Jepson & Ladle 2009), and median income was not associated with the number of pets in a household in Brazil (Martins et al. 2013). Invertebrates are relatively affordable pets to keep. For example, the estimated average yearly cost is A$924 for keeping a medium size dog, and A$890 for keeping a pet cat (Micheli 2014). Information provided by online pet stores suggest that the average yearly cost of keeping a stick insect is A$10–$45 (Thijs 2021), and owning a tarantula, A$30–$90 (David 2020). In 2019, 61% of all Australian households owned a pet. However, as little as 2% of these households owned an invertebrate (Animal Medicines Australia 2019). All these factors taken together suggest that owning and caring for pet invertebrates may be an attractive alternative to traditional pets from a financial perspective.

Overall, pet store prices for the same species were around A$7 more then on classifieds websites. Pet stores prices are set by the store owner and are impacted by external influences such as competition from comparable online stores, costs associated with maintaining a physical pet store, and pet store regulations (i.e., *South Australian Standards and Guidelines for Breeding and Trading Companion Animals*) (DEW 2017). Classifieds prices are chosen by the individual seller, and thus, prices can vary greatly within one species. Studies looking at price differences between online and offline retailers found a slight trend for online prices to be lower priced (on average 18%) (Cavallo 2017). Both e-commerce platforms used for this research were online, however, the majority of online pet stores we included also maintain a physical storefront, which may explain the differences in prices. For example, tarantula species *Selenocosmia crassipes*, cost an average of A$130.30 per individual on online pet stores, and A$50.06 per individual on the classifieds website.

Although we observed 264 species traded, we cannot be entirely certain of the identity of all of these species. Classifieds invertebrate sellers may lack knowledge on the species they are selling, which is also reflected by the lack of identification in the advertised invertebrate listing (Stringham et al. 2020). Vague listing titles and descriptions were found in 78 listings, including titles such as ‘Scorpion’, ‘Stick insect’ and ‘Unidentified queen ant’ (Figure 8). We speculate that sellers with poor knowledge of the species they are selling are also less knowledgeable on the invertebrate’s value, as determined by the broader hobby. Surveying invertebrate keepers and breeders may reveal further relationships between an individual’s knowledge on invertebrates, and their sale.

As all our data were sourced from online listings, it was difficult to verify the validity of the listings. For example, there is the possibility of listings being fake or misidentifying the species of invertebratefor sale. To reduce the possibility of misidentifications and false advertisement, a further research pathway could involve contacting sellers and visiting brick-and-mortar pet stores to verify species identifications from firsthand observations. Similarly, we encourage future research involving the collection of invertebrate advertisement data from a wider set of e-commerce platforms, and over a longer period. This will not only allow for observations of seasonal variation within the trade, but ideally produce a broader and more conclusive summary of the invertebrate species diversity traded online in Australia.

In summary, we have identified that there is a large and diverse online invertebrate trade for exotic pets in Australia. Although we did not identify a large number of conservation or biosecurity threats from the invertebrate trade, we warn that future growth and expansion of the trade could have severe consequences for environmental security if not better monitored and regulated. Additionally, the minimal biosecurity threats we identified in the trade could correlate with the lack of documentation and risk assessments on invertebrate species. Going forward, many opportunities lie within the research of invertebrate distributions across Australia; including studying the relationships between invertebrate sales with other environmental and socio-demographics (e.g., climate, rainfall, and employment rates), and developing investigative methods to determine whether species are being captive bred or wild harvested (i.e., isotopes or DNA methods; (Andersson et al. 2021; Lyons & Natusch 2015).

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CONFLICT OF INTEREST STATEMENT

We declare no conflict of interest.

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REFERENCES

ALA. (2022) Atlas of Living Australia, vol. 2021, Available from: https://www.ala.org.au/ [Accessed 16th September 2021].

