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The U.S. market for imported wildlife not listed in the CITES multilateral treaty

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Article impact statement: Compared with CITES-listed imports, live nonlisted wild imports to the United States contain 3.6 times more species and 11 times the total trade quantity.

Abstract

The international wildlife trade presents severe conservation and environmental security risks, yet no international regulatory framework exists to monitor the trade of species not listed in the appendices of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). We explored the composition and dynamics of internationally regulated versus nonregulated trade, with a focus on importations of wild-caught terrestrial vertebrates entering the United States from 2009 to 2018. We used 10 years of species-level trade records of the numbers of live, wild-caught animals imported to the United States and data on International Union for the Conservation of Nature (IUCN) estimates of extinction risk to determine whether there were differences in the diversity, abundance, and risk to extinction among imports of CITES-listed versus unlisted species. We found 3.6 times the number of unlisted species in U.S. imports compared with CITES-listed species (1366 vs. 378 species). The CITES-listed species were more likely to face reported conservation threats relative to unlisted species (71.7% vs. 27.5%). However, 376 unlisted species faced conversation threats, 297 species had unknown population trends, and 139 species were without an evaluation by the IUCN. Unlisted species appearing for the first time in records were imported 5.5 times more often relative to CITES-listed species. Unlisted reptiles had the largest rate of entry, averaging 53 unique species appearing in imports for the first time per year. Overall trade quantities were approximately 11 times larger for imports of unlisted species relative to imports of CITES-listed species. Countries that were top exporters of CITES-listed species were mostly different from exporters of unlisted species. Because of the vulnerabilities of unlisted, traded species entering the United States and increasing global demand, we strongly recommend governments adapt their policies to monitor and report on the trade of all wildlife.

KEYWORDS
exotic pets, international wildlife trade, IUCN, LEMIS, wildlife regulation

El Mercado Estadunidense de Fauna Importada No Enlistada en el Tratado Multilateral CITES

Resumen: Aunque el mercado internacional de fauna representa un riesgo severo para la conservación y la seguridad ambiental, no existe un marco internacional de regulación para monitorear el mercado de especies que no están en los apéndices de la Convención sobre el Comercio Internacional de Especies Amenazadas de Fauna y Flora Silvestres (CITES). Exploramos la composición y las dinámicas del mercado regulado internacionalmente frente al que no lo está, enfocados en la importación de vertebrados terrestres capturados en vida silvestre que entraron a Estados Unidos entre 2009 y 2018. Usamos el registro

de comercio a nivel de especie del número de animales vivos capturados en vida silvestre e importados a Estados Unidos durante diez años y datos de los estimados de extinción de la Unión Internacional para la Conservación de la Naturaleza (UICN) para determinar si hay diferencias en la diversidad, abundancia y el riesgo de extinción entre las especies importadas enlistadas o no en CITES. Encontramos 3.6 veces más el número de especies no enlistadas en las importaciones a Estados Unidos en comparación con las especies enlistadas en CITES (1,366 versus 378 especies). Fue más probable que las especies de CITES enfrentaran amenazas de conservación reportadas en relación con las especies no enlistadas (71.7% vs. 27.5%). Sin embargo, 376 especies no enlistadas enfrentaron amenazas de conservación, 297 especies no cuentan con tendencias poblacionales conocidas y 139 especies no estaban evaluadas por la UICN. Las especies no enlistadas que aparecieron por primera vez en los registros fueron importadas 5.5 más veces en relación con las especies en CITES. La mayor tasa de entrada la tuvieron los reptiles no enlistados, con un promedio de 53 especies únicas al año registradas por primera vez en las importaciones. La cantidad generalizada de intercambios fue once veces mayor para la importación de especies no enlistadas en relación con la importación de especies CITES. La mayoría de los principales países exportadores de especies CITES fue diferente a la de los exportadores de especies no enlistadas. Debido a la vulnerabilidad de las especies comerciales no enlistadas que entran a los Estados Unidos y al incremento de la demanda global, recomendamos firmemente que los gobiernos adapten sus políticas para monitorear y reportar el mercado de toda la fauna.

PALABRAS CLAVE
LEMIS, mascotas exóticas, mercado internacional de fauna, regulación de fauna, UICN

【摘要】
野生动物国际贸易对保护和环境安全造成了严重风险, 但目前却没有国际监管框架来监测未列入《濒危野生动植物种国际贸易公约(CITES)》附录物种的贸易情况。本研究探讨了国际上有监管与无监管贸易的组成和动态, 重点关注了2009年至2018年进入美国的野外捕获陆生脊椎动物的进口情况。我们使用了10年间物种水平的贸易记录, 包括进口到美国的活的、野生捕获的动物数量, 以及世界自然保护联盟 (IUCN) 的灭绝风险估计数据, 以确定列入与未列入 CITES 的进口物种之间是否存在多样性、丰度和灭绝风险的差异。我们发现美国进口的未列入 CITES 的物种数量是列入物种的3.6倍 (1366种比378种)。相对于未列入CITES的物种, 列入物种更可能被报告面临保护威胁 (71.7%比27.5%)。然而, 有376个未列入物种面临着保护威胁, 297个物种的种群趋势不明, 139个物种没有得到IUCN评估。首次出现在记录中的未列入物种的进口频率是列入物种的5.5倍。未列入CITES的爬行动物的进口率最高, 平均每年有53个物种首次被记录进口到美国。未列入物种的总体贸易量比列入物种高11倍。此外, 未列入物种与列入物种的主要出口国也存在很大差异。由于进入美国的未列入CITES的贸易物种的脆弱性和全球需求的增加, 我们强烈建议政府调整政策, 以监测和报告所有野生动物的贸易情况。**【翻译: 胡怡思; 审校: 聂永刚】**

环境治理: 外来宠物, 国际野生动物贸易, 世界自然保护联盟(IUCN), 美国鱼类及野生动物管理局执法管理信息系统(LEMIS), 野生动物法规

INTRODUCTION

The vulnerability of large-bodied charismatic species to overharvesting and exploitation from the wildlife trade has attracted considerable scientific and popular attention (Cardoso et al., 2021). Yet, the risk that the international wildlife market poses to the survival of many lesser-known or less charismatic species is frequently overlooked (Fukushima et al., 2020; Margulies et al., 2019). Annually, tens of thousands of species are traded globally to supply the widespread demand for traditional medicines, food, luxury items, exotic pets, and plant cultivation (Harfoot et al., 2018). Accordingly, the wildlife trade has emerged as one of the leading threats to global biodiversity and environmental security (Gore et al., 2019; Maxwell et al., 2016).

Wild populations are particularly at risk of extinction from overexploitation when harvesting practices are not sustainably managed (Harris et al., 2016; Lenzen et al., 2012; McRae et al., 2022). Around 18% of all terrestrial vertebrate species have been recorded in global trade (approximately 5600 species), and traded species are at greater risk of extinction than nontraded species (Morton et al., 2021; Scheffers et al., 2019). Additionally, the transnational wildlife trade poses substantial disease risks for both wildlife and humans, a fact that has been frequently highlighted by the ongoing COVID-19 pandemic (Aguirre et al., 2020; O'Hanlon et al., 2018).

