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Mapping the global dimensions of US wildlife imports

Highlights

- Wildlife trade represents a major, yet neglected, threat to many species' survival
- Understanding wildlife trade dynamics facilitates effective targeted management
- We map the global dynamics of wildlife trade flows into the US
- Many species are largely declared as wild sourced, with no data on trade impacts

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In brief

Wildlife trade represents one of the greatest threats to species survival, yet almost no data exist on what is in trade, the origins, or the impacts on wild populations. Marshall et al. explore the global footprint of US wildlife trade, highlighting the scale of trade and data gaps that require attention.

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Mapping the global dimensions of US wildlife imports

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SUMMARY

Wildlife trade remains a major driver of accelerating global biodiversity loss, yet our knowledge of this trade remains fragmented. Our understanding of trade origins and flows is particularly poor, which prevents decision makers from identifying trends or assessing law enforcement efficacy. We assess the global dimensions of trade into the US across multiple taxonomic groups over two decades. We analyze geographic patterns to identify the origins of traded wildlife, including in endemic and threatened species. We identify major inconsistencies in provenance of wild species exports, as many traded species are labeled "wild," but not native to the country of export. The European Union represents a major source of arachnids and reptiles, many declared as wild. We further highlight a range of likely reporting errors, potential species laundering, and possible Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) violations. Counteracting biodiversity threats posed by the global wildlife trade requires better data, better standardization, and clear interventions to manage trade sustainably.

INTRODUCTION

Wildlife trade is a globalized, predominantly legal activity with varied socio-environmental dimensions, such as providing raw materials for businesses, income for producers, and goods for consumers.[1,2] It is also recognized as a major threat to the survival of potentially thousands of species, with an estimated annual value in the hundreds of billions of US$.[3] Illegal wildlife trade is valued at around 10% of legal trade, yet it is considered one of the most valuable illegal markets globally.[4] Although ComCodes (https://comtradeplus.un.org/) allow some valuation of trade, this approach does not provide the species-level data needed to understand and manage trade. Measuring the total number of species in trade remains challenging, and, at present, the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) provides the only global mechanism for international wildlife trade (see Methods S1.0). However, CITES has a remit of regulating and monitoring species listed to CITES appendices once trade is demonstrated to represent a potential threat. As such, CITES only includes a small fraction of species in trade, and issues regarding compliance and misreporting are frequently acknowledged.[5] Furthermore, most species legally in trade are traded outside CITES; for example, at least 37% of extant reptile species have been recorded in trade, but only 9% of species are covered by CITES.[6,7] Many species are traded before their extinction vulnerability has been assessed, leaving them particularly vulnerable to overexploitation.[8,9] Non-CITES-listed species are entering trade at higher rates but rarely have any population-level data to assess the impacts of trade.[10] Even for CITES-listed species, adaptive management and change of quotas may be lacking, likely due to a lack of population monitoring.[11]

Compounding this data problem is the limited understanding of the pathways involved in wildlife trade, including entry and exit points, how and when species move through global markets, and who ultimately uses them. Without clearer information on these pathways, it is difficult to develop effective strategies or make well-informed policy decisions that balance conservation concerns with economic interests. Although some work has attempted to assess the geographic dimensions of trade in CITES-listed species,[7,12–14] only a fraction of species in trade have been examined.[5,6,8,15–18] These analyses highlight the role of the global tropics in supplying many taxa to developed economies, but further examination is required to understand the global footprint and routes of international wildlife trade. Understanding geographic dimensions can help identify where large volumes of trade for certain taxa likely require attention, to assess sustainability or determine patterns of compliance and facilitate interventions where key gaps exist and help manage trade more sustainably.[19] Examining international trade routes can also help highlight inaccurate declarations or signal potential laundering; for example, where large numbers of non-native species are declared as coming from the wild. Similarly, these data can aid in determining the impact of global or regional policy, such as the European Union (EU) Wild Bird Directive, while possibly highlighting the potential for species invasion[20] and the spread of zoonotic diseases.[21]