Alacs, E. & Georges, A. (2008) Wildlife across our borders: a review of the illegal trade in Australia. *Australian Journal of Forensic Sciences*, 40(2), 147–160. Available from: https://doi.org/10.1080/00450610802491382

Andersson, A., Gibson, L., Baker, D., Cybulski, J.D., Wang, S., Leung, B., et al. (2021) Stable isotope analysis as a tool to detect illegal trade in critically endangered cockatoos. *Animal Conservation*, 24(6), 1021–1031. Available from: https://doi.org/10.1111/acv.12705

Animal Medicines Australia. (2019) Pets in Australia: a national survey of pets and people. Available from: https://animalmedicinesaustralia.org.au/wp-content/uploads/2019/10/ANIM001-Pet-Survey-Report19_v1.7_WEB_low-res.pdf

Australian Bureau of Statistics. (2017) Australia (AUS) ASGS Ed 2016 Digital Boundaries in ESRI Shapefile Format (ed. ABS), Main Structure and Greater Capital City Statistical Areas, Available from: https://www.abs.gov.au/AUSSTATS/abs@.nsf/DetailsPage/1270.0.55.001July%202016?OpenDocument [Accessed 1st May 2021].

Australian Bureau of Statistics. (2020) Total income 2011–12 to 2017–18, Personal Income in Australia, Available from: https://www.abs.gov.au/statistics/labour/earnings-and-working-conditions/personal-income-australia/2011-12-2017-18 [Accessed 1st May 2021].

Australian Bureau of Statistics. (2021) Population estimates by Local Government Area, 2019 to 2020, Regional Population, Available from: https://www.abs.gov.au/statistics/people/population/regional-population/2019-20 [Accessed 5th May 2021].

Bending, Z.J. (2015) An introduction to the illegal trade in wildlife: a snapshot of the illicit trade in rhinoceros horn. *Australian Journal of Environmental Law*, 2, 123.

Black, S.H., Shepard, M. & Allen, M.M. (2001) Endangered invertebrates: the case for greater attention to invertebrate conservation. *Endangered Species Update*, 18, 41–49.

Blacket, M.J., Shea, M., Semeraro, L. & Malipatil, M.B. (2016) Introduced Helicidae garden snails in Australia: morphological and molecular diagnostics, species distributions and systematics. *Records of the Australian Museum*, 68(3), 99–116. Available from: https://doi.org/10.3853/j.2201-4349.68.2016.1648

Braby, M.F. (2018) Threatened species conservation of invertebrates in Australia: an overview. *Austral Entomology*, 57(2), 173–181. Available from: https://doi.org/10.1111/aen.12324

Braby, M.F., Yeates, D.K. & Taylor, G.S. (2021) Population declines and the conservation of insects and other terrestrial invertebrates in Australia. *Austral Entomology*, 60(1), 3–8. Available from: https://doi.org/10.1111/aen.12519

Bradshaw, C.J., Hoskins, A.J., Haubrock, P.J., Cuthbert, R.N., Diagne, C., Leroy, B., et al. (2021) Detailed assessment of the reported economic costs of invasive species in Australia. *NeoBiota*, 67, 511–550. Available from: https://doi.org/10.3897/neobiota.67.58834

Bush, E.R., Baker, S.E. & Macdonald, D.W. (2014) Global trade in exotic pets 2006–2012. *Conservation Biology*, 28(3), 663–676. Available from: https://doi.org/10.1111/cobi.12240

Caldas, A.T.M., Dias, M. & Peres, M. (2018) Invertebrate (Araenae: Mygalomorphae) illegal trade: an ignored side of wildlife trafficking. *American Journal of Zoology*, 1, 20–23.

