frontiers | Frontiers in Arachnid Science

TYPE Original Research
PUBLISHED 07 July 2023
DOI 10.3389/frchs.2023.1161383

OPEN ACCESS

EDITED BY
Matjaz Kuntner,
National Institute of Biology (NIB), Slovenia

REVIEWED BY
Stefano Mammola,
National Research Council (CNR), Italy
Klemen Čandek,
National Institute of Biology (NIB), Slovenia

*CORRESPONDENCE
Volker Herzig
vherzig@usc.edu.au
Tim Lüddecke
tim.lueddecke@outlook.com

RECEIVED 08 February 2023
ACCEPTED 19 June 2023
PUBLISHED 07 July 2023

CITATION
Herzig V, Hauke TJ and Lüddecke T (2023) Unmasking trends and drivers of the international arachnid trade.
Front. Arachn. Sci. 2:1161383.
doi: 10.3389/frchs.2023.1161383

Unmasking trends and drivers of the international arachnid trade

Volker Herzig[1,2*], Tobias J. Hauke[3] and Tim Lüddecke[4,5*]

[1]Centre for Bioinnovation, University of the Sunshine Coast, Sippy Downs, QLD, Australia, [2]School of Science, Technology and Engineering, University of the Sunshine Coast, Sippy Downs, QLD, Australia, [3]Independent Researcher, Munich, Germany, [4]Department for Bioresources, Fraunhofer Institute for Molecular Biology and Applied Ecology, Gießen, Germany, [5]LOEWE Centre for Translational Biodiversity Genomics (TBG), Frankfurt, Germany

Introduction: The global biodiversity crisis represents a major threat to humanity, with the worldwide animal trade being identified as a major driving force. Although vertebrate trade has been subject to intensified research, the extent of invertebrate trade remains understudied. Recent analyses of arachnids (i.e., spiders and scorpions) suggest that there is a large and still-expanding international market which has the potential to threaten natural populations. Whether or not captive breeding has the potential to decrease collection pressure on wild arachnid populations has not been investigated, nor have the temporal dynamics or the trade purposes of arachnids been examined.

Methods: We herein seek to broaden our understanding of these areas by analyzing arachnid import and export data from two major international wildlife trade databases (CITES and LEMIS).

Results: Historically, a large proportion of tarantulas and scorpions have been traded for the pet sector. Our analysis of the LEMIS data shows that imports of pet arachnids have declined by up to 55% in the past decade. Furthermore, an annual breakdown of US imports shows that at least 43% of specimens are not traded as pets but for other purposes, including research, souvenirs, and traditional medicine, with the souvenir sector experiencing an unprecedented growth. CITES data for protected tarantulas, but not scorpions, further indicate a shift toward trade with captive-bred specimens.

Discussion: These trends need to be considered in efforts to conserve natural populations. Coordinated captive breeding may represent a path toward increased sustainability by meeting the demand for traded arachnids and also providing an important resource for scientific research across disciplines.

KEYWORDS
arachnoculture, pet trade, arachnids, tarantulas, scorpions, conservation

1 Introduction

The global biodiversity decline, also referred to as the sixth mass extinction, represents a major threat to the functionality of ecosystems across the globe and thus also to humanity (Cowie et al., 2022). The populations of a wide range of species are significantly affected due to anthropogenic effects, including habitat destruction and fragmentation, hunting, or environmental pollution. It is estimated that one million animal and plant species are threatened by extinction (United Nations, 2019). However, recent studies suggest that, in addition to the above factors, international trade with exotic animals represents an important yet commonly overlooked driver of the biodiversity crisis (Cardoso et al., 2021; Morton et al., 2021). It has been established that approximately 40% of all reptile and approximately 20% of all amphibian species known are present in the international pet trade (Marshall et al., 2020; Hughes et al., 2021). Similarly, several exotic mammals, birds, or fish are traded internationally and sometimes reach significant market values (Meier et al., 1991; Nijman et al., 2022). However, to what extent traded animals originate from captive-bred stocks is often highly uncertain, and it is commonly acknowledged that legal and illegal collection from natural habitats plays an important role in this context. In addition to these prominent animal groups, there is a large international community that enthusiastically keeps arthropods as pets. Examples of such arthropods include ants, butterflies, large beetles, and arachnids, in particular tarantulas (Theraphosidae) and scorpions (Goka, 2022). Although the community of arthropod enthusiasts has existed for decades, little is known about the effects that the trade of such animals may impose on native populations (Tournant et al., 2012; Mendoza and Francke, 2016; Fukushima et al., 2019; Mendoza and Francke, 2020; Battiston et al., 2022). However, considering the growing consciousness about the biodiversity crisis, the first scientific explorations on the sustainability of the invertebrate trade are underway. These often emphasize that arachnids are the most commonly kept terrestrial arthropod pets (Fukushima et al., 2020).

Among the studies focusing on the global arachnid trade, a recent study by Marshall and colleagues represents the most current and sophisticated analysis (Marshall et al., 2022). In their study, the authors applied a data-mining workflow to reveal patterns and gain a better perspective on the global trade of arachnids. The authors sourced trading data on spiders and scorpions from three major sources: (i) online pet shops in nine languages, (ii) public databases from the Law Enforcement Management Information System (LEMIS) of the US Fish and Wildlife Service, and (iii) the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) database (Eskew et al., 2019; Convention on International Trade in Endangered Species of Wild Fauna and Flora, 2022). They proposed that about 1,300 arachnid taxa, with millions of individuals originating predominantly from the wild, are traded worldwide, in a mostly unregulated market. For some groups, such as for tarantulas, 50% of known species were found to be present in the global trade, and a correlation between coloration and demand was proposed (Marshall et al., 2022). The authors argue that the trade volume is primarily due to the high demand for arachnids in the pet sector, and thus identify the pet sector as a potential driver of arachnid biodiversity loss (Marshall et al., 2022).

A question that remains unresolved is how much the breeding of arachnids in captivity contributes toward the overall supply of pet arachnids. Some popular arachnid pet species have been included in global conservation programs (e.g., CITES) and are therefore subject to international monitoring. Whether or not their inclusion had any impacts on their trade dynamics remains unclear. Furthermore, it has not yet been determined if the pet sector indeed features as the main purpose for the international arachnid trade. There may be other economic forces at play that threaten the global arachnofauna. In this study, we aim to shed light on these questions by providing a concise perspective on the details and nuances driving international arachnid trade. We therefore utilized data provided by two major international wildlife trade databases and examined the percentages of wild-caught *vs.* captive-bred specimens. In addition, we analyzed trajectorial changes in trade following inclusion in CITES and the purposes for which arachnids were imported.