This lack of data on species,[22,23] quantities, and routes hinders efforts to reduce the suite of negative impacts associated with both legal and illegal wildlife trade.[24–26] Although some work has been done on invasive potential, in most cases data do not exist to understand the impacts of wildlife trade on communities or ecosystems.[27–30] When studies have explored the impacts on traded populations, declines in population size were recorded, particularly when international trade was involved.[28] For most of the more than 50,000 species that are in trade, there is no assessment on the impact of offtake or even where species are coming from.[31]

However, one system that can provide species-level trade information is the United States (US) Law Enforcement Management Information System (LEMIS) database maintained by the US Fish and Wildlife Service (USFWS). LEMIS was primarily developed to aid allocation of customs and law enforcement resources and ensure adequate law enforcement; as part of this process, it collates data on wildlife trade. As wildlife data collation is not a primary goal, the LEMIS system is known to contain various errors when reporting species identities, origins, and sources[32] (Methods S1.0). It is also subject to significant data gaps and omissions, either from non-reporting or purposeful redactions; thus, interpretation is challenging, and although patterns are likely to be representative, further work is needed to improve the accuracy of data recorded in LEMIS. Nonetheless, LEMIS provides a key source of species-specific wildlife trade data, while also supplying information on the source (captive, wild, etc.) and geographic origins.[2] Although LEMIS is limited to trade to and from the US, the US is one of the largest global wildlife markets by volume and value.[1,12,33] LEMIS data from 2000–2022 revealed that over 21,000 of these species were imported into the US alone; when CITES wildlife trade data are included, this increases to approximately 30,000 species.[2] LEMIS data therefore represent a useful component of determining global trade and provide important lessons for the databasing of trade at all levels.

Given the lack of data on import and export of wildlife from most countries, the US represents an ideal case study, both due to its global role in wildlife trade and because of the ability to understand that trade. To this end, we explore LEMIS data on wildlife trade flows, focusing on the origins of traded species, the quantities traded, the International Union for Conservation of Nature (IUCN) Red List status, and any discrepancies between reported collection locations and their known geographic range. We also explore how countries engage with CITES in terms of the listing of species: by comparing CITES-traded species to all wildlife trade based on LEMIS, we aim understand how countries show differing levels of engagement in listing potentially threatened wildlife.[34–36] This is to understand whether countries with many species listed within LEMIS also have many species regulated via CITES, as a mismatch (high volumes in LEMIS and few in CITES) could represent countries with less regulatory attention on wildlife trade. We seek to advance understanding about the geographic patterns and trends of wildlife trade, the countries involved, and areas where the collection of wild species likely requires special attention to understand the impacts and focus efforts to identify and manage unsustainable trade.

RESULTS

Origins of trade

Based on data of wildlife imported into the US between 2000–2022, the geographic origins of wildlife traded into the US varied substantially between taxa (Figure 1). Although it is true that these dimensions likely vary considerably over time (see Marshall et al.[2]), reflecting both space and time requires separate attention to understand in sufficient detail. For terrestrial taxa, there was a high diversity of species originating from tropical countries, with high numbers of species coming from the wild, though in many cases species may be sourced from both wild and captive sources from each source country (Figures S2 and S3). For example, seven countries have over 100 amphibian species in trade, with all but two of these (Germany and Canada) showing over 73% of species declared, at least in part, from the wild (Figures S4 and S5). Also, Germany supplied vastly more reptile species than anywhere else, with 813 species but only 29% of species declared as coming from the wild (7% individuals), followed by Canada at 519 species (24% species wild, 39% of individuals wild). Patterns varied considerably by taxa, as well as showing very different dimensions for wild caught vs. captive bred (see Figure S1; Methods S1.1).

In addition to understanding the number of species in trade, we explored the quantities of wildlife imported into the US over the two-decade period, as well as where these individuals originated (Figures 1 and S1). We only included "whole individuals" in trade, which will clearly underestimate trade of species imported by weight, but is easier to compare between taxa (see Figure S1). Although patterns of trade will inevitably have changed over time,[2] we focus on the complete picture to understand the overall scale of trade, which often showed very different patterns from diversity, highlighting that understanding drivers of trade, and use post trade, represent important