Canyon, D., Speare, R., Naumann, I. & Winkel, K. (2002) Environmental and economic costs of invertebrate invasions in Australia. In: Pimental, D. (Ed.) *Biological invasions: economic and environmental cost of alien plant, animal and microbe species*. London: CRC press. https://doi.org/10.1201/9781420041668.ch4

Cardoso, P., Amponsah-Mensah, K., Barreiros, J.P., Bouhuys, J., Cheung, H., Davies, A., et al. (2021) Scientists' warning to humanity on illegal or unsustainable wildlife trade. *Biological Conservation*, 263, 109341. Available from: https://doi.org/10.1016/j.biocon.2021.109341

Cardoso, P., Borges, P.A.V., Triantis, K.A., Ferrández, M.A. & Martín, J.L. (2011) Adapting the IUCN Red List criteria for invertebrates. *Biological Conservation*, 144(10), 2432–2440. Available from: https://doi.org/10.1016/j.biocon.2011.06.020

Cardoso, P., Erwin, T., Borges, P. & New, T. (2011) The seven impediments in invertebrate conservation and how to overcome them. *Biological Conservation*, 144(11), 2647–2655. Available from: https://doi.org/10.1016/j.biocon.2011.07.024

Carnegie, A.J. & Nahrung, H.F. (2019) Post-border forest biosecurity in Australia: response to recent exotic detections, current surveillance and ongoing needs. *Forests*, 10(4), 336. Available from: https://doi.org/10.3390/f10040336

Cavallo, A. (2017) Are online and offline prices similar? Evidence from large multi-channel retailers. *American Economic Review*, 107(1), 283–303. Available from: https://doi.org/10.1257/aer.20160542

Chamberlain, S., Szoecs, E., Foster, Z., Arendsee, Z., Boettiger, C., Ram, K., Bartomeus, I., Baumgartner, J., O'Donnell, J., Oksanen, J., & Tzovaras, B.G. (2020) Taxize: Taxonomic information from around the web. F1000 Research. Available at: https://github.com/ropensci/taxize [Accessed 30th May 2021].

David, Z. (2020) How much does a tarantula cost? [Initial & Yearly Cost Breakdown]. In: David, Z. (Ed.) *Beyond the treat*, Beyond the treat. Available from: Vol. 2021. Available from: https://beyondthetreat.com/how-much-does-a-tarantula-cost/ [Accessed 10th September 2021].

Department of Agriculture, Water and Environment. (2021) The National Priority List of Exotic Environmental Pests, Weeds and Diseases. Available from: https://www.agriculture.gov.au/sites/default/files/documents/eepl-information-paper.pdf [Accessed 20th June 2021].

Department of Environment and Water. (2017) South Australian Standards and Guidelines for Breeding and Trading Companion Animals. Available from: https://cdn.environment.sa.gov.au/environment/docs/standards-and-guidelines-for-breeding-and-trading-of-companion-animals-gen.pdf [Accessed 30th May 2021].

dos Santos, J.W., Correia, R.A., Malhado, A.C., Campos-Silva, J.V., Teles, D., Jepson, P., et al. (2020) Drivers of taxonomic bias in conservation research: a global analysis of terrestrial mammals. *Animal Conservation*, 23(6), 679–688. Available from: https://doi.org/10.1111/acv.12586

Eisenhauer, N., Bonn, A. & Guerra, C. (2019) Recognizing the quiet extinction of invertebrates. *Nature Communications*, 10, 1–3.

Fink, C., Toivonen, T., Correia, R.A. & Di Minin, E. (2021) Mapping the online songbird trade in Indonesia. *Applied Geography*, 134, 102505. Available from: https://doi.org/10.1016/j.apgeog.2021.102505

Fukushima, C.S., Tricorache, P., Toomes, A., Stringham, O.C., Rivera-Téllez, E., Ripple, W.J., et al. (2021) Challenges and perspectives on tackling illegal or unsustainable wildlife trade. *Biological Conservation*, 263, 109342. Available from: https://doi.org/10.1016/j.biocon.2021.109342

GBIF. (2021) Global Biodiversity Information Facility, vol. 2021. Available from: https://www.gbif.org/ [Accessed 22nd April 2021].