2 Material and methods

2.1 CITES data

For all CITES data, the data archived in the CITES trade database website (Convention on International Trade in Endangered Species of Wild Fauna and Flora, 2022) were examined. At the time of writing, only a few arachnid taxa were listed in the CITES appendices (see Table 1). For scorpions, the trade of only some species from the genus *Pandinus* (including *Pandinoides dictator*, a former member of *Pandinus*) is currently regulated. For spiders, several taxa are CITES-relevant, all belonging to Theraphosidae (tarantulas). All species of *Brachypelma* (including all former members now placed in *Tliltocatl*, *Sericopelma*, and *Sandinisia*, and also *Brachypelma albiceps*, which is still listed as *Aphonopelma albiceps*), plus all species of *Poecilotheria*, a single species of *Aphonopelma* (*Aphonopelma pallidum*), and *Caribena* (*Caribena versicolor*) are listed. All CITES-protected arachnids are shown in Appendix II (with the exception of *Caribena versicolor*, which is in Appendix III), and many are important species within the pet sector. However, *Poecilotheria* and *Caribena versicolor* have only recently been added to the CITES appendices, and thus no long-term data exist for these taxa. Therefore, we focused our analysis on the genera *Pandinus* and *Brachypelma* (including former members/synonyms) as representatives of scorpions and spiders, respectively. To identify the temporal patterns in the trade of our genera of focus, we compared their trade numbers in the 5-year period after their placement on CITES (Appendix II), with the numbers available for the most recent 5-year period. Therefore, we downloaded data from the CITES trade database (Convention on International Trade in Endangered Species of Wild Fauna and Flora, 2022) for *Brachypelma* and *Pandinus* between 1995 and 1999 (reflecting the 5-year period after their listing under CITES) and between 2016 and

TABLE 1 Overview of CITES-protected arachnids. Explanations given for each appendix are taken from the CITES database (CITES, 2023) and presented alongside the arachnids assigned to each appendix.

Appendices	Explanation	Listed arachnids with current synonyms
Appendix I	"Appendix I lists species that are the most endangered among CITES-listed animals and plants […]. They are threatened with extinction and CITES prohibits international trade in specimens of these species except when the purpose of the import is not commercial."	None
Appendix II	"Appendix II lists species that are not necessarily now threatened with extinction but that may become so unless trade is closely controlled. It also includes so-called "look-alike species", i.e., species whose specimens in trade look like those of species listed for conservation reasons […]. International trade in specimens of Appendix-II species may be authorized by the granting of an export permit or re-export certificate. No import permit is necessary for these species under CITES."	Araneae: *Aphonopelma pallidum, Brachypelma albiceps, B. auratum, B. baumgarteni, B. boehmei, B. emilia, B. hamorii, B. klaasi, B. smithi, Sandinista lanceolatum, Sericopelma angustum, S. embrithes, Tliltocatl albopilosus, T. epicureanus, T. kahlenbergi, T. sabulosus, T. schroederi, T. vagans, T. verdezi, Poecilotheria fasciata, P. formosa, P. hanumavilasumica, P. metallica, P. miranda, P. ornata, P. rajaei, P. regalis, P. rufilata, P. smithi, P. striata, P. subfusca, P. tigrinawesseli*, and *P. vittata* (all *Brachypelma* spp. and *Poecilotheria* spp.) Scorpiones: *Pandinopsis dictator, Pandinus gambiensis*, and *P. imperator*
Appendix IIII	"Appendix III is a list of species included at the request of a Party that already regulates trade in the species and that needs the cooperation of other countries to prevent unsustainable or illegal exploitation […]. International trade in specimens of species listed in this Appendix is allowed only on presentation of the appropriate permits or certificates."	*Caribena versicolor*

Species are presented in accordance with their most recent nomenclature as per the World Spider Catalog (World Spider Catalog, 2023) and The Scorpion Files (Rein, 2023).

2020 (as the most recent 5-year period available). The CITES identifiers W (wild-caught) and R (ranched) were used to represent wild-caught specimens, and C (bred in captivity) was used to represent captive-bred specimens. For assessing the numbers of traded specimens, we used either the numbers of imported or exported specimens (i.e., the highest value was always selected). The summed-up annual trade numbers (C + W + R) were averaged in their respective 5-year period and the captive-bred percentage ratios were calculated using the following formula:

$$\text{ratio} = C/(C + W + R)100$$

The compiled data matrix for the CITES data analysis is available as Supplementary Data ("CITES-Calculation periods" tab). In addition, we extracted the export numbers for traded *Brachypelma* spiders and *Pandinus* scorpions based on their countries of origin (in terms of their respective natural distribution ranges; the countries of origin for CITES-protected spiders were extracted from the World Spider Catalog (World Spider Catalog, 2023), and for scorpions from Holstein et al. (2017) (Holstein et al., 2017)). Detailed CITES export data are available in the Supplementary Data ("CITES-*Brachypelma* exports" and "CITES-*Pandinus* exports" tabs).

2.2 LEMIS data

The Law Enforcement Management Information System (LEMIS) database of the US Fish and Wildlife Service contains well-curated data on the import and export of wild animals to and from the United States. Contrary to CITES, it contains data on a wider variety of imported taxa, instead of being solely focused on taxa available in CITES appendices. Accordingly, it is well suited as an additional database for complementary analyses conducted using the CITES database, and for the analysis of pet trade on a broader scale. We downloaded the LEMIS data provided by Marshall et al. (Eskew et al., 2019; Marshall et al., 2022) and exported them into a Microsoft Excel file consisting of 16,977 entries for arachnids imported to the USA from 2000 to 2014. In the original data set, all entries for the "taxa" column were listed as "spider", independent of the order of imported arachnids. The column "generic_name" provided some classification into different orders; however, on several occasions we had to correct the taxonomic assignments. To enable data analysis to be carried out based on the respective taxonomic levels, we extended the data set by adding three extra columns, for organism, order, and family (Supplementary Data—"LEMIS-Edited" tab). We then calculated the annual total import numbers for each of the years from 2000 to 2014 for spiders, scorpions, and other arachnids (Supplementary Data—"LEMIS-Annual USA imports" tab). Simple linear regression analysis in GraphPad Prism 9 for Mac was used to construct graphical representations of the annual trends in traded arachnids (for details on confidence intervals, see Supplementary Data—"LEMIS-Linear regression" tab). For statistical analysis, Mann–Kendall tests were carried out online (Wessa, 2023) to reveal significant trends in annual sales from 2000 to 2014 (Supplementary Data—"LEMIS- Mann-Kendall tests" tab).

All trade data for the scorpion genus *Mesobuthus* were extracted and total trade numbers were summarized over the 2012–2014 period (i.e., the period when *Mesobuthus* imports dominated the market) for each specific importer and exporter to construct the respective importer and exporter rankings (Supplementary Data—"LEMIS-*Mesobuthus*" tab). To further categorize the importers according to their respective import purposes, we introduced the following four categories based on the respective importer name (Supplementary Data—"LEMIS-Importers" tab): "academic, research, education" (including names containing the following words or variations thereof: science, university, museum, academy, zoo, aquarium, college, learning, institute, conservation, education, laboratories, and research; this category also included well-known state organizations and pharmaceutical companies involved in science and research); "arts, craft, souvenirs, clothing" (including names containing the following words or variations thereof: fashion, gallery, taxidermy, gifts, gems, art, souvenirs, creations, jewelry, artistry, treasure, and decorative); and "herbs, medicine, food, other" (including names containing the following words or variations thereof: pest, herb, entertainment, foods, medical, natural, and bait). For some importers, whose purpose was not apparent from their name, a Google search was conducted, and, if available, the link to the respective importers website was provided (Supplementary Data—"LEMIS-Importers" tab). All other importers not classified into any of the above three categories were presumed to be involved in "pet trade".