Species at risk of overexploitation from international trade are not automatically designated as protected. The Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) is the largest body regulating the international trade in wildlife (CITES, 2020). Currently, of all extant described species, only 10.5% of amphibians, birds, mammals, and reptiles are listed in CITES (c. 3691 species). For all species without a CITES listing, no such regulatory framework exists to monitor their international trade. It is only after the documentation of major declines in wild populations or large volumes of illegal trade seizures that many species are identified as at risk from trade (e.g., Bergin et al., 2017; Challender et al., 2014; Shepherd & Ibarrondo, 2005; Waeber et al., 2019). However, for many species, data on key life history and population metrics are either unavailable or incomplete, making the assessment of the anticipated risks associated with trade potentially ineffectual (Smith et al., 2011). Intentional use (i.e., deliberate harvesting) is a driver of extinction risk for close to one-quarter of species assessed as threatened or near threatened by the International Union for Conservation of Nature (IUCN). Further, because over 28% of threatened species on the IUCN Red List recognized as being active in international trade are not currently listed in the CITES appendices, there is a clear disconnect between the scientific community and policymakers (Challender et al., 2021; Frank & Wilcove, 2022; Frank et al., 2019; Marsh et al., 2021). Improving the collection and access to data on the international trade in wildlife not listed in the CITES appendices would aid significantly in the identification and mitigation of trade-related threats to wildlife and be an efficient precursor to an evaluation pathway for species to be considered for inclusion in CITES (Andersson et al., 2021).

Individual governments may maintain import and export records for species not listed by CITES, but the scope and availability of data depend largely on the efforts and priorities of local authorities. Furthermore, few countries have historically kept any records, let alone publicly available records, of importation and exportation data for species not listed by CITES. To better understand the scale of trade (e.g., quantities and diversity of species), data on the trade of unlisted species need to be collected and standardized. The United States keeps a detailed database of both CITES-listed and unlisted traded species. The U.S. Law Enforcement Management Information System (LEMIS) database, maintained by the U.S. Fish and Wildlife Service (USFWS), retains records of all declared imported and exported wildlife of both CITES-listed and unlisted species entering and leaving the country. In terms of monetary value, the United States is the largest trader of wildlife and wildlife products worldwide (Andersson et al., 2021). The data from LEMIS, therefore, offer a valuable opportunity to investigate the scope of the trade in species not listed in the CITES treaty.

We focused on importations of wild-caught amphibians, birds, mammals, and reptiles entering the United States from 2009 to 2018. Although several studies offer comparisons on the diversity of select species groups (e.g., amphibians [Hughes et al., 2021] and reptiles [Marshall et al., 2020]) involved in the international trade of unlisted and CITES-listed species, our study is novel in that it directly compared the diversity and relative trade quantities (numbers) of live individuals of all wild-caught individual terrestrial vertebrate species entering the United States, the largest global importer of exotic pets. We explored the composition and dynamics of the trade in species not listed in CITES appendices and compared trade dynamics with the trade in CITES-listed species. Specifically, we assessed how a trade might affect wild populations by examining species vulnerability according to IUCN classifications (specifically those threatened by extinction, those with declining populations, and those threatened by intentional harvesting); compared the species composition of imports and the dynamics of species traded through time; compared the trade quantities of imports; and identified key exporting countries, highlighting those with high trade quantities and species richness of exports. We considered how the differences in trade dynamics of unregulated species present an opportunity for reform in the ways international wildlife trade is monitored and regulated.

METHODS

Data compilation

We obtained records for 2009–2018 from the USFWS LEMIS database (obtained via requests to the U.S. government). (See Romagosa et al. [2009] for detailed information on the database.) The records provide data on imports, exports, and re-exports between the United States and other countries. Each row in the database represents a record for specimens or products of one taxon (i.e., species) with the same importer, exporter, shipping dates, and trade-term codes. We focused on records of imports of live animals entering the United States from wild-caught sources. Transactions reported as commercial or personal were included, whereas transactions reported as scientific, research, or educational were excluded. We excluded records with no identifiable species name (e.g., genus or family-level identification, 5.7% of live terrestrial vertebrate wild-caught records) and excluded records with no specified country of export origin from our analysis. We standardized species names to the most recent versions of the following taxonomic databases: AmphibiaWeb (AmphibiaWeb, 2021), International Ornithological Congress (IOC) World Bird List (Gill & Donsker, 2021), Mammal Diversity Database (Mammal Diversity Database, 2021), and the Reptile Database (Uetz, 2021).

To determine whether traded species were more likely to be assessed as vulnerable to extinction, we collected data on several assessment categories for species classified by the IUCN (2021) (as of November 2021). First, we defined species as threatened with extinction if their IUCN Red List category was vulnerable (VU), endangered (EN), or critically endangered (CR) (IUCN, 2021). Next, we recorded whether the IUCN threats classification scheme (version 3.2) listed species as being under an ongoing threat from intentional harvest or use (code 5.1.1 Intentional Use: Hunting and Collecting Terrestrial Animals). We also recorded whether the species was listed by the IUCN as present in international-level trade and intentional use. We described species as having a declining population if their population trend status was listed as decreasing. Finally, we determined whether the IUCN's assessment of each species was out of date (i.e., occurred before 2011). The IUCN (2021) considers an assessment out of date if it is >10 years old.

Statistical analyses

We determined whether there were differences in the proportion of CITES-listed species versus unlisted species for each of the following IUCN assessment categories: red-list status (threatened, not threatened, not evaluated); population trend (declining, stable or increasing, unknown); and threatened by intentional use (threatened, not threatened). This was repeated for each taxonomic class. To perform these comparisons, we used contingency-type analyses, testing for statistical independence with Fisher's exact tests (Appendix S1).

To assess whether the number of unique species appearing in yearly imports of CITES-listed and unlisted species varied significantly over the 10 years the data set spanned, we used generalized linear models (GLMs) with a Poisson distribution and with the number of unique species (per year) as the response variable and year as the predictor variable. We excluded 2009 data from the GLM because this was used as a reference year to determine the baseline composition of species. We further explored the temporal trends of species occurrence in imports with species accumulation curves across time, which plots the number of unique species appearing in imports of CITES-listed and unlisted species for the first time from 2010 to 2018, with 2009 as the reference year.

We quantified import quantities per species by tallying the total number of imported live animals for each species over the 10-year sampling period. To evaluate whether significant differences in the total import quantities across species occurred between CITES-listed and unlisted species, we used GLMs with the total quantity of each species as the response variable and CITES status as the explanatory variable for all species and all species by the IUCN category.

We tested various model distributions (Poisson, negative binomial, and Gaussian) to assess which would best fit the data. We used model diagnostics to simulate model residuals, and the best fitting model was that with the least amount of deviation was a Gaussian distribution with the response variable quantity on the $\log_{10}$ scale (Appendix S7). Although transforming ecological count data is not appropriate in some circumstances (O'Hara & Kotze, 2010), our data did not fit these assumptions for models with either all species or all species by the IUCN category (i.e., no zero observations and the log-transformed Gaussian model performed well due to the underlying distribution of data being extremely dispersed).