Gippet, J.M.W., Liebhold, A.M., Fenn-Moltu, G. & Bertelsmeier, C. (2019) Human-mediated dispersal in insects. *Current Opinion in Insect Science*, 35, 96–102. Available from: https://doi.org/10.1016/j.cois.2019.07.005

Green, K., Caley, P., Baker, M., Dreyer, D., Wallace, J. & Warrant, E. (2021) Australian Bogong moths Agrotis infusa (Lepidoptera: Noctuidae), 1951–2020: decline and crash. *Austral Entomology*, 60(1), 66–81. Available from: https://doi.org/10.1111/aen.12517

Guo, Q. & Ricklefs, R.E. (2010) Domestic exotics and the perception of invasibility. *Diversity and Distributions*, 16(6), 1034–1039. Available from: https://doi.org/10.1111/j.1472-4642.2010.00708.x

Heinrich, S., Toomes, A., Shepherd, C., Stringham, O., Swan, M. & Cassey, P. (2021) Strengthening protection of endemic wildlife threatened by the international pet trade: the case of the Australian shingleback lizard. *Animal Conservation*, 25, 91–100.

Hernandez-Castro, J. & Roberts, D.L. (2015) Automatic detection of potentially illegal online sales of elephant ivory via data mining. *PeerJ Computer Science*, 1, 10.

Hinsley, A., Lee, T.E., Harrison, J.R. & Roberts, D.L. (2016) Estimating the extent and structure of trade in horticultural orchids via social media. *Conservation Biology*, 30(5), 1038–1047. Available from: https://doi.org/10.1111/cobi.12721

Hoffmann, B.D. & Broadhurst, L.M. (2016) The economic cost of managing invasive species in Australia. *NeoBiota*, 31, 1–18. Available from: https://doi.org/10.3897/neobiota.31.6960

Hoffmann, B.D., Graham, R. & Smith, D. (2017) Ant species accumulation on Lord Howe Island highlights the increasing need for effective biosecurity on islands. *NeoBiota*, 34, 41–52. Available from: https://doi.org/10.3897/neobiota.34.10291

IUCN. 2022. IUCN Red List of Threatened Species, vol. 2022. Available from: https://www.iucnredlist.org/ [Accessed 30th October 2022].

Jarrett, L., Williams, G. & Charnock, S. (2020) Australia's biosecurity future: unlocking the next decade of resilience. In: CSIRO. (Ed.) *CSIRO Futures*. Melbourne, Victoria, Australia: CSIRO, p. 48.

Jepson, P. & Ladle, R.J. (2009) Governing bird-keeping in Java and Bali: evidence from a household survey. *Oryx*, 43(3), 364–374. Available from: https://doi.org/10.1017/S0030605309990251

Karam-Gemael, M., Decker, P., Stoev, P., Marques, M.I. & Jr, A.C. (2020) Conservation of terrestrial invertebrates: a review of IUCN and regional Red Lists for Myriapoda. *ZooKeys*, 930, 221–229. Available from: https://doi.org/10.3897/zookeys.930.48943

Kearney, M.R., Hossain, M.A., Sinclair, S.J. & Song, H. (2021) Grasshopper country before and after: a resurvey of Ken Key's collecting expeditions in New South Wales, Australia, 70 years on. *Austral Entomology*, 60(1), 52–65. Available from: https://doi.org/10.1111/aen.12515

Kumschick, S., Devenish, A., Kenis, M., Rabitsch, W., Richardson, D.M. & Wilson, J.R. (2016) Intentionally introduced terrestrial invertebrates: patterns, risks, and options for management. *Biological Invasions*, 18(4), 1077–1088. Available from: https://doi.org/10.1007/s10530-016-1086-5

Lach, L. & Thomas, M.L. (2008) Invasive ants in Australia: documented and potential ecological consequences. *Australian Journal of Entomology*, 47(4), 275–288. Available from: https://doi.org/10.1111/j.1440-6055.2008.00659.x

Leggatt, J. (2003) Lord Howe's stolen rare beetles go home. In: *The Sun–Herald*. Sydney: Fairfax Media. Available from: https://www.smh.com.au/national/lord-howes-stolen-rare-beetles-go-home-20030105-gdg29j.html