3 Results

3.1 CITES data

The percentage ratios of captive-bred specimens yielded rather disparate results for *Brachypelma* and *Pandinus* (Table 2). For *Brachypelma*, there was a clear increase in the percentage of traded captive-bred specimens, that is, from 44.4% to 99.9%, between the two periods analyzed. Concurrently, overall trade numbers increased by 330%, that is, from 6,764 to 22,322 specimens. In contrast, for *Pandinus*, the captive-bred ratio remained similarly low (1.0% *vs*. 0.2%), whereas the overall annual trade numbers decreased significantly by 86.3%, that is, from 82,046 to 11,225 specimens.

Further analysis of the countries of origin revealed important insights into the trade with CITES-protected arachnids. For spiders of the genera *Brachypelma* and *Tliltocatl* (Table 3), *T. albopilosus* comprise more than half (55.3%) of all exports and the top five species (*T. albopilosus, B. smithi, B. boehmei, B. auratum*, and *B. klaasi*) constitute 86.9% of all exported animals. Nicaragua and Mexico are the most important exporting countries, providing 92.9% of all exports. Overall, 116,290 *Brachypelma* and *Tliltocatl* specimens were documented as being exported since their inclusion in CITES in 1985 (*B. smithi*) and 1994 (remaining species). For *Pandinus* scorpions (Table 4), exports were almost exclusively composed of *P. imperator* (99.4%) scorpions, with three countries (Ghana, Togo, and Benin) contributing the majority (96.0%) of all exported specimens. With more than 2.3 million *Pandinus* scorpions being exported since their CITES listing in 1994, their export numbers dwarf the numbers of all CITES-protected spiders by a factor of over 20.

3.2 LEMIS data

Annual US imports recorded in LEMIS revealed no statistically significant trends for different arachnid orders (Figure 1A). For details of the statistical analysis conducted using Mann–Kendall tests, see Supplementary Data ("LEMIS-Mann-Kendall tests" tab). Our analysis of popular spider and scorpion families (Figure 1B)

TABLE 2 Trade numbers for the CITES-protected arachnid genera *Brachypelma* and *Pandinus*.

		Brachypelma		*Pandinus*	
Period	Year	Number of traded specimens	Captive-bred percentage	Number of traded specimens	Captive-bred percentage
Initial period	1995	3,447	65.6%	44,058	1.13%
	1996	3,186	18.7%	60,222	1.89%
	1997	8,534	56.8%	87,950	0.74%
	1998	7,752	44.5%	108,574	0.38%
	1999	10,902	36.2%	109,426	0.92%
	Annual average	**6,764**	**44.4%**	**82,046**	**1.01%**
Recent period	2016	10,567	100.0%	1,424	0.00%
	2017	15,307	99.7%	5,193	0.00%
	2018	16,348	100.0%	25,091	0.00%
	2019	34,180	100.0%	10,816	0.61%
	2020	35,207	100.0%	13,600	0.15%
	Annual average	**22,322**	**99.9%**	**11,225**	**0.15%**

The average annual numbers of traded *Brachypelma* spiders and *Pandinus* scorpions were extracted from the CITES database (Convention on International Trade in Endangered Species of Wild Fauna and Flora, 2022) for the 5-year period immediately after their listing under CITES (1995–1999) and the most recent available 5-year period (2016–2020). The formula [ratio = C/(C + W + R) * 100] was used to calculate the captive-bred percentage ratios. Annual average values are indicated in bold.

TABLE 3 Export numbers for CITES-protected spiders of the genera *Brachypelma* and *Tliltocatl* based on their countries of origin.

Brachypelma/Tliltocatl species	Country of origin						
	Nicaragua	Mexico	Honduras	Belize	Costa Rica	Total	Percentage
T. albopilosus	57,217	0	7,146	0	3	64,366	**55.3**
B. smithi	100	15,319	100	0	0	15,519	**13.3**
B. boehmei	0	13,546	0	0	0	13,546	**11.6**
B. auratum	0	4,717	0	0	0	4,717	**4.1**
B. klaasi	0	2,864	0	0	0	2,864	**2.5**
T. verdezi	0	2,363	0	0	0	2,363	**2.0**
B. albiceps	0	2,064	0	0	0	2,064	**1.8**
B. emilia	0	1,920	0	0	0	1,920	**1.7**
T. epicureanus	0	1,770	0	0	0	1,770	**1.5**
T. vagans	0	1,406	0	307	0	1,713	**1.5**
B. hamorii	0	1,367	0	0	0	1,367	**1.2**
B. baumgarteni	0	879	0	0	0	879	**0.8**
T. kahlenbergi	0	301	0	0	0	301	**0.3**
T. schroederi	0	166	0	0	0	166	**0.1**
unspecified*	2,056	5	650	2	22	2,735	**2.4**
Total	59,373	48,687	7,896	309	25	116,290	
Percentage	**51.1**	**41.9**	**6.8**	**0.3**	**0.0**		

The data were extracted from CITES database (Convention on International Trade in Endangered Species of Wild Fauna and Flora, 2022) and the total numbers and percentages have been calculated for each country of origin and species, respectively. *Note that "unspecified" indicates data for *Sandinista lanceolatum* and unspecified or misidentified *Brachypelma* or *Tliltocatl* species. Percentage values are indicated in bold.

uncovered a significant increase for Buthidae scorpions (Kendall $\tau = 0.6381$, $P = 0.0011$) and "Other" spiders (Kendall $\tau = 0.4476$, $p = 0.0228$), and a significant decrease for Scorpionidae scorpions (Kendall $\tau = -0.5238$, $P = 0.0075$). Overall imports in the three most recent years were dominated by Buthidae scorpions, which constituted 48.7% of all imported arachnids, followed by tarantulas (Theraphosidae, 22.2%), and Scorpionidae scorpions (16.4%). Analysis of the most popular imported arachnid genera (Figure 1C) revealed significantly increasing trajectories for *Heterometrus* (Kendall $\tau = 0.5619$, $p = 0.0041$) and *Mesobuthus* scorpions (Kendall $\tau = 0.5992$, $p = 0.0049$), and also for *Avicularia* spiders (Kendall $\tau = 0.3905$, $P = 0.0478$), but significantly decreasing trends for *Pandinus* scorpions (Kendall $\tau = -0.6571$, $P = 0.0008$) and *Grammostola* spiders (Kendall $\tau = 0.4667$, $p = 0.0175$). Among these popular genera, *Mesobuthus* (61.5%) dominated the imports between 2012 and 2014, followed by *Pandinus* (12.3%) and *Grammostola* (11.5%). The import numbers for *Mesobuthus* in 2014 were 1,652-fold higher than those recorded in 2006. A closer analysis of the 2012–2014 timeframe revealed that the top four exporters and importers for *Mesobuthus* scorpions,

TABLE 4 Export numbers for CITES-protected scorpion species of the genus *Pandinus* based on their countries of origin.