We identified the key exporting countries of origin for CITES-listed and unlisted species over the 10-year sampling period based on the total quantity of trade from countries whose exporting quantity to the United States was ≥5% of total exports for that trade type (country-type relationships were visualized with Sankey diagrams) and species richness of exports (visualized with choropleth maps).

The VCD package was used for mosaic plots (Meyer et al., 2006, 2021). All plots and choropleth maps were made with the Ggplot2 package (Wickham, 2016). Sankey diagrams were made with Ggplot2 and Ggforce packages (Pedersen, 2021). All other analyses were performed with base functions in the R statistical software 4.1.2 (R Core Team, 2021).

RESULTS

Over three times the number of unlisted species (1356 wild-caught species) were imported to the United States compared with 378 CITES-listed species. For each taxonomic group, the number of imported unlisted species was greater than the number of CITES-listed imported species, ranging from approximately triple (reptiles, $n = 803$ unlisted species) to seven times (amphibians, $n = 232$ unlisted species) (Figure 1).

Compared with unlisted species, CITES-listed species of all taxonomic classes were significantly more likely to be categorized on the IUCN Red List as threatened with extinction, having declining populations, and being threatened by intentional use (except mammals for the latter category) (Figure 2 & Appendix S1). At the same time, 376 unlisted species were categorized as threatened, having a declining population, or being threatened by intentional use. Reptiles had the most unlisted species (153) followed by unlisted amphibians (96), birds (90), and mammals (37) (Appendix S2). For imported, unlisted species on the IUCN Red List, 297 had unknown population trends (Appendix S2) and 139 were not evaluated (Figure 2). Around one-half of imported, unlisted species were not recorded by the IUCN as being intentionally used and were not present in international trade (Appendix S3).

Although all species of imported birds and mammals on the IUCN Red List have been assessed in the past decade (as of November 2021), 40% of unlisted and 20.6% of CITES-listed amphibian species and 32% of unlisted and 35% of listed reptile species had their most recent IUCN assessment completed over a decade ago (Appendix S4).

The number of new species imported to the United States increased each year for all taxa over the 10 years covered by the data set (Figure 3). On average, new species were imported at a rate of 17 per year for CITES-listed species relative to 93 for unlisted species (Figure 3). This difference was most pronounced for reptiles, for which, on average, 53 new unlisted

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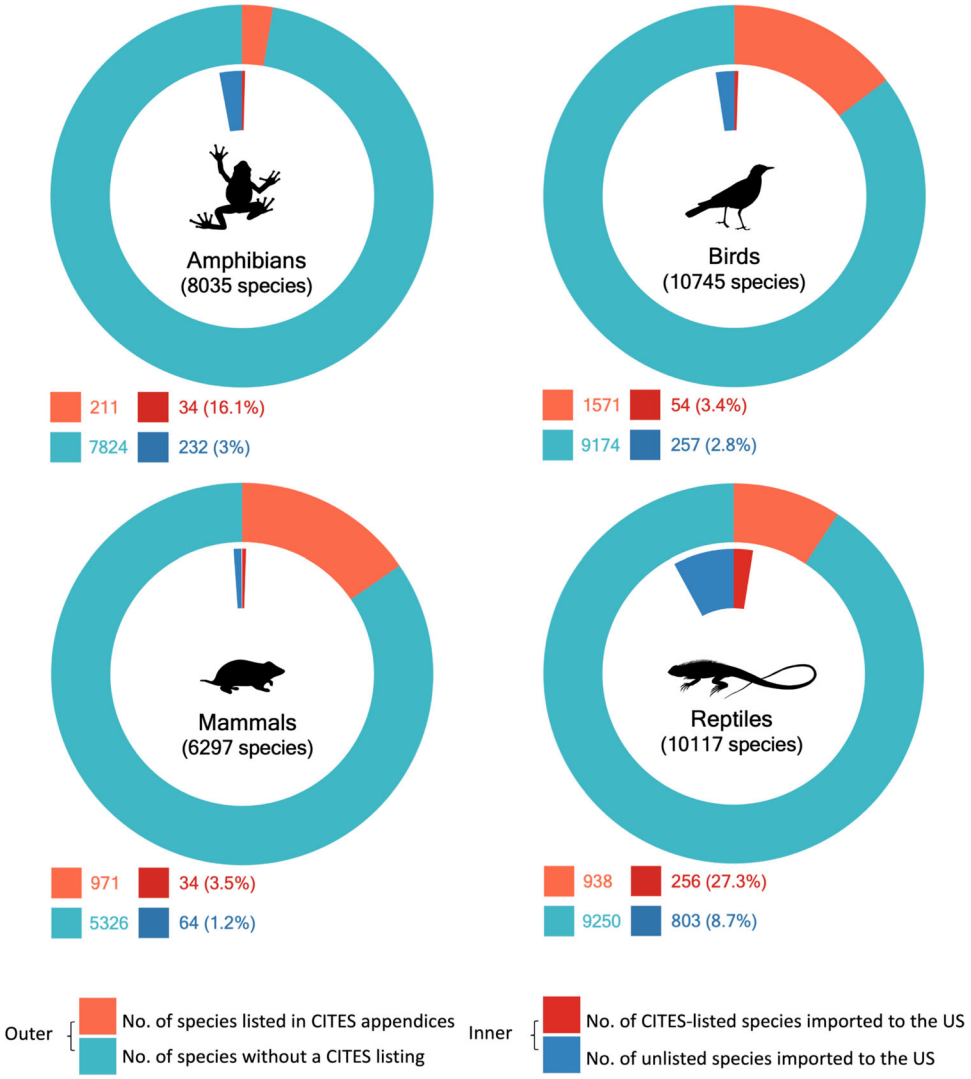

FIGURE 1 Wild-caught live trade in Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) listed and unlisted species in comparison with the total number of currently described extant species (outer circles, the total number of described species for each taxonomic class [i.e., global diversity as of 2020] separated into CITES-listed and unlisted classes; inner circles, the number of listed and unlisted species imported to the United States from 2009 to 2018 [from the LEMIS database] according to their CITES status as of December 2021)

species were imported per year, relative to 10 CITES-listed species (amphibians, 14 new unlisted species imported vs. 1 listed species imported; birds, 21 vs. 3; mammals, 4 vs. 2). The number of unique species imported each year varied by taxa, but imports of most taxa declined or were constant, except for unlisted reptile species, for which the number of unique species imported through time increased (Appendices S5 & S6).