Linacre, A. (2021) Wildlife crime in Australia. *Emerging Topics in Life Sciences*, 5(3), 487–494. Available from: https://doi.org/10.1042/ETLS20200288

Lockwood, J.L., Welbourne, D.J., Romagosa, C.M., Cassey, P., Mandrak, N.E., Strecker, A., et al. (2019) When pets become pests: the role of the exotic pet trade in producing invasive vertebrate animals. *Frontiers in Ecology and the Environment*, 17(6), 323–330. Available from: https://doi.org/10.1002/fee.2059

Lowe, S., Browne, M., Boudjelas, S., & De Poorter, M. (2000) 100 of the world's worst invasive alien species: a selection from the global invasive species database. Invasive Species Specialist Group (ISSG) a specialist group of the Species Survival Commission (SSC) of the World Conservation Union (IUCN), Auckland.

Lyons, J. & Natusch, D. (2015) Methodologies for differentiating between wild and captive-bred CITES-listed snakes. *AC28 Inf*, 9, 35.

Lüdecke, D., Mattan, S.B.-S., Patil, I., Waggoner, P. & Makowski, D. (2021) Performance: an R package for assessment, comparison and testing of statistical models. *Journal of Open Source Software*, 6(60), 3139. Available from: https://doi.org/10.21105/joss.03139

Martins, C.M., Mohamed, A., Guimarães, A.M.S., de Barros, C.C., Pampuch, R.S., Svoboda, W., et al. (2013) Impact of demographic characteristics in pet ownership: modeling animal count according to owners income and age. *Preventive Veterinary Medicine*, 109(3-4), 213–218. Available from: https://doi.org/10.1016/j.prevetmed.2012.10.006

Micheli, R. (2014) The simple truth about pet-ownership economics. In: *CNBC*. New Jersey: CNBC, p. 1.

Mohanty, N.P. & Measey, J. (2019) Taxonomic bias and traits of the global amphibian pet-trade. *bioRxiv*, 645259.

Morcatty, T.Q., Feddema, K., Nekaris, K.A.I. & Nijman, V. (2021) Online trade in wildlife and the lack of response to COVID-19. *Environmental Research*, 193, 110439. Available from: https://doi.org/10.1016/j.envres.2020.110439

Nelufule, T., Robertson, M.P., Wilson, J.R., Faulkner, K.T., Sole, C. & Kumschick, S. (2020) The threats posed by the pet trade in alien terrestrial invertebrates in South Africa. *Journal for Nature Conservation*, 55, 125831. Available from: https://doi.org/10.1016/j.jnc.2020.125831

New, T. & Yen, A. (2013) Invertebrate conservation in Australia: problems in policy and practice. *Pacific Conservation Biology*, 19(2), 104–109. Available from: https://doi.org/10.1071/PC130104

Nxumalo, F. & Pacini-Ketchabaw, V. (2017) 'Staying with the trouble' in child-insect-educator common worlds. *Environmental Education Research*, 23(10), 1414–1426. Available from: https://doi.org/10.1080/13504622.2017.1325447

Oksanen, J., Blanchet, F., Friendly, M., Kindt, R., Legendre, P., McGlinn, D., Minchin, P.R., O'Hara, R.B., Simpson, G.L., Solymos, P., & Stevens, M.H.H. (2020) Vegan: community ecology package. Available from: https://github.com/vegandevs/vegan [Accessed 30th May 2021].

R Core Team. (2021) *R: a language and environment for statistical computing*. Vienna, Austria: R Foundation for Statistical Computing.