	Country of origin					
Pandinus species	Benin	Ghana	Togo	Other countries	Total	Percentage
P. dictator*	250	0	0	11,285	11,535	**0.5**
P. gambiensis	300	0	0	0	300	**0.0**
P. imperator	230,916	1,375,547	624,734	82,832	2,314,029	**99.4**
Unspecified	0	0	3,000	25	3,025	**0.1**
Total	231,466	1,375,547	627,734	94,142	2,328,889	
Percentage	**9.9**	**59.1**	**27.0**	**4.0**		

The data were extracted from the CITES database (Convention on International Trade in Endangered Species of Wild Fauna and Flora, 2022) and the total numbers and percentages have been calculated for each country of origin and species, respectively. *Note that *P. dictator* has been reclassified as *Pandinopsis dictator* (Rossi, 2015). "Other countries" indicates data for the Democratic Republic of Congo, Central African Republic, Republic of Congo, Côte d'Ivoire, Cameroon, Guinea, Equatorial Guinea, Mali, Niger, Nigeria, Senegal, and Chad. Percentage values are indicated in bold.

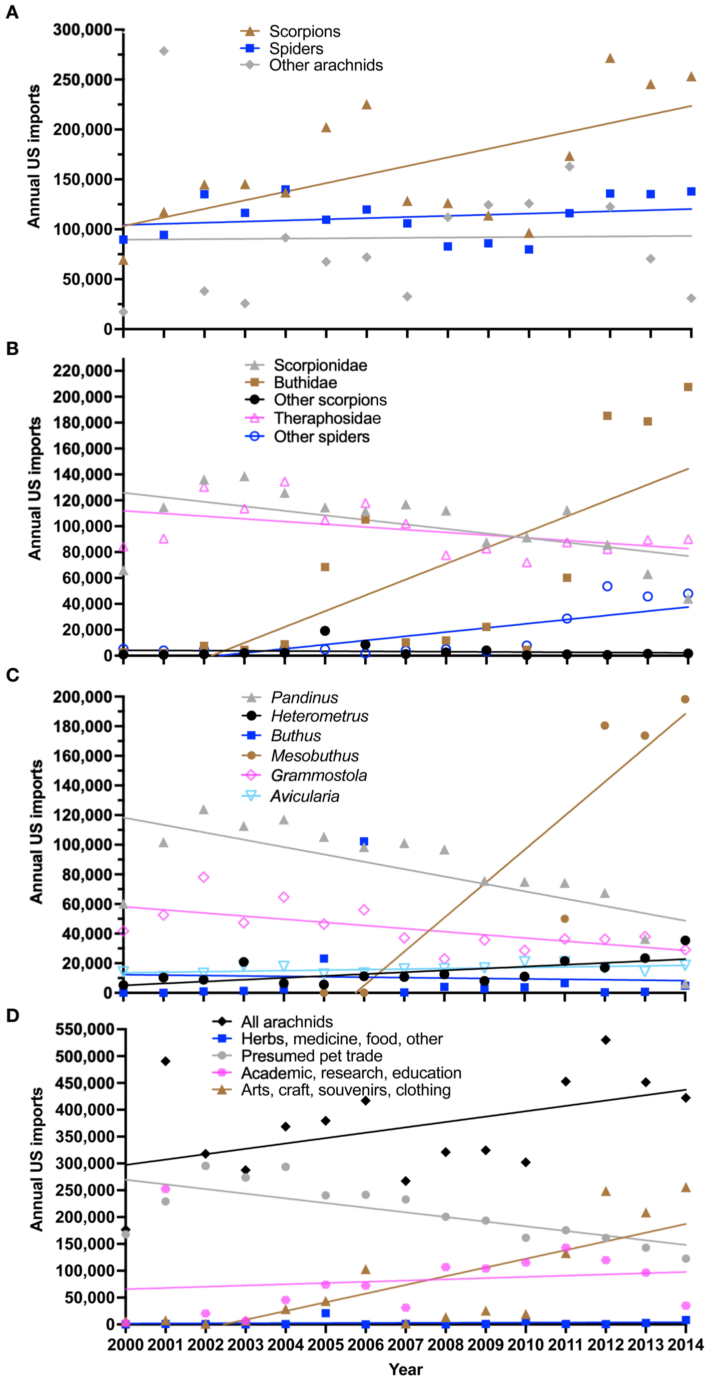

FIGURE 1
Annual arachnid trade. **(A)** All US import numbers taken from the LEMIS database for the period 2000–2014 and analyzed at the level of arachnid orders; **(B)** the most frequently imported families; **(C)** genera; and **(D)** for different import purposes. Arachnids imported for the pet trade were calculated by subtracting the total annual numbers for all arachnids from the numbers for arachnids imported for other purposes (including education, research, arts, craft, souvenirs, clothing, herbs, medicine, food, and others). All trend lines are based on simple linear regression analysis carried out using GraphPad Prism 9 for macOS.

constituting 93.5% and 96.5%, respectively, of all *Mesobuthus* specimens imported to the USA, had a business focus on plastic or resin products, toys, gifts, and souvenirs (see Supplementary Data "LEMIS-*Mesobuthus*" tab for details)

The analysis of different purposes of arachnid trade according to the presumed business area of the respective importer revealed significant trends for two categories only (Figure 1D): an increasing trend was observed for "arts, craft, souvenirs, clothing" (Kendall $\tau = 0.6190$, $p = 0.0015$), whereas a decreasing trend was observed for "presumed pet trade" (Kendall $\tau = -0.6381$, $p = 0.0011$). Over the 15-year period, the "presumed pet trade" constituted the majority of all traded arachnids (56.9%), whereas the "academic, research, education" and "arts, craft, souvenirs, clothing" categories each constituted > 20% of all traded specimens (Figure 2). "Herbs,

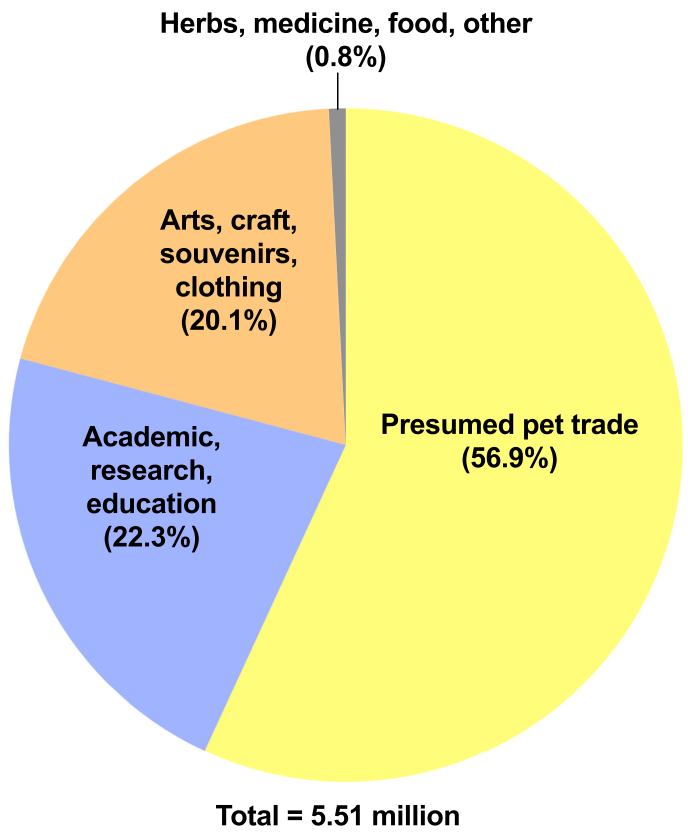

FIGURE 2
LEMIS trade purposes. Four different trade purposes were categorized based on the respective importer names (see Supplementary Data "LEMIS importer" tab for details).

medicine, food, other" played only a minor role (0.8%). Interestingly, in the most recent 3 years, imports to the USA were mainly for the "arts, craft, souvenirs, clothing" sector (50.8%), with "presumed pet trade" (30.4%) ranking second, and "academic, research, education" (17.9%) ranking third.