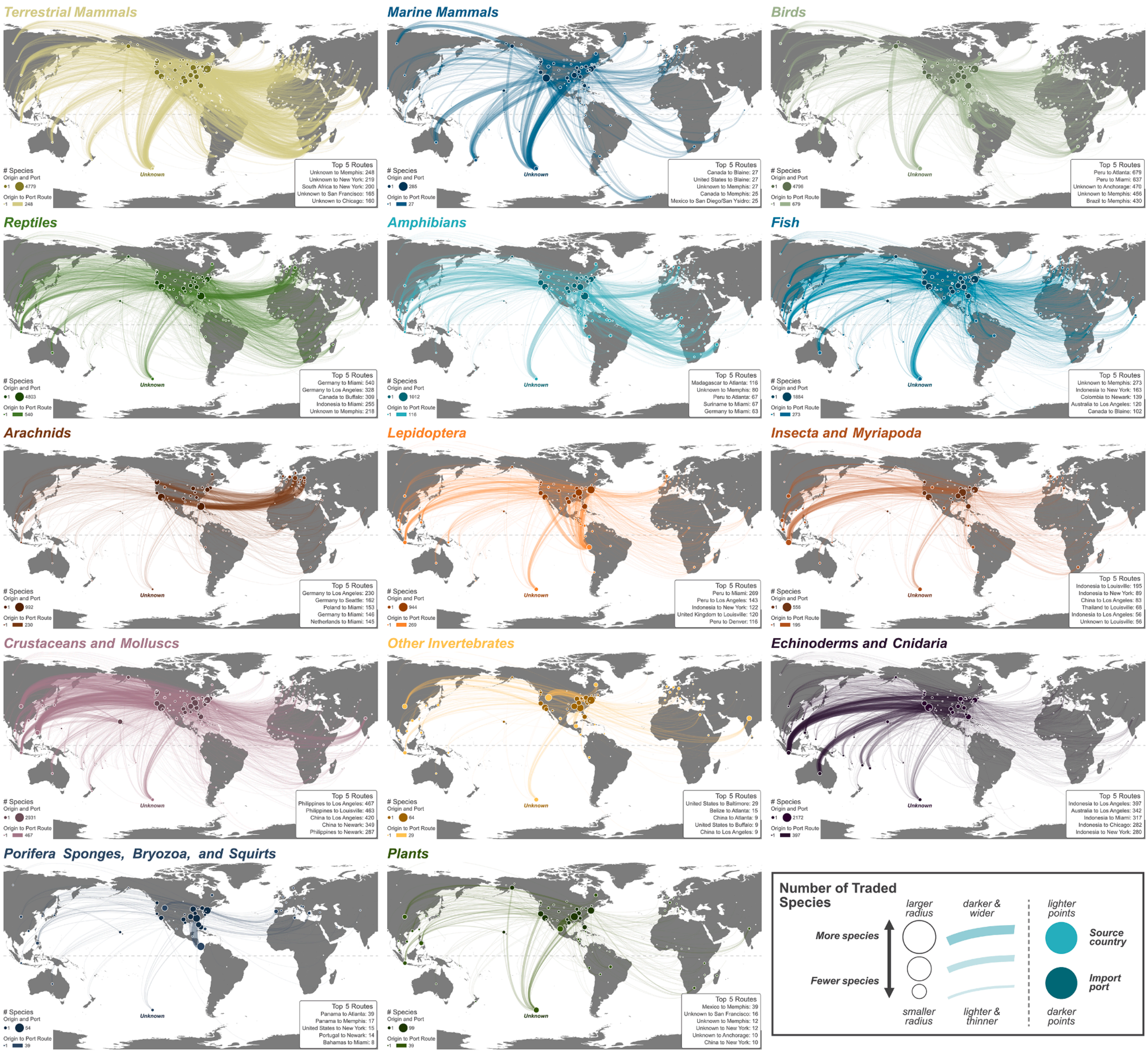

Figure 1. An overview of the origin and destination of all wildlife traded into the US based on the number of traded species between the US and exporting countries

Larger circles and wider connecting lines indicate more species being transported. Many declarations lack a recorded origin and default to unknown (shown here in the South Pacific).

See Figure S1 for numbers of individuals.

considerations when attempting to understand trade (Figure S1; Methods S1.2).