In terms of overall import quantity, 11 times as many individuals of unlisted species were imported relative to CITES-listed species (8.84 vs. 0.8 million individuals). This varied by taxa: unlisted amphibians were imported at 96 times the rate of CITES-listed species (5,378,985 vs. 56,008 individuals); unlisted birds were imported at 210 times the rate (204,700 vs. 973); and unlisted reptiles were imported at four times the rate (3,244,132 vs. 737,785). However, when examining the distribution of the number of imports per species, only birds had significantly more per-species imports in unlisted species (Figure 4 & Appendix S8). Amphibians and mammals showed no significant difference (Figure 4 & Appendix S8). Unlisted reptiles had significantly fewer per-species imports (Figure 4 & Appendix S8). This difference largely came from imports of nonthreatened reptiles, which were imported in significantly lower numbers compared with CITES-listed species, and import quantities of threatened reptiles were not significantly different (Appendices S9a, S9b, & S10). The large difference in the total overall import quantities of imported CITES-listed and unlisted species was largely due to the significant quantities of a few highly traded species. The top five imported, unlisted species composed 50–84% of total trade quantity (Appendices S12 & S13). Species imported in the largest quantities were mostly species designated as not threatened by the IUCN, with the exception of the most traded by quantity reptile species,

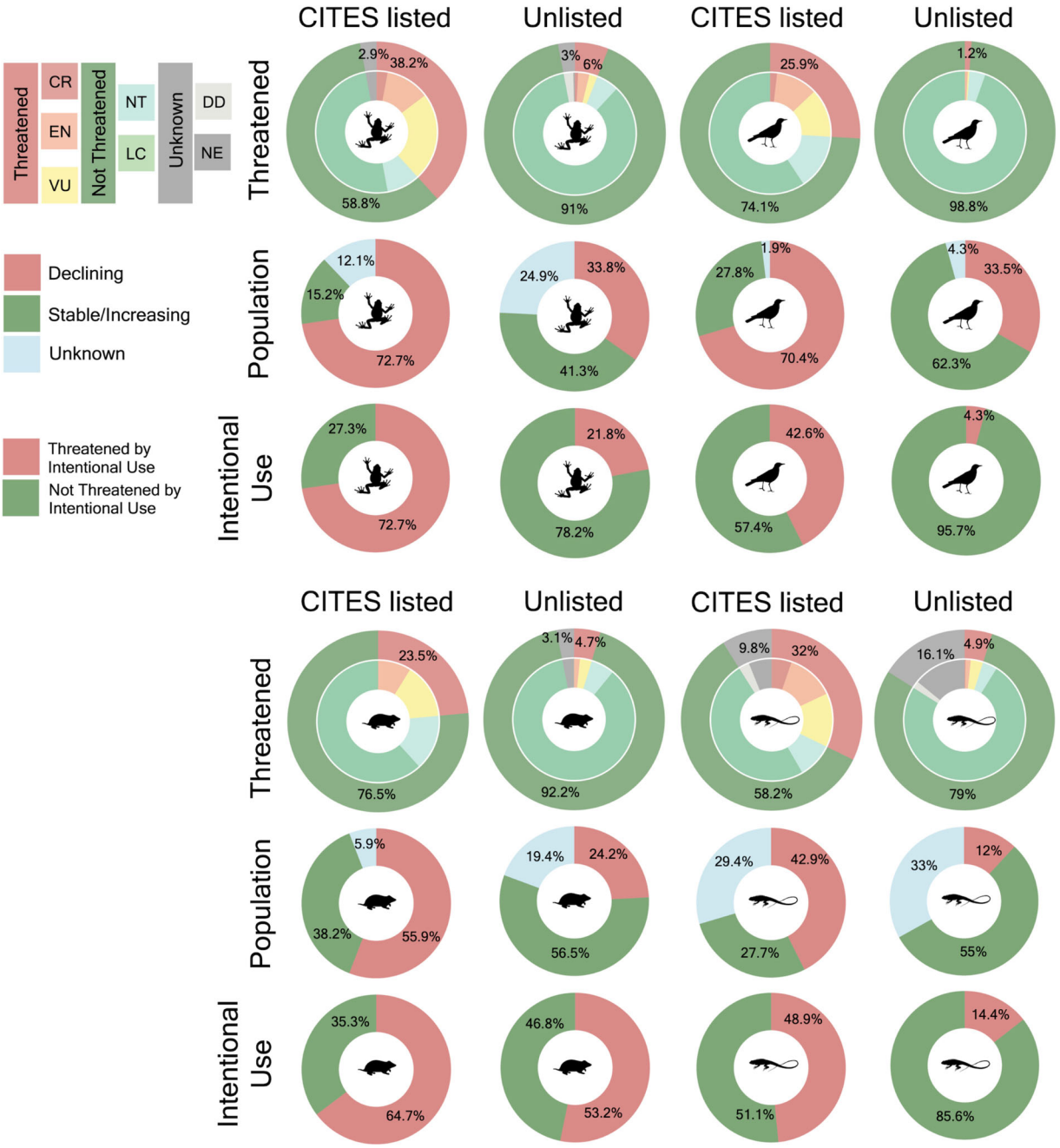

FIGURE 2 Comparison of International Union for the Conservation of Nature (IUCN) assessment category with Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) listed and unlisted species imported to the United States from 2009 to 2018 for (a) proportion of the total number of imported species by threatened status, where a species is classified as threatened if its status is critically endangered (CR), endangered (EN), or vulnerable (VU); not threatened if its status is near-threatened (NT) or least-concern (LC); and unknown if its status is data deficient (DD) or not evaluated (NE); (b) proportion of the total number of IUCN-evaluated imported species by population trend classification; and (c) proportion of the total number of IUCN-evaluated imported species listed as being under an ongoing threat from intentional use (code 5.1.1 Intentional Use: Hunting and Collecting Terrestrial Animals) for amphibians, birds, mammals, and reptiles. Population trend and intentional use categories only compare species that have been evaluated by the IUCN (i.e., not included are those with a threat status of unknown). Results of statistical comparisons are in Appendix S1

Testudo horsfieldii (VU, CITES listed) and *Physignathus cocincinus* (VU, unlisted), both of which also had negative population trends. *Rangifer tarandus* (VU, unlisted) and *Pelomedusa subrufa* (unlisted) were also imported in large quantities but have not yet been assessed by the IUCN. There was considerable variation in the quantities of trade through time for the most traded species. Only the two most traded, unlisted mammal species (*Dasyprocta leporina* and *Choloepus didactylus*) and *P. subrufa* showed a significant increase in trade quantity through time (Appendices S12 & S13).

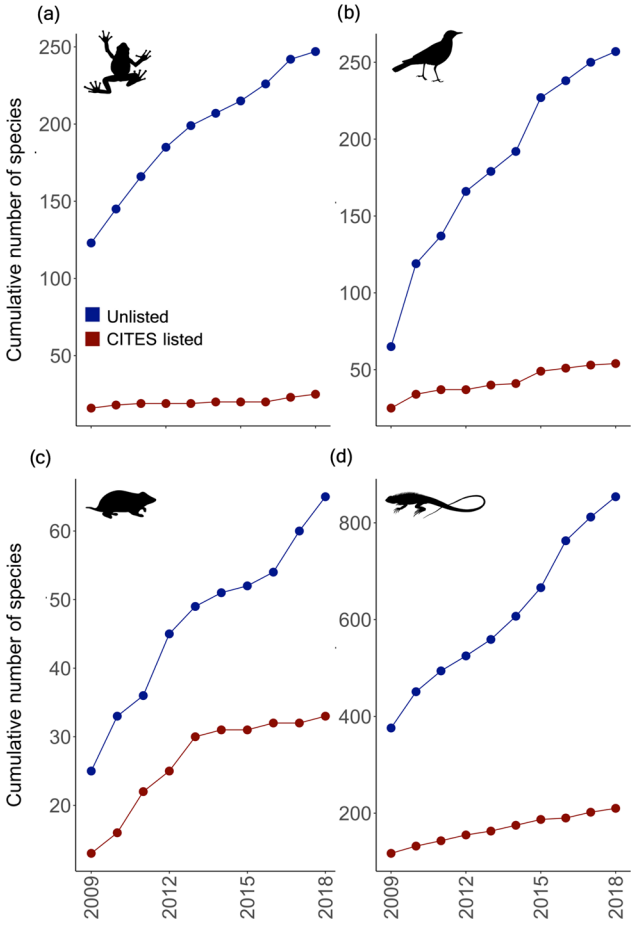

FIGURE 3 Cumulative number of species (each species is counted for the first year it appears in imports as either Convention on International Trade in Endangered Species of Wild Fauna and Flora [CITES] listed or unlisted) of (a) amphibians, (b) birds, (c) mammals, and (d) reptiles imported to the United States from 2009 to 2018 (points, the number of new species imported)