4 Discussion

4.1 Trends within the international arachnid trade

For arachnids, reliable trade data is scarce and limited to only a few sources, each with their specific limitations. The CITES database (Convention on International Trade in Endangered Species of Wild Fauna and Flora, 2022), for instance, contains data for a few protected species only; the vast majority of arachnids are currently not (internationally) protected, and therefore their trade is not recorded. The LEMIS database (Eskew et al., 2019), on the other hand, records data for wildlife imports and exports, including all arachnid species. However, it has a major limitation in that these data are only collected for a single country, the USA. In addition, both LEMIS and CITES databases do not take account of trade that takes place within individual nations. A final drawback, which is common to all wildlife trade databases containing import/export data, is that illegally collected and trafficked animals are not necessarily included. Illegal arachnid trade, for example, with purposely mislabeled specimens, may play an important and hitherto understudied role. Thus, future works should aim to clarify the extent of this potentially problematic field.

However, our data, and that available in previously published studies of the global arachnid trade, clearly demonstrate that the exotic pet market is a major contributor to the global arachnid trade, with millions of traded individuals (Marshall et al., 2022). To this end, a detailed analysis of the temporal dynamics of the global arachnid trade has not been conducted in prior studies, and accordingly we set out to broaden our understanding of this topic. By conducting an annual breakdown of the LEMIS data, we demonstrated that hundreds of thousands of arachnids are imported each year to the USA alone. In addition, we uncovered several hitherto-overlooked trends within the global arachnid trade. For example, we noted that there was an unprecedented increase in the number of *Mesobuthus* scorpion US imports from 2012 to 2014. Interestingly, the genus *Mesobuthus* plays only a marginal role in the exotic pet community. For instance, *Mesobuthus* is not even among the top 20 most commonly kept scorpion genera (Hauke and Herzig, 2021). However, the species *Mesobuthus* (*Olivierus*) *martensii* is commonly used in traditional Chinese medicine under the name "Quanxie" for treating pain, convulsions, or tetanus, and it seems plausible that some of the traded *Mesobuthus* scorpions are used for Quanxie production instead as pets (Liu and Ji, 2015). However, an even more probable explanation for the increasing numbers of *Mesobuthus* US imports could be the use of *Mesobuthus* scorpions as gifts and souvenirs. We found that the top four exporters and importers of *Mesobuthus* scorpions, which constituted 93.5% and 96.5% of all traded *Mesobuthus* specimens, are businesses that are working in the areas of resin or plastic products, toys, gifts, or souvenirs.

Although the recent study by Marshall and colleagues argued that the popularity of arachnids as pets is increasing (Marshall et al., 2022), we did not find solid evidence to support this statement. In contrast, we found several independent lines of evidence indicating the opposite. Given that the arachnid pet market, in terms of the number of traded species, is largely dominated by tarantulas (Hauke and Herzig, 2021; Marshall et al., 2022), it is intriguing that we observed a slight (although not significant (Kendall τ = -0.2952, p = 0.1376)) decline in their US import numbers (Figure 1B). This aligns with our previous findings that the number of reported bites and stings from pet arachnids, which were predominantly caused by theraphosids, decreased from the first to the second decade of this century (Hauke and Herzig, 2021). One could argue that these are only local trends that are restricted to particular regions, and that the arachnid pet markets differ between geographical regions. Although our previous study was mainly based on data for the North American and European pet markets (Hauke and Herzig, 2021), a recent study of the South African pet market (Shivambu et al., 2020) showed that, of the top 30 most popular tarantula genera, 70% are common to all these regions (Hauke and Herzig, 2022). Using the list of tarantula genera with the most frequent mentions of color from Marshall and colleagues (Marshall et al., 2022) as an estimate of the popularity of the respective genus results in a 66.7% overlap with the top 30 genera from the South African study, and a 56.7% overlap with our previous data for the European and North American markets (Supplementary Data—"LEMIS-popular genera" tab). Overall, this provides support for an extensive overlap in the arachnid pet markets of different geographical regions, at least for tarantulas. Furthermore, in the most recent 3-year period, from 2012 to 2014, over 50% of US imports were made for the "arts, craft, souvenirs, clothing" sector, and the pet trade, with about 30% of US imports, ranking only second. In conclusion, the observed regional trends do not support an increasing global popularity of arachnid pets as previously suggested, (Marshall et al., 2022). On the other hand, the analyzed databases contain data on legal trade in arachnids only between different countries, meaning that the contributions of illegal trafficking or domestic trade to overall arachnid trade could be underestimated.

4.2 Driving forces behind the arachnid trade

Previous examinations of the arachnid trade have largely focused on the pet sector (Marshall et al., 2022). In comparison, other driving forces and their respective contributions toward the global arachnid trade have received little attention. In our analysis of the LEMIS data, we therefore categorized the arachnids imported in accordance with the presumed business activities of the respective importing businesses. An interesting observation we made is that several of the importer and exporter names indicated an academic research purpose of the traded animals. The importer names included, for example, universities, colleges, museums, zoos, governmental agencies, and pharmaceutical or biomedical companies. Although the exporter names of only 3.3% of all traded arachnids indicated an academic purpose, 22.3% of all traded arachnids were linked to importers working in the "academic, research, education" sector. The disparity between those numbers might be explained by the fact that research organizations often purchase their specimens from exporters, such as commercial pet suppliers, that do not have a solely scientific focus. Therefore, the value of 22.3% based on the importer names is a more likely to be a representation of the actual numbers of arachnid specimens traded for academic and scientific purposes. In this regard, it needs to be acknowledged that in most cases of an importer being in the category "academic, research, education", the respective exporters were also from within this category. This trade in arachnid specimens for research purposes includes loans of (mostly dead) specimens between academic institutions.

In addition, we found that 20.1% and 0.8% of all traded arachnids were linked to importers in the "arts, craft, souvenirs, clothing" or in the "herbs, medicine, food, others" sectors, respectively. Overall, this indicates that at least 43% of all traded arachnids recorded in the LEMIS database were not traded for the pet sector. Furthermore, even more non-pet-related purchases might have been masked in the database if they have been processed through wholesalers from the pet supply sector instead of direct imports. Thus, we anticipate these 43% to be a rather conservative approximation of the actual numbers and presume that non-pet-sector-related imports are much higher. An intriguing observation is that the annual import numbers of arachnids for the pet sector have been significantly decreasing (Figure 1D). From 2002 to 2014, the numbers of arachnids traded for the pet sector in the USA have reduced by 58.4%, contradicting the proposition that arachnids as pets are increasing in popularity (Marshall et al., 2022).