Tracing trade

Understanding the routes via which different taxa are imported may help apportion resources to ports where the diversity or volume of species is high. The most diverse trade route for any taxa was Peru to Atlanta for Birds with 679 species, followed by Peru to Miami (637 species). Germany to Miami is also high at 540 species (Figures 1 and S1). For other taxa, it was Germany to Miami for Reptiles (540 species), followed by Philippines to Los Angeles (467 species) and Philippines to Louisville (463 species), both for Crustaceans and Mollusks. These results highlight the roles of the Philippines and Germany as high-diversity wildlife exporters. Germany and Peru were also key countries of origin for other taxa. Peru to Miami and Peru to Los Angeles were the top two routes for Lepidoptera, at 269 and 143 species, and Germany to Los Angeles and Germany to Seattle were the top two routes for arachnids, with 230 and 162 species, respectively. Indonesia appears to be a key route also, appearing in the top three routes for the Echinoderms and Cnidaria, Fish, Insecta and Myriapoda, and Lepidoptera.

In terms of quantities of whole individuals, the greatest number was Arachnids (predominantly mites specifically), with

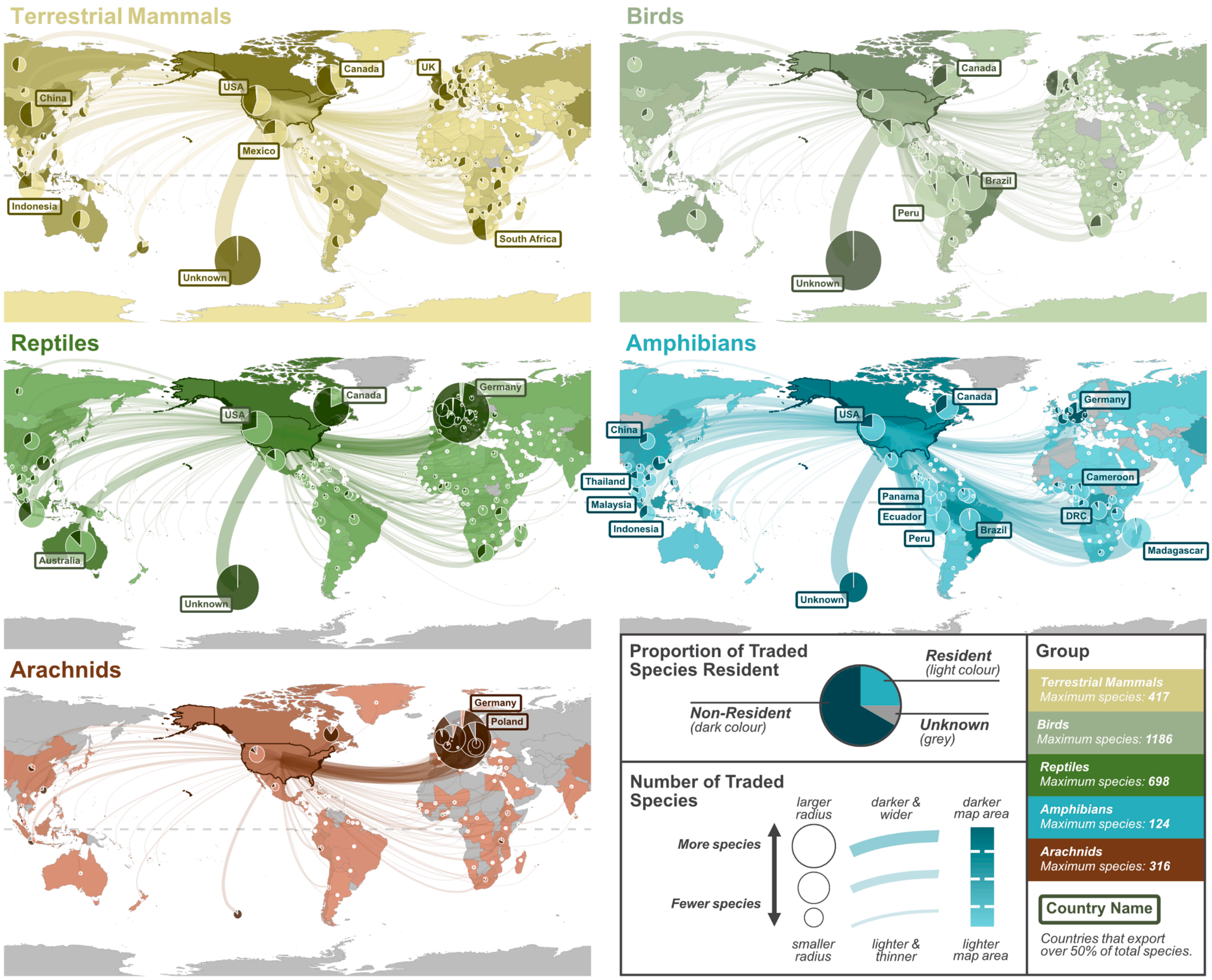

Figure 2. Map showing the routes of wildlife traded into the US, listed as wild sourced, and residency of species in trade belonging to the four vertebrate groups and arachnids

Larger circles indicate more species, where darker coloration shows the proportion of species classed as non-resident. Routes are connecting curves, with width indicating the number of species traveling from the origin country to the USA. XX denotes shipments of unknown origin (“XX” country coded in the LEMIS data) are shown in the South Pacific. See Figure S3 for the associated plot of “non-resident” species traded labeled as “wild” for each country, and Figure S2 for wild trade per nation for all taxa. Figures S3 and S4 provide the overall proportions of species and individuals from different sources.