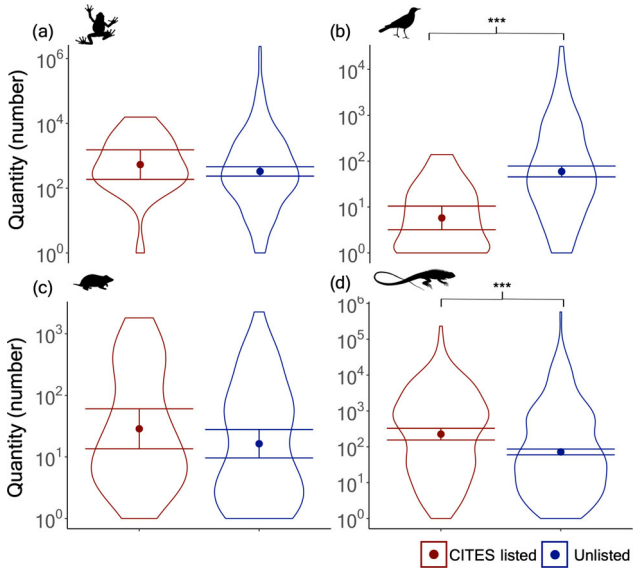

FIGURE 4 Results of generalized linear models comparing total quantity (number) of wild-caught, imported live animals (log_{10} scale) per species, measured as individual animals for Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) listed and unlisted species of (a) amphibians, (b) birds, (c) mammals, and (d) reptiles entering the United States from 2009 to 2018 (points, median; error bars, 95% CI; ***, $p < 0.001$). Details of model results are in Appendix S8

The countries that were top exporters of CITES-listed species were largely different from the top exporting countries of unlisted species, by total quantity and in the number of exported species (Figures 5 & 6) (complete description in Appendix S14). For instance, amphibians had no major exporting countries in common between CITES-listed and unlisted species. For birds, mammals, and reptiles, only one-quarter of major exporting countries exported both CITES-listed and unlisted species (Figure 5).

DISCUSSION

The global wildlife trade is a multibillion-dollar business (Andersson et al., 2021; Nellemann et al., 2014). New species appear in trade each year, and thousands of species are traded without regulatory protections (Marshall et al., 2020). We elucidated a thriving market for the legal trade in species not listed in the CITES appendices. This trade is increasing over time and, importantly, we identified over 350 terrestrial vertebrate species not listed in CITES that are threatened, yet are still being traded. We argue that the trade of species not listed in CITES demands closer attention from researchers and policymakers for both conservation and environmental security reasons. One potential path forward is the adaptation of a global monitoring scheme to track the international trade of all wildlife.

The global trade in live terrestrial vertebrates, mainly for pets, is increasing (Bush et al., 2014; Lockwood et al., 2019), and we found a growing demand for unregulated and novel species entering the United States. The United States is the largest importer of wild-caught, CITES-listed species (Liew et al., 2021) and of global wildlife trade in terms of monetary value (Andersson et al., 2021). Without the requirement for international export permits stating legal obtainment as is required with CITES species, regulating and preventing illicit and unsustainable trade in unlisted species is currently a growing concern. Evidence for ongoing international trade in unlisted reptiles and songbirds has been found in popular pet trade destinations in Asia, Europe, and the United States, with animals being traded in contravention of national range state protection laws (Heinrich et al., 2021a; Heinrich et al., 2021b; Janssen & Leupen, 2019; Janssen & Shepherd, 2018; Leupen et al., 2018). Recent research continues to highlight that the number of species involved in the trade is greater than subsequently thought, particularly for understudied species groups popular as exotic pets (Fukushima et al., 2020; Hughes et al., 2021; Marshall et al., 2020, 2022).

Of all extant described species, 17% of amphibians and 36% of reptiles have been found in trade, with unlisted species potentially being vulnerable to exploitation due to lack of trade regulations and high demand, particularly for rare and novel species, many of which have small or unknown ranges (Hughes et al., 2021; Marshall et al., 2020). Our results are consistent