Taken together, our findings for US imports highlight that, besides the pet sector, arachnids are also traded for scientific and academic purposes, for gifts and souvenirs, and, to a lesser degree, for food and traditional medicine. Based on the LEMIS data for 2012–2014, the souvenir sector has taken the top spot from the pet sector as the leading purpose of arachnid trade, with research and education as the third most common purpose, with other purposes playing only an insignificant role. If governments are aiming is to protect arachnid wildlife by restricting arachnid trade, detailed knowledge regarding the purposes of this trade is of pivotal importance. This will help in the development of tailor-made solutions for specific purposes and taxa. For example, if certain (e.g., potentially endangered) species are imported in large numbers to be embedded in resin and sold as souvenirs (see 4.1), one solution would be to replace them with more common species, or those that can be easily bred in sufficient numbers in captivity. That said, our analysis of the arachnid trade conducted herein is based on a subset of CITES-protected species and data, and is focused on the USA as a model region. Therefore, to understand the details and nuances of the international arachnid trade on a global scale, subsequent studies with additional taxa and methods for varying geographic regions need to be conducted. Such future works are pivotal because uninformed or misinformed policymaking in conservation can cause harm to species that require intensive protective measures (Challender et al., 2022).

4.3 The role of captive breeding

Another point that remains to be examined is the contribution of captive breeding to the arachnid trade. Although it has previously been estimated that the ratio of arachnids sourced from the wild ranges between 67% and 70%, based on LEMIS data (Marshall et al., 2022), it is unclear to what extent captive-bred specimens contributed to the overall arachnid trade. In this context, it has been proposed that many taxa were sold online but were absent from LEMIS and CITES trade databases, which was regarded as a result of the under-regulation of arachnid trade and the ability of businesses to ship specimens easily (Marshall et al., 2022). However, as these databases monitor only international trade and imports, the role of nationally captive-bred and traded specimens remains undetermined. Furthermore, our analysis of the CITES data revealed some important insights as to the potential of captive breeding to meet the demand for protected arachnid species. In the case of the *Brachypelma* and *Tliltocatl* species, we noticed that, after being listed under CITES protection, the supply of these tarantulas shifted almost exclusively (> 99%) toward captive-bred specimens, despite a 330% increase in traded numbers. On the other hand, for *Pandinus* scorpions, the captive-bred ratio remained extremely low (below 1%) and the overall trade numbers reduced by > 86%. These apparent discrepancies might be explained by reproductive biology, as *Pandinus* scorpions give birth to only a few dozen juveniles (Lourenço and Cloudsley-Thompson, 1999; Ross, 2002), whereas it is well known that many tarantula species (including *Brachypelma*) produce hundreds and sometimes thousands of offspring per egg sac, and some females even produce multiple egg sacs after an instance of successful copulation (Montes de Oca and Mendoza, 2020). Yet, whether or not there can be a continuous supply of wild-caught specimens also depends on national conservation approaches in the countries of origin. In Mexico, for example, *Brachypelma* species are protected by national law (Mendoza and Francke, 2020). The CITES data therefore imply that international regulations (in particular, as supplements to national conservation approaches) have the potential to shift the global arachnid trade toward captive-bred instead of wild-caught specimens, as exemplified in the case of the protected *Brachypelma* and *Tliltocatl* species, with their large offspring numbers. In contrast, for protected *Pandinus* scorpions, which have small offspring numbers and few national conservation approaches in their countries of origin, the demand for wild-caught specimens was not affected by their listing under CITES. As in all economically driven areas, the trade dynamics of arachnids are heavily influenced by costs and potential revenue. If wild-caught specimens can be obtained at a cheaper rate than captive-bred individuals, such imports will represent an important obstacle to the facilitation of a full shift toward captive-bred individuals. In such instances, a concerted effort of the countries of origin and wildlife protection agencies needs to aim at increasing the "price tag" for wild-caught specimens. Concurrently, both exporting and importing countries need to jointly facilitate and incentivize captive-breeding efforts to render captive-bred specimens more economically competitive. Importantly, specific requirements and ecological traits need to be considered separately for each arachnid species to enable successful captive-breeding programs to be implemented.

4.4 Toward a sustainable arachnid trade—the potential of hobbyists for conservation and science

The fact that annual arachnid import numbers in the USA alone are averaging between 300,000 and 500,000 suggests that overall worldwide trade is on a much larger scale, with import numbers most probably ranging in the millions. This represents a significant economic market and financial aspects are undoubtedly a factor in the global arachnid trade. Although arachnid pet husbandry certainly plays an important role here, we have demonstrated that the trading of arachnids as souvenirs has emerged as a novel and increasing area of the market, of a comparable volume to that of the pet sector. Thus, focusing only on the exotic pet market would certainly mean adopting a one-dimensional perspective on this multidimensional topic (Research highlights, 2022). Furthermore, although the practices of husbandry and trade in exotic pets have negative side effects, they simultaneously harbor a tremendous potential that could be used for conservation and science. In the case of arachnids in particular, several important studies in taxonomy (Huesser, 2018), evolution (Lueddecke et al., 2018; Foley et al., 2019), or toxinology and drug discovery (Klint et al., 2015; Osteen et al., 2016; Jiang et al., 2021; Finol-Urdaneta et al., 2022) have been conducted with sample material provided by hobbyists. It is apparent that the arachnocultural community can be employed as a powerful tool to foster arachnid research when implemented under the right preconditions (e.g., using only specimens with well-recorded locality data and under the supervision of professional arachnologists). The arachnocultural community may also play a role in arachnid conservation under the same preconditions. For instance, *ex situ* breeding programs can represent an important means of conservation by establishing "back-up" populations for species threatened in the wild, and hobbyists could establish and run such projects (Crespo et al., 2014). There are already early success stories associated with such projects: the Indian tarantula species *Poecilotheria metallica* is considered to be critically endangered due to the massive loss of its biotope because of deforestation (Molur et al., 2008). However, based on specimens obtained from the international pet trade, where it is regularly bred, this species has recently been included in an *ex situ* breeding program that is professionally coordinated by the European Association of Zoos and Aquaria (European Association of Zoos and Aquaria, 2022).

5 Future perspectives

Based on our findings and data from the literature, there is a variety of drivers behind the global arachnid trade in addition to the pet sector. This includes the use of arachnids for academic and scientific purposes, for traditional medicine (Liu and Ji, 2015), ethnopharmaceuticals, as food (Yen and Ro, 2013), and also for gifts and souvenirs (Smith, 2011). We further expect that there will be substantial geographical variations in the extent to which these markets play a role and thus varying degrees of threat-potentials for wild arachnofauna when looking at different regions. For example, the souvenir and pet markets might dominate in more industrialized Western countries, whereas those for food or traditional medicine might be the dominant drivers in Asian and African countries (Marshall et al., 2022). However, as we have learned from the public management of illegal drugs, extensive prohibitions paradoxically increase associated criminal offenses, and, regulation of the market has therefore been suggested as a better alternative (Werb et al., 2011; Wodak, 2018). Wildlife trade bans are equally controversial (Xiao et al., 2021) and have been shown to increase wildlife trade in some cases (Rivalan et al., 2007). For trade with exotic arachnids, we therefore need to develop more sustainable solutions that prevent the exploitation of natural habitats, provide benefits to the countries of origin, and ensure that there are sufficient supplies of arachnid species for commercial purposes and research. We suggest that fostering coordinated breeding programs could be an efficient means of achieving these aims. To develop successful breeding programs, each arachnid species needs to be assessed on a case-by-case basis to achieve the best possible outcome. Strong ongoing collaborations between the importing countries and the countries of origin will ensure mutual benefits, including financial benefits, expertise with rearing conditions, and the maintenance of genetic diversity. We are confident that the use of coordinated captive-breeding programs will meet a significant proportion of the overall demand for many arachnid pet species. In addition, such programs could also provide opportunities for fostering collaborative research projects (Krehenwinkel, 2008; Bushell, 2015).