Ricciardi, A. (2015) Chapter 5 - Ecology of invasive alien invertebrates. In: Thorp, J.H. & Rogers, D.C. (Eds.) *Thorp and Covich's freshwater invertebrates*, Fourth edition. Boston: Academic Press, pp. 83–91. https://doi.org/10.1016/B978-0-12-385026-3.00005-X

Rix, M.G., Huey, J.A., Main, B.Y., Waldock, J.M., Harrison, S.E., Comer, S., et al. (2017) Where have all the spiders gone? The decline of a poorly known invertebrate fauna in the agricultural and arid zones of southern Australia. *Austral Entomology*, 56(1), 14–22. Available from: https://doi.org/10.1111/aen.12258

Scheffers, B.R., Oliveira, B.F., Lamb, I. & Edwards, D.P. (2019) Global wildlife trade across the tree of life. *Science*, 366(6461), 71–76. Available from: https://doi.org/10.1126/science.aav5327

Serniotti, E. N., Guzmán, L. B., Beltramino, A. A., Vogler, R. E., Rumi Macchi, A., & Peso, J. G. (2019). New distributional records of the exotic land snail Bradybaena similaris (Férussac, 1822) (Gastropoda, Bradybaenidae) in Argentina.

Stringham, O.C., Toomes, A., Kanishka, A.M., Mitchell, L., Heinrich, S., Ross, J.V., et al. (2020) A guide to using the Internet to

monitor and quantify the wildlife trade. *Conservation Biology*, 35, 1130–1139.

't Sas-Rolfes, M., Challender, D.W., Hinsley, A., Veríssimo, D. & Milner-Gulland, E. (2019) Illegal wildlife trade: scale, processes, and governance. *Annual Review of Environment and Resources*, 44, 201–228.

Taylor, G.S., Braby, M.F., Moir, M.L., Harvey, M.S., Sands, D.P.A., New, T.R., et al. (2018) Strategic national approach for improving the conservation management of insects and allied invertebrates in Australia. *Austral Entomology*, 57(2), 124–149. Available from: https://doi.org/10.1111/aen.12343

Thijs. (2021) How much do stick insects cost: initial & yearly cost breakdown. In: Bugs, K. (Ed.) *Keeping bugs*, Vol. 2021. Netherlands: Keeping Bugs.

Toomes, A., García, P., Stringham, O., Ross, J., Mitchell, L. & Cassey, P. (2021) Drivers of the live pet trade: the role of species traits, socio-economic attributes and regulatory systems. *Journal of Applied Ecology*, 59, 1268–1278.

Wickham H. 2016. *ggplot2: elegant graphics for data analysis*. Springer-Verlag New York. Available from: https://ggplot2.tidyverse.org [Accessed 15th May 2021]. https://doi.org/10.1007/978-3-319-24277-4

Wickham, H., François, R., Henry, L., & Müller, K. (2021) dplyr: a grammar of data manipulation. Available from: https://dplyr.tidyverse.org [Accessed 15th May 2021].

Wilson-Wilde, L. (2010) Wildlife crime: a global problem. *Forensic Science, Medicine, and Pathology*, 6(3), 221–222. Available from: https://doi.org/10.1007/s12024-010-9167-8

Wyatt, T., Maher, J., Allen, D., Clarke, N. & Rook, D. (2021) The welfare of wildlife: an interdisciplinary analysis of harm in the legal and illegal wildlife trades and possible ways forward. *Crime, Law and Social Change*, 77, 69–89.

Yen, A.L. (1995) Australian spiders: an opportunity for conservation. *Records of the Western Australian Museum Supplement*, 52, 39–47.

Yen, A.L. (2010) Edible insects and other invertebrates in Australia: future prospects. In: Durst, P.B., Johnson, D.V., Leslie, R.L. & Shono, K. (Eds.) *Forest insects as food: humans bite Back, proceedings of a workshop on Asia-Pacific resources and their potential for development*, pp. 65–84.

Young, E. (2017) Man arrested smuggling thousands of beetles, spiders, scorpions from Perth. In: *WA Today*. Perth: Fairfax Media. Available from: https://www.watoday.com.au/national/western-australia/man-arrested-smuggling-thousands-of-beetles-spiders-scorpions-from-perth-20170318-gv160l.html

SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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