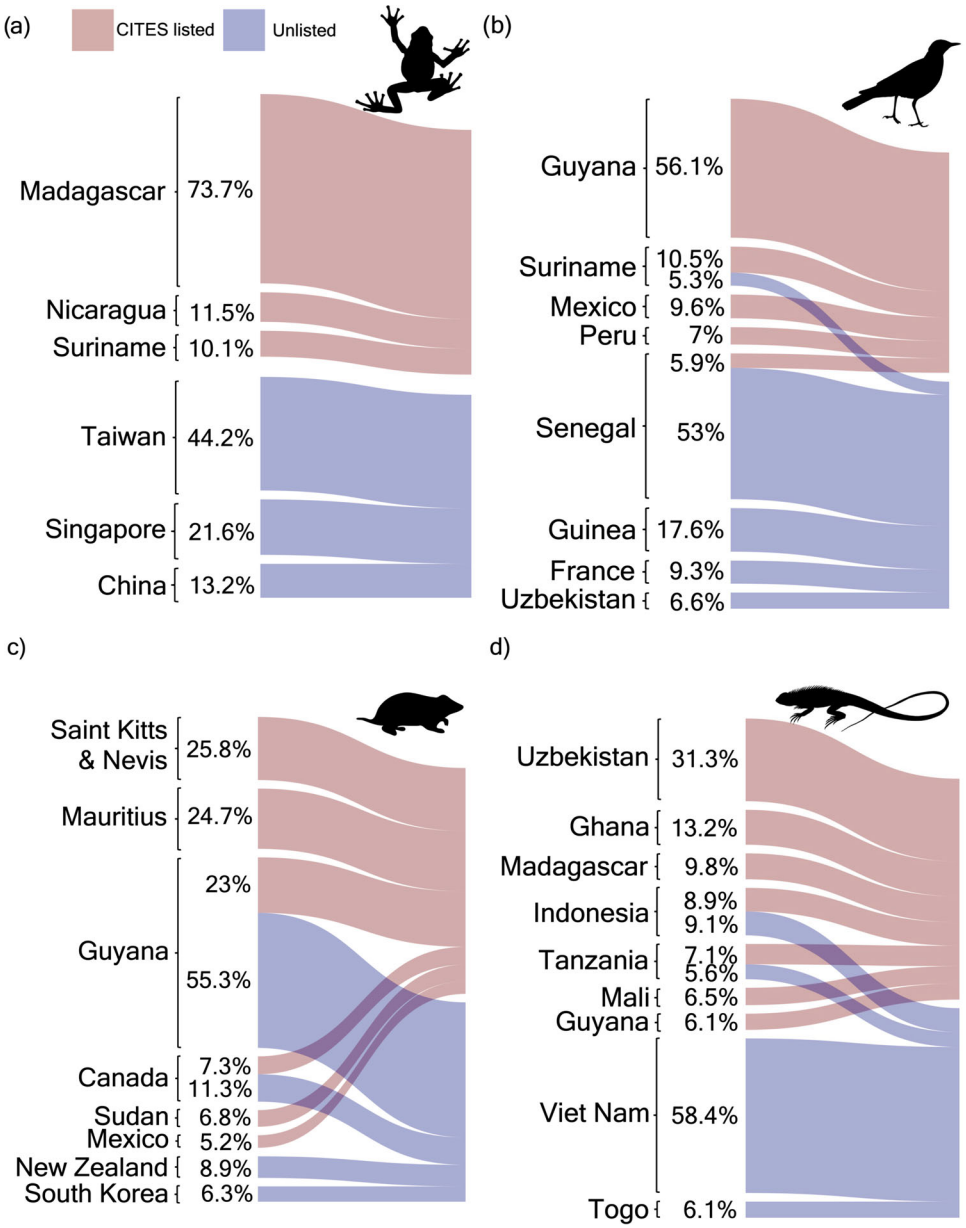

FIGURE 5 Percentage of wild-caught live imports of (a) amphibians, (b) birds, (c) mammals, and (d) reptiles from exporting countries, measured as individual animals imported to the United States from 2009 to 2018 for the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) listed and unlisted species (width of shaded area, percentage of the total amount of trade each country or territory accounts for). Countries with a total trade percentage of ≤5% are not shown

with these findings. Unlisted amphibians and reptiles had the highest import quantities and the greatest number of species of conservation concern and species with unknown or outdated IUCN assessments. The number of novel unlisted reptile species appearing in imports averaged 53 species per year, nearly four times the average number that appeared in imports of CITES-listed species. These findings suggest that the demand for amphibians and reptiles as pets is greater than ever. Yet, there is no rigorous population assessment or monitoring; thus, one cannot be sure what level of harvest is sustainable for the majority of the species in trade (McRae et al., 2022; Morton et al., 2021; Weinbaum et al., 2013).

For many species, the removal of individuals from the wild can have a serious impact, especially for threatened species with limited ranges or small populations (Morton et al., 2021). Conservation protocols can vary significantly by species, and exploitation is subject to change at any point, especially in an unchallenged situation, such as unregulated trade (Eaton et al., 2015; Leupen et al., 2020). Our assessment of the sustainability of the trade is limited for many species found in U.S. imports by the uncertainty of the effects of harvest on wild populations. Many traded species are understudied and basic data on population distribution, dynamics, and threatening processes are deficient (Figure 7) (Altherr & Lameter, 2020; Jensen et al.,

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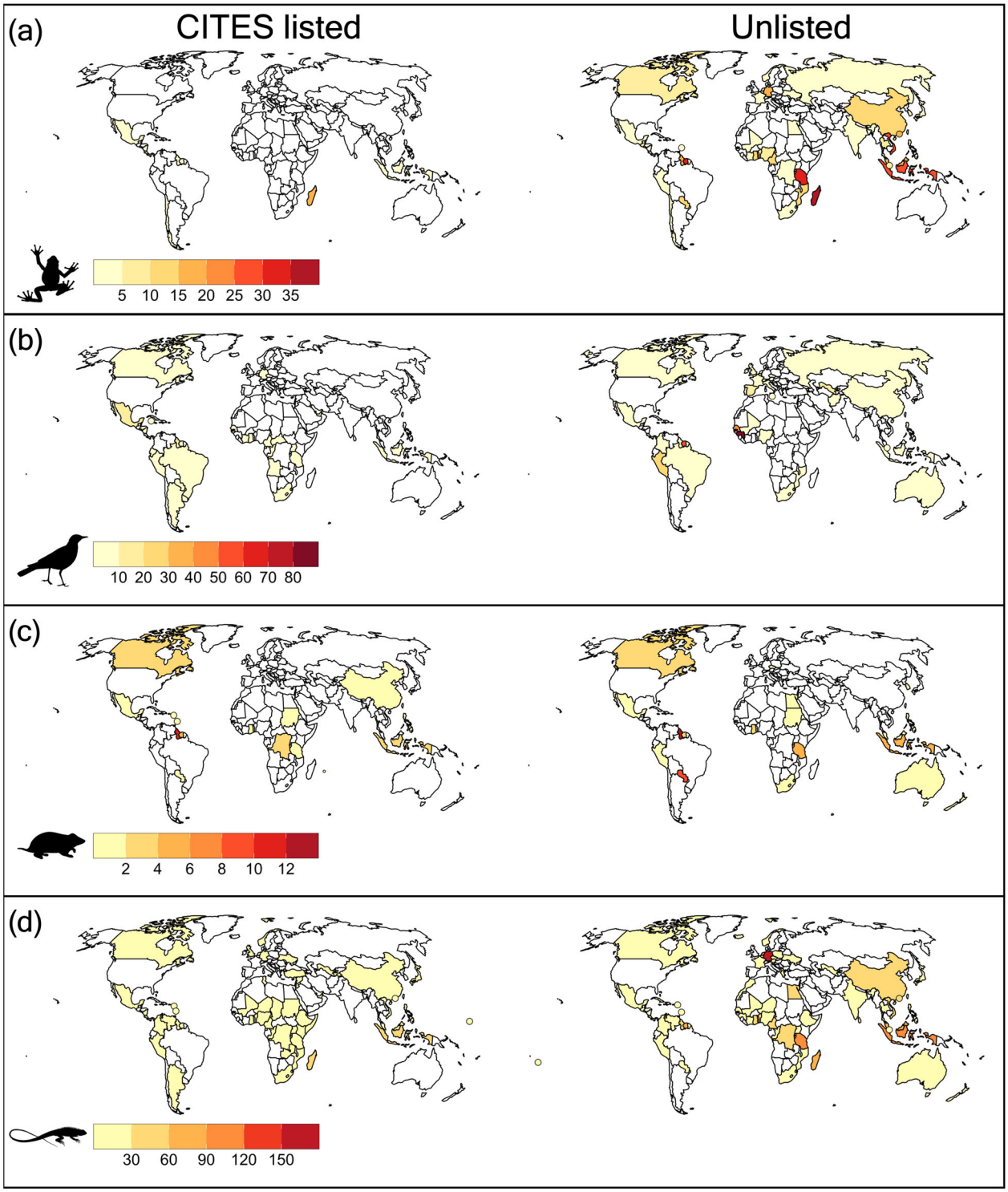

FIGURE 6 Total species richness of wild-caught live exports from each country or territory for the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) listed and unlisted traded species entering the United States from 2009 to 2018 for (a) amphibians, (b) birds, (c) mammals, and (d) reptiles (points, the geographic center of countries with a landmass of <5000 km^2 and a species export richness of ≥1)