See also Figure S5.

822,682,150 individuals imported from the Netherlands to Louisville. This is followed by 191,250,291 Insecta and Myriapoda from Mexico to Los Angeles and 104,743,300 between the Netherlands and Louisville. Following this is the first vertebrate taxa, with 91,104,615 Fish transported from Mexico to Los Angeles.

Resident or non-resident

The collection and export of wild individuals has a greater potential to impact species survival than the trade of captive-reared individuals, though it is important to note that individuals with undeclared sources may be automatically recorded as “wild” (and more care is clearly needed to prevent incorrect records being filed). Species may be listed as exported from the wild from countries where they do not occur in the wild; this may be attributable to recording errors in the status of specimens being traded (wild vs. captive), movement from a country in which they are resident without being declared (possibly due to tighter export regulations from that country), or potential laundering between neighboring states with stricter regulations for international export (though it may also indicate gaps in IUCN data regarding species ranges). Although the Lacey Act should prevent the import of species into the US when it contravenes national laws, assessing legality can be challenging if animals are laundered into an intermediary (third) country prior to import into the US, circumventing any national legislation in the country of origin. Alarmingly, huge numbers of non-resident species were declared as exported from the "wild" for many taxa, with large numbers of such specimens originating from European countries (such as Germany) (Figures 2, S2, and S3).