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material. Further inquiries can be directed to the corresponding authors.

Author contributions

VH, TH, and TL designed the study. VH analyzed the LEMIS data; TH and TL analyzed the CITES data. All authors contributed to the article and approved the submitted version.

Funding

VH was supported by an Australian Research Council (ARC) Future Fellowship (FT190100482). TL acknowledges generous funding from the Hesse Ministry of Science and Art via the LOEWE Center for Translational Biodiversity Genomics (LOEWE-TBG).

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

The authors VH and TL declared that they were editorial board members of Frontiers at the time of submission. This had no impact on the peer review process and the final decision.

Publisher's note

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/frchs.2023.1161383/full#supplementary-material

References

Battiston, R., Di Pietro, W., and Anderson, K. (2022). The pet mantis market: a first overview on the praying mantis international trade (Insecta, mantodea). *J. Orthoptera Res.* 31 (1), 63–68. doi: 10.3897/jor.31.71458

Bushell, M. (2015). Conservation of the critically endangered desertas wolf spider - the story so far…. *Brit. Tarantula Soc J.* 30 (2), 34–39.

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. *Biol. Conserv.* 263 (109341), 1–9. doi: 10.1016/j.biocon.2021.109341

Challender, D. W. S., Brockington, D., Hinsley, A., Hoffmann, M., Kolby, J. E., Massé, F., et al. (2022). Mischaracterizing wildlife trade and its impacts may mislead policy processes. *Conserv. Lett.* 15 (e12832), 1–10. doi: 10.1111/conl.12832

CITES (2023) *Convention on international trade in endangered species of wild fauna and flora*. Available at: https://cites.org/eng (Accessed 4.4.2023).

Convention on International Trade in Endangered Species of Wild Fauna and Flora (2022). Available at: https://trade.cites.org/ (Accessed 31/05/2022).

Cowie, R. H., Bouchet, P., and Fontaine, B. (2022). The sixth mass extinction: fact, fiction or speculation? *Biol. Rev. Camb. Philos. Soc* 97 (2), 640–663. doi: 10.1111/brv.12816

Crespo, L. C., Silva, I., Borges, P. A. V., and Cardoso, P. (2014). Assessing the conservation status of the strict endemic desertas wolf spider, *Hogna ingens* (Araneae, lycosidae). *J. Nat. Conserv.* 22, 516–524. doi: 10.1016/j.jnc.2014.08.005

Eskew, E. A., White, A. M., Ross, N., Smith, K. M., Smith, K. F., Rodríguez, J. P., et al. (2019) *United states LEMIS wildlife trade data curated by EcoHealth alliance*. Available at: https://zenodo.org/record/3565869#.YpWv7JNBzD8.

European Association of Zoos and Aquaria (2022). *"Gooty sapphire ornamental spider ex-situ programme"*. Available at: https://www.eaza.net/conservation/programmes/eep-pages/gooty-sapphire-ornamental-spider-eep/.

Finol-Urdaneta, R. K., Ziegman, R., Dekan, Z., McArthur, J. R., Heitmann, S., Luna-Ramirez, K., et al. (2022). Multitarget nociceptor sensitization by a promiscuous peptide from the venom of the king baboon spider. *Proc. Natl. Acad. Sci. U.S.A.* 119 (5), 1–25. doi: 10.1073/pnas.2110932119

Foley, S., Lueddecke, T., Cheng, D. Q., Krehenwinkel, H., Kunzel, S., Longhorn, S. J., et al. (2019). Tarantula phylogenomics: a robust phylogeny of deep theraphosid clades inferred from transcriptome data sheds light on the prickly issue of urticating setae evolution. *Mol. Phylogenet. Evol.* 140, 106573. doi: 10.1016/j.ympev.2019.106573

Fukushima, C. S., Mammola, S., and Cardoso, P. (2020). Global wildlife trade permeates the tree of life. *Biol. Conserv.* 247, 108503. doi: 10.1016/j.biocon.2020.108503

Fukushima, C., Mendoza, J. I., West, R. C., Longhorn, S. J., Rivera, E., Cooper, E. W. T., et al. (2019). Species conservation profiles of tarantula spiders (Araneae, theraphosidae) listed on CITES. *Biodivers. Data J.* 7, e39342. doi: 10.3897/BDJ.7.e39342

Goka, K. (2022). Conservation biology for the commercial insect trade in Japan: agricultural bumblebees and companion insects as examples. *Rev. Sci. Tech.* 41 (1), 132–141. doi: 10.20506/rst.41.1.3310

Hauke, T. J., and Herzig, V. (2021). Love bites - do venomous arachnids make safe pets? *Toxicon* 190, 65–72. doi: 10.1016/j.toxicon.2020.12.003

Hauke, T. J., and Herzig, V. (2022). The most popular tarantula genera in the pet-keeping hobby – a quantitative approach. *Brit. Tarantula Soc J.* 37 (1), 6–11.

Holstein, J., Wendt, I., and Rossi, A. (2017). The emperor is back! rediscovery and redescription of the holotype of *Pandinus imperator* (Scorpiones: scorpionidae). *Arachnologische Mitt.* 54 (54), 44–47. doi: 10.5431/aramit5410

Huesser, M. (2018). A first phylogenetic analysis reveals a new arboreal tarantula genus from south America with description of a new species and two new species of tapinauchenius ausserer 1871 (Araneae, mygalomorphae, theraphosidae). *Zookeys* 784), 59–93. doi: 10.3897/zookeys.784.26521

Hughes, A. C., Marshall, B. M., and Strine, C. T. (2021). Gaps in global wildlife trade monitoring leave amphibians vulnerable. *Elife* 10, 1–23. doi: 10.7554/eLife.70086

Jiang, Y., Castro, J., Blomster, L. V., Agwa, A. J., Maddern, J., Schober, G., et al. (2021). Pharmacological inhibition of the voltage-gated sodium channel $Na_V1.7$ alleviates chronic visceral pain in a rodent model of irritable bowel syndrome. *ACS Pharmacol. Transl. Sci.* 4 (4), 1362–1378. doi: 10.1021/acsptsci.1c00072

Klint, J. K., Smith, J. J., Vetter, I., Rupasinghe, D. B., Er, S. Y., Senff, S., et al. (2015). Seven novel modulators of the analgesic target NaV1.7 uncovered using a high-throughput venom-based discovery approach. *Br. J. Pharmacol.* 172 (10), 2445–2458. doi: 10.1111/bph.13081

Krehenwinkel, H. (2008). Eine neue, baumbewohnende *Orphnaecus*-art von der philippinen-insel panay. *Arachne* 13 (5), 23–26.