2019). One-third of imported unlisted species in our study had unknown population trends (436 species, including 139 without an IUCN assessment), whereas 40% of unlisted amphibians and 35% of unlisted reptiles had IUCN assessments completed over a decade ago, meaning data on population metrics may be outdated. Outdated conservation assessments and those lacking population data may not reflect a species' present circumstance, leaving the sustainability of trade in such species in doubt. Further, we found that one-half of unlisted species ($n = 652$) were also not considered by IUCN to be present in international use or trade despite being present in U.S. imports. Because IUCN Red List data are frequently used to inform key international

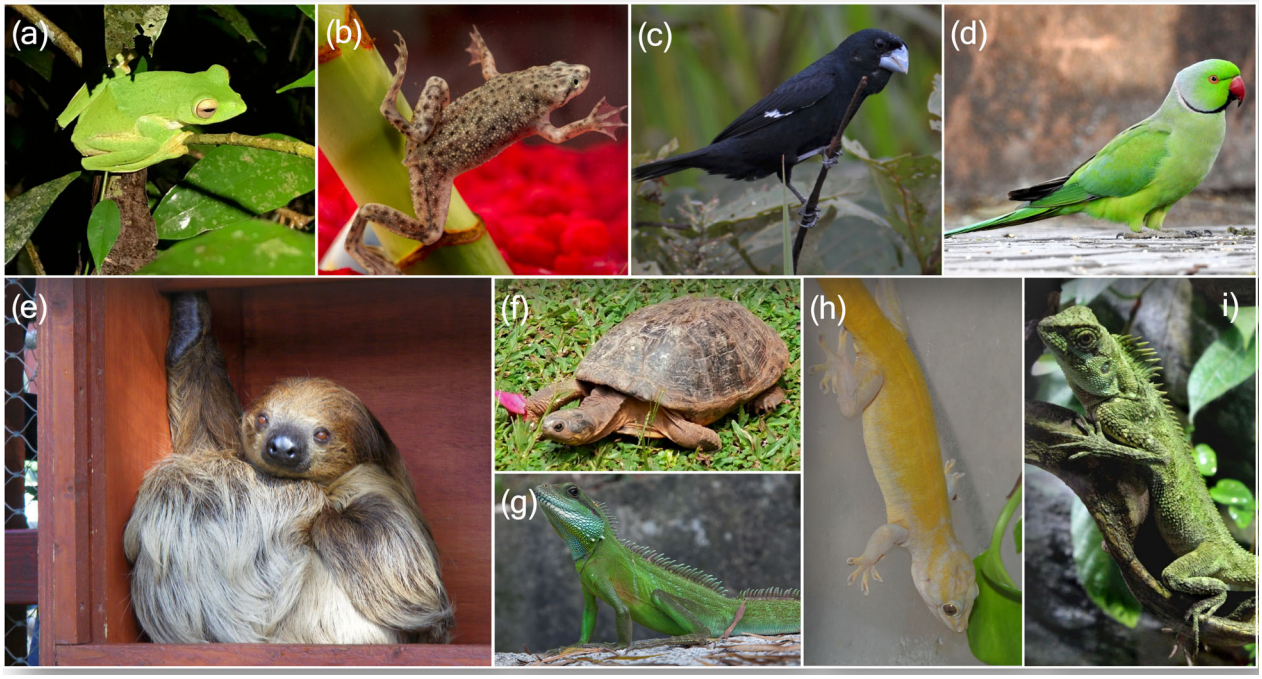

FIGURE 7 A subset of species imported to the United States from 2009 to 2018 that are not listed in the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) multilateral treaty but whose trade highlights potential conservation or biosecurity problems (species information derived from the IUCN [2021]): (a) *Rhacophorus helenae* (endangered [EN], populations isolated and extensively fragmented); (b) *Hymenochirus curtipes* (least concern [LC], potential supply chain traceability problems because they are imported from Singapore, where they are not native or invasive); (c) *Sporophila maximiliani* (EN, imported from Brazil, where population has been estimated to not exceed five subpopulations each with <50 mature individuals); (d) *Psittacula krameri* (LC, invasive species of known agricultural and conservation risk in the United States); (e) *Choloepus didactylus* (LC, individuals imported increasing); (f) *Pelomedusa subrufa* (not evaluated by International Union for the Conservation of Nature [IUCN]); (g) *Physignathus cocincinus* (vulnerable [VU], most imported reptile species with severely fragmented populations and a declining wild population); (h) *Gekko badenii* (EN, overharvesting serious threat); (i) *Acanthosaura capra* (near-threatened [NT], distribution and exact population unknown; IUCN lists species as not appearing to be harvested or used). All photos are licensed under the Creative Commons Attribution-Share Alike 4.0 International license. Photo attributions: (a) herpingvietnam, (b) James Gathany, (c) Ruben D. Layme, (d) Raju Kasambe, (e) Marie Hale, (f) Bernard Dupont, (g) Žilvinas Pūtys, (h) Heroinabspeutzer, and (i) Pavel Hrdlička

conservation planning and policy (IUCN, 2018), the availability of accurate data on activities that may have adverse effects on wild populations, such as wild harvest for international trade, is essential. Further assessment of the effects of trade on a species basis, including monitoring and management of source populations, is strongly recommended to assess the sustainably of current harvesting practices and to detect when potential risks emerge (Fukushima et al., 2021; McRae et al., 2022).

Recent events surrounding the global SARS-CoV-2 (COVID-19) pandemic have turned the public eye toward the relationship between zoonotic disease and the wildlife trade (Andersen et al., 2020; Lu et al., 2020). Approximately 75% of the infectious diseases emerging today are zoonoses, representing a major global threat to the public, agricultural, ecosystem, and economic well-being (Gebreyes et al., 2014). The global wildlife trade provides ideal conditions for disease transmission and the emergence of novel diseases, yet there are currently no international organizations that manage the trade in wildlife based on these issues (Bell et al., 2004; Karesh et al., 2012; Shivaprakash et al., 2021). Although we did not focus on the biosecurity issues involved in the use of wildlife, the substantial quantity and diversity of imports and lack of regulation imply a high risk for the transmission of emerging and re-emerging infectious diseases. For instance, a recent study involving imports of live North American bullfrog (*Rana catesbeiana)* to the United States through three major national ports over 5 years showed overall chytridiomycosis (*Batrachochytrium dendrobatidis)* infection prevalence of 62% in newly arrived shipments. Chytridiomycosis is a fungal disease that infects amphibians and is responsible for extensive declines in many native species worldwide (Schloegel et al., 2009). *R. catesbeiana* accounted for 44.4% (2,376,809 individuals) of the total unlisted amphibian import quantity during our study.

In another example, the leading exporting country of unlisted wild birds in our study, Senegal, contributed 53% of the total quantity of unlisted imports, had high export species richness, and yet is a region that the U.S. government department of Animal and Plant Health Inspection Service (APHIS) has recognized as affected with zoonotic diseases, such as highly pathogenic avian influenza, a disease that poses a great threat to the U.S. agricultural industry (APHIS, 2021). Exports from Senegal also included large shipments of invasive species, such as rose-ringed parakeets (*Psittacula krameri)* (not listed in CITES and c. 19,000 individuals total exported), a species whose population establishment is a known agricultural and conservation risk in the United States (Klug et al., 2019). With an average

of 93 new unlisted terrestrial vertebrate species entering U.S. imports annually, this trade deserves closer inspection purely for biosecurity concerns. Increased trade surveillance could aid in addressing current concerns regarding the need for managing wildlife trade based on zoonotic disease risks and invasion potential and further highlights the necessity for broader monitoring, data collection, and regulation on a by-species basis of the global wildlife trade (Sinclair et al., 2021).