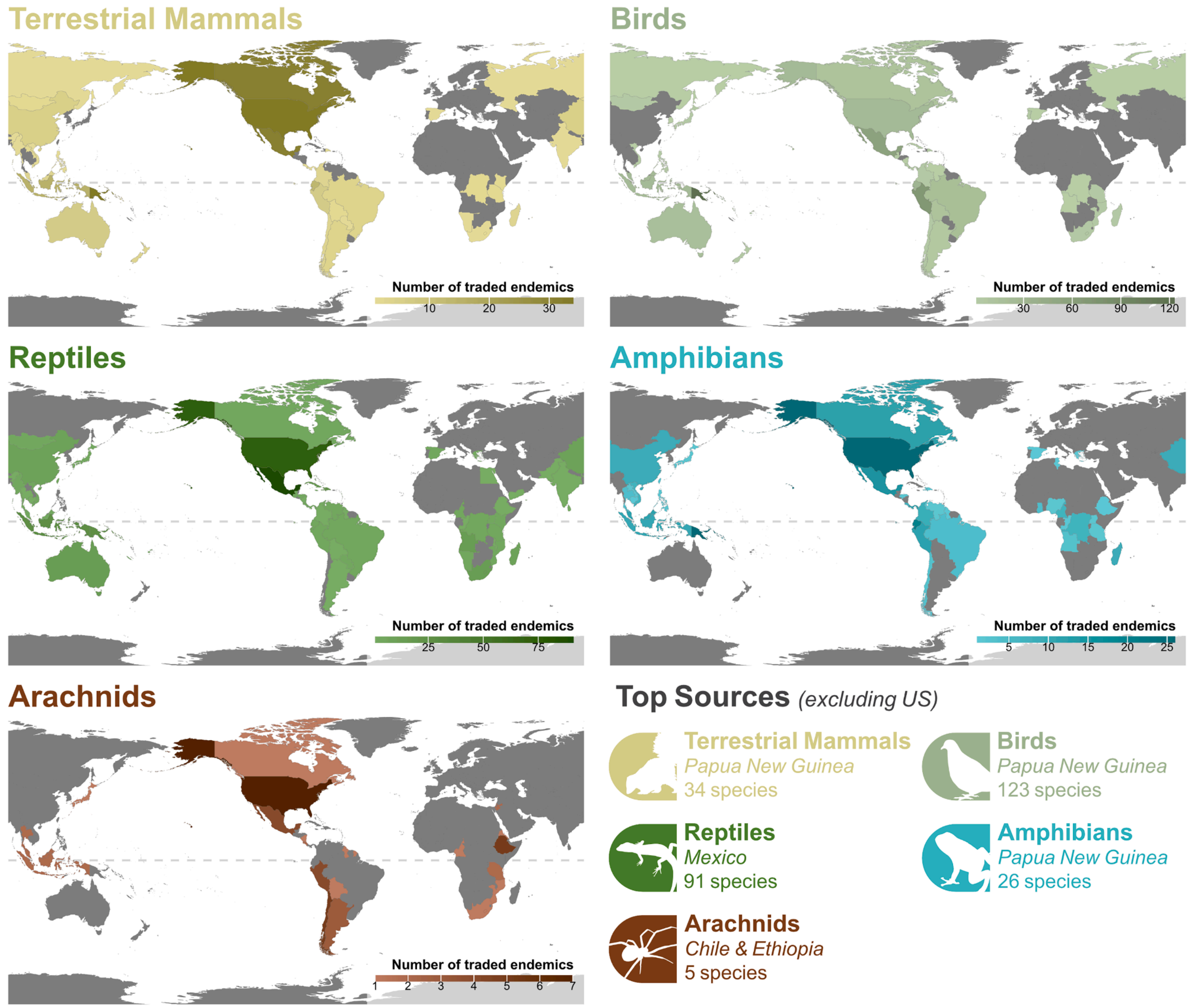

Figure 3. Choropleth maps indicating national-level counts of traded endemic species
Four terrestrial vertebrate groups and Arachnids with some level of wild sourcing are shown.

In terrestrial Mammals, tropical countries (i.e., with centers within −23.5 to 23.5 latitude) show 48.1% ± SD 32.5 traded species are resident, whereas non-tropical countries show 61.7% ± 23.9% of traded species are non-resident. Canada and South Africa both have the most traded terrestrial Mammal species, and reasonably high numbers of those species are non-resident (39.5% and 46.4%, respectively). Other taxa show similar patterns, with high diversity coming from the wild from tropical regions and generally lower or captive breeding occurring in temperate regions, though possible laundering is occurring in regions such as Europe, especially for reptiles (see Figure S3 and Methods S1.3 for calibration).

Endemic species and origin

We assessed the origins and counts of countries' endemic species (i.e., species only distributed in a single country and had some level of declared wild sourcing), revealing differing patterns between the terrestrial vertebrate groups and Arachnids (Figure 3). Trade of endemic mammals originated from all countries to some degree, but with particular hotspots coming from Canada (32), Papua New Guinea (34), and Mexico (32). This largely mirrors the overall patterns of species trade in terrestrial Mammals. Traded endemic Birds, like Mammals, tend to originate from areas with high numbers of traded species generally, namely South American countries such as Peru (72) and Mexico (56). But there are also high numbers of endemic Birds originating from Papua New Guinea (123), making up ∼60% of all resident Birds exported from Papua New Guinea. Traded endemic Reptiles have a more even spread, with many tropical countries having multiple endemic species traded. In contrast to the patterns in number of species traded, Europe is entirely absent, reflecting the fact that much of the reptile trade out of Europe is in non-resident species. Mexico also appears to be a major source for endemic traded Reptiles