Liu, Z. R., and Ji, Y. H. (2015). ""Scorpion venom research around the world: Chinese scorpion mesobuthus martensii karsch,"," in *Scorpion venoms*. Eds. P. Gopalakrishnakone, L. F. Possani, E. Schwartz and R. Rodríguez de la Vega (Dordrecht: Springer).

Lourenço, W. R., and Cloudsley-Thompson, J. L. (1999). Variation in energy spent on reproduction between forest and savanna populations of *Pandinus imperator* (Koch) (Scorpiones, scorpionidae) in the ivory coast. *Bull. Brit. Arachnol. Soc* 11 (4), 136–138.

Lueddecke, T., Krehenwinkel, H., Canning, G., Glaw, F., Longhorn, S. J., Tanzler, R., et al. (2018). Discovering the silk road: nuclear and mitochondrial sequence data resolve the phylogenetic relationships among theraphosid spider subfamilies. *Mol. Phylogenet. Evol.* 119, 63–70. doi: 10.1016/j.ympev.2017.10.015

Marshall, B. M., Strine, C. T., Fukushima, C. S., Cardoso, P., Orr, M. C., and Hughes, A. C. (2022). Searching the web builds fuller picture of arachnid trade. *Commun. Biol.* 5 (1), 448. doi: 10.1038/s42003-022-03374-0

Marshall, B. M., Strine, C., and Hughes, A. C. (2020). Thousands of reptile species threatened by under-regulated global trade. *Nat. Commun.* 11 (1), 4738. doi: 10.1038/s41467-020-18523-4

Meier, W., Wahli, T., and Schmitt, M. (1991). Der fisch und seine bedeutung aus internationaler und schweizer sicht. *Schweiz. Arch. Tierheilkd.* 133, 205–213.

Mendoza, J., and Francke, O. (2016). Systematic revision of *Brachypelma* red-kneed tarantulas (Araneae : Theraphosidae), and the use of DNA barcodes to assist in the identification and conservation of CITES-listed species. *Invertebr. Syst.* 31 (2), 157–179. doi: 10.1071/IS16023

Mendoza, J., and Francke, O. (2020). Systematic revision of Mexican threatened tarantulas *Brachypelma* (Araneae: theraphosidae: theraphosinae), with a description of a new genus, and implications on the conservation. *Zool. J. Linn. Soc* 188 (1), 82–147. doi: 10.1093/zoolinnean/zlz046

Molur, S., Daniel, B.A., and Siliwal, M. (2008). Poecilotheria metallica. *The IUCN Red List of Threatened Species* 2008, e.T63563A12681959. doi: 10.2305/IUCN.UK.2008.RLTS.T63563A12681959.en

Montes de Oca, L., and Mendoza, J. (2020). "New world tarantulas. zoological monographs," in *"Tarantulas in captivity: raising and breeding,"*. Ed. F. Pérez-Miles (Cham: Springer).

Morton, O., Scheffers, B. R., Haugaasen, T., and Edwards, D. P. (2021). Impacts of wildlife trade on terrestrial biodiversity. *Nat. Ecol. Evol.* 5 (4), 540–548. doi: 10.1038/s41559-021-01399-y

Nijman, V., Morcatty, T. Q., Feddema, K., Campera, M., and Nekaris, K. A. I. (2022). Disentangling the legal and illegal wildlife trade-insights from Indonesian wildlife market surveys. *Animals* 12 (5), 1–23. doi: 10.3390/ani12050628

Osteen, J. D., Herzig, V., Gilchrist, J., Emrick, J. J., Zhang, C., Wang, X., et al. (2016). Selective spider toxins reveal a role for the Nav1.1 channel in mechanical pain. *Nature* 534 (7608), 494–499. doi: 10.1038/nature17976

Rein, J. O. (2023) *The scorpion files*. Available at: https://www.ntnu.no/ub/scorpion-files/.

Research highlights (2022). Pet shops crawl with wild-caught spiders. *Nature* 606, 10. doi: 10.1038/d41586-022-01411-w

Rivalan, P., Delmas, V., Angulo, E., Bull, L. S., Hall, R. J., Courchamp, F., et al. (2007). Can bans stimulate wildlife trade? *Nature* 447 (7144), 529–530. doi: 10.1038/447529a

Ross, L. K. (2002). The emperor scorpion, *Pandinus imperator* (C.L. Koch) in captivity part II: breeding and contributions to conservation. *Brit. Tarantula Soc J.* 17 (4), 108–111.

Rossi, A. (2015). Sui sottogeneri di pandinus thorell 1876 con revisione del genere pandinurus fet 1997 stat. n. e descrizione di sette nuove specie e tre nuovi sottogeneri (Scorpiones: scorpionidae). *Onychium* 11, 10–66.

Shivambu, T. C., Shivambu, N., Lyle, R., Jacobs, A., Kumschick, S., Foord, S. H., et al. (2020). Tarantulas (Araneae: theraphosidae) in the pet trade in south Africa. *Afr. Zool.* 55 (4), 323–336. doi: 10.1080/15627020.2020.1823879

Smith, A. (2011). Tarantula notes 8 – from times past & far flung lands. *Brit. Tarantula Soc J.* 26, 110–121.

Tournant, P., Joseph, L., Goka, K., and Courchamp, F. (2012). The rarity and overexploitation paradox: stag beetle collections in Japan. *Biodivers. Conserv.* 21, 1425–1440. doi: 10.1007/s10531-012-0253-y

United Nations (2019). "United nations sustainable development," in *"Nature's dangerous decline 'unprecedented'; species extinction rates a'ccelerating"'*. Available at: https://www.un.org/sustainabledevelopment/blog/2019/05/nature-decline-unprecedented-report/.

Werb, D., Rowell, G., Guyatt, G., Kerr, T., Montaner, J., and Wood, E. (2011). Effect of drug law enforcement on drug market violence: a systematic review. *Int. J. Drug Policy* 22 (2), 87–94. doi: 10.1016/j.drugpo.2011.02.002

Wessa, P. (2023) *Free statistics software, office for research development and education*. Available at: https://www.wessa.net/.

Wodak, A. (2018). From failed global drug prohibition to regulating the drug market. *Addiction* 113 (7), 1225–1226. doi: 10.1111/add.14111

World Spider Catalog (2023) *World spider catalog* (Natural History Museum Bern). Available at: http://wsc.nmbe.ch (Accessed 4.4.2023).

Xiao, L., Lu, Z., Li, X., Zhao, X., and Li, B. V. (2021). Why do we need a wildlife consumption ban in China? *Curr. Biol.* 31 (4), R168–R172. doi: 10.1016/j.cub.2020.12.036

Yen, A., and Ro, S. (2013). The sale of tarantulas in Cambodia for food or medicine: is it sustainable? *J. Threat. Taxa* 5 (1), 3548–3551. doi: 10.11609/JoTT.o3149.153