No systematic alert or standard procedure exists to identify when a species may require CITES listing. Further, many parties have insufficient resources or incentives to implement adequate monitoring and research to scientifically verify that harvesting is not threatening wild populations (Abensperg-Traun, 2009; Challender et al., 2015). The IUCN Red List is underutilized in the CITES listing process, with no automated notification system existing to advise CITES parties or the CITES Secretariat of unlisted species present in international trade that are classified by IUCN as threatened (Frank et al., 2019). Alerting CITES policymakers to vulnerable, traded, unlisted species would allow those that meet the criteria for CITES listing to be identified and proposed for inclusion in the appendices in a prompt approach that keeps pace with current scientific assessments of species conservation status. This lack of communication and inhibited data exchange can affect even highly traded species, such as the Asian water dragon (*P. cocincinus*). Asian water dragons were imported in larger total numbers than the most highly imported CITES-listed reptile species; they composed 19.3% of total unlisted reptile trade quantity, despite their being listed as threatened by extinction and having a severely fragmented and declining wild population. This species and the several hundred others we found facing similar threats should be further investigated to ascertain whether a trade is unsustainable or further protections are required.

Various reforms have been suggested to better regulate the international wildlife trade, including reverse listing, whereby only species whose trade could be assessed to be sustainable could be traded (Couzens, 2013; Macdonald et al., 2021; Marshall et al., 2020). Targeted trade bans can be an effective method of reducing disease transmission and establishment of invasive species, as well as benefitting wild populations (Cardador et al., 2019; Reino et al., 2017). The U.S. Wild Bird Conservation Act of 1992 prohibits all CITES-listed species of exotic birds from importation except for those included on an approved sustainable-use list (e.g., a species may be imported if wild-caught individuals were harvested following an approved management plan for sustainable use of the species). That we found the trade quantity and species richness of bird imports were significantly higher for unlisted species than listed species suggests that an approach that restricts imports of unlisted species with the same level of scrutiny and conservation concern as CITES-listed species could be extended to unlisted species or other at-risk groups to alleviate pressure on wild populations, while also reducing the risks that can arise from unintentional introductions of invasive species and their pathogens. However, bans are not a catch-all solution and may also cause negative impacts; they could hinder sustainable development, create alternate trade routes, or increase illegal trade activities (Rivalan et al. 2007; Fischer 2010). Some argue that bans impede the ability of communities in exporting countries to help manage and conserve sustainable populations because locals are more likely to adhere to and enforce policies when their livelihoods are involved (Alioune & Catanzano 2005; Challender et al. 2015). Extending trade restrictions to additional species or higher taxa would first require research into trade quantities, sources of supply and demand, and international trade routes to determine where and how measures should be focused. These actions require access to broader, freely available, and transparent international trade documentation, particularly regarding species not listed in CITES.

The purpose of CITES is to regulate and ensure sustainable and traceable legal international trade in traded species. Proposals to add new species to its appendices are put forward by the governments of participating countries, but many countries do not record or closely monitor their imports and exports for species not listed in CITES. There is presently no official authority tasked with systematically monitoring the international trade trends for unlisted species that may need the protections offered by CITES. This kind of network-wide investigation would be impossible to successfully implement without the systematic monitoring of all species in the international legal trade network (Sinclair et al., 2021). Our investigation into U.S. importations of unlisted species illustrates why monitoring the trade of all species is needed. Specifically, the lack of intersection between the major exporting countries regarding unlisted and CITES-listed wildlife imports exemplifies just how broadly trade routes can differ; many major unlisted export hubs are underrepresented if only CITES trade data are taken into account. Supply chain traceability is hampered by not monitoring all legal trade. For example, we found Singapore to be the second largest exporter of wild-caught unlisted amphibians bound for the United States. By quantity, 99.5% of its exports were made up of the pipid species *Hymenochirus boettgeri* and *H. curtipes*. Both these species are native to equatorial Africa and neither has known introduced populations in Singapore. If data from other international trade routes were available, steps could be taken to establish whether shipments with such irregularities are actually transiting through intermediate countries (e.g., Singapore) from a different source region.

Unsustainable trade and trade in at-risk species can have severe and sustained consequences for conservation and human livelihoods (Cardoso et al., 2021). It is, therefore, in the interest of the global community to ensure its future sustainability. The global scope of the challenge means significant and sustained funding, commitment, and political will are required for an integrated approach to be successfully developed and implemented. The flow of the international trade in wildlife is predominantly from lower-income to higher-income countries (Liew et al., 2021); therefore, wealthier nations should take the lead in the funding and implementation of a universal framework to manage and report all international wildlife trade, as well as financially supporting less affluent source countries in the development of practices that are biologically sustainable and take the livelihoods of local communities currently dependent on the global wildlife trade into account (Abensperg-Traun,

2009; Fukushima et al., 2021). Regulating the international legal trade of wildlife under a standardized electronic system would increase compliance, traceability, data accuracy, and integration between countries. The considerable resources required to develop and implement such a system would be somewhat alleviated if an existing framework could be adapted for utilization. One suggestion is the updating and expansion of wildlife-related codes used by the United Nations (UN) Comtrade Database, which accounts for >98% of global commodity trade but is currently limited by its lack of taxonomic classification (Andersson et al., 2021; Chan et al., 2015). Going forward, international trade reporting and monitoring and communication among relevant groups must be considered to ensure the early detection and prevention of overexploitation, trade in high-risk invasive species, and the emergence of pathogens in species considered reservoirs for emerging zoonotic disease (Roe et al., 2020).

Our study draws much-needed attention to an often-overlooked side of the international legal wildlife trade. In highlighting the details of the wild-caught unlisted trade entering the United States, a picture begins to emerge on the pervasiveness of the legal international trade in species not listed in CITES. Thus, there is an urgent need for the international legal wildlife trade to be monitored at the species level. This effort may be more feasible with the expansion of existing systems, such as the UN Comtrade database. Further, trade in unlisted species needs to be periodically tracked and reviewed, which, in partnership with CITES, could offer a standardized way to alert parties to potential at-risk species. Because CITES has no mandate for disease surveillance, the expanded monitoring of all legal international trade would have greater power to identify future pandemics (both human and wildlife) and avoid the massive economic costs of future invasive species (Can et al., 2019). Priority must be given to programs that promote and measure the sustainable use of wild populations on a species-by-species basis to curb trade-related conservation risks (Bennett et al., 2021) and ensure that proposed regulations be grounded in robust scientific underpinning (Fukushima et al., 2021). Affluent countries where demand originates, such as the United States, need to accept their role in the building of sustainable trade practices (Liew et al., 2021), including providing support for supply countries and pushing for a unified data management framework through applicable enforcement agencies to protect human well-being and safeguard biodiversity.

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SUPPORTING INFORMATION

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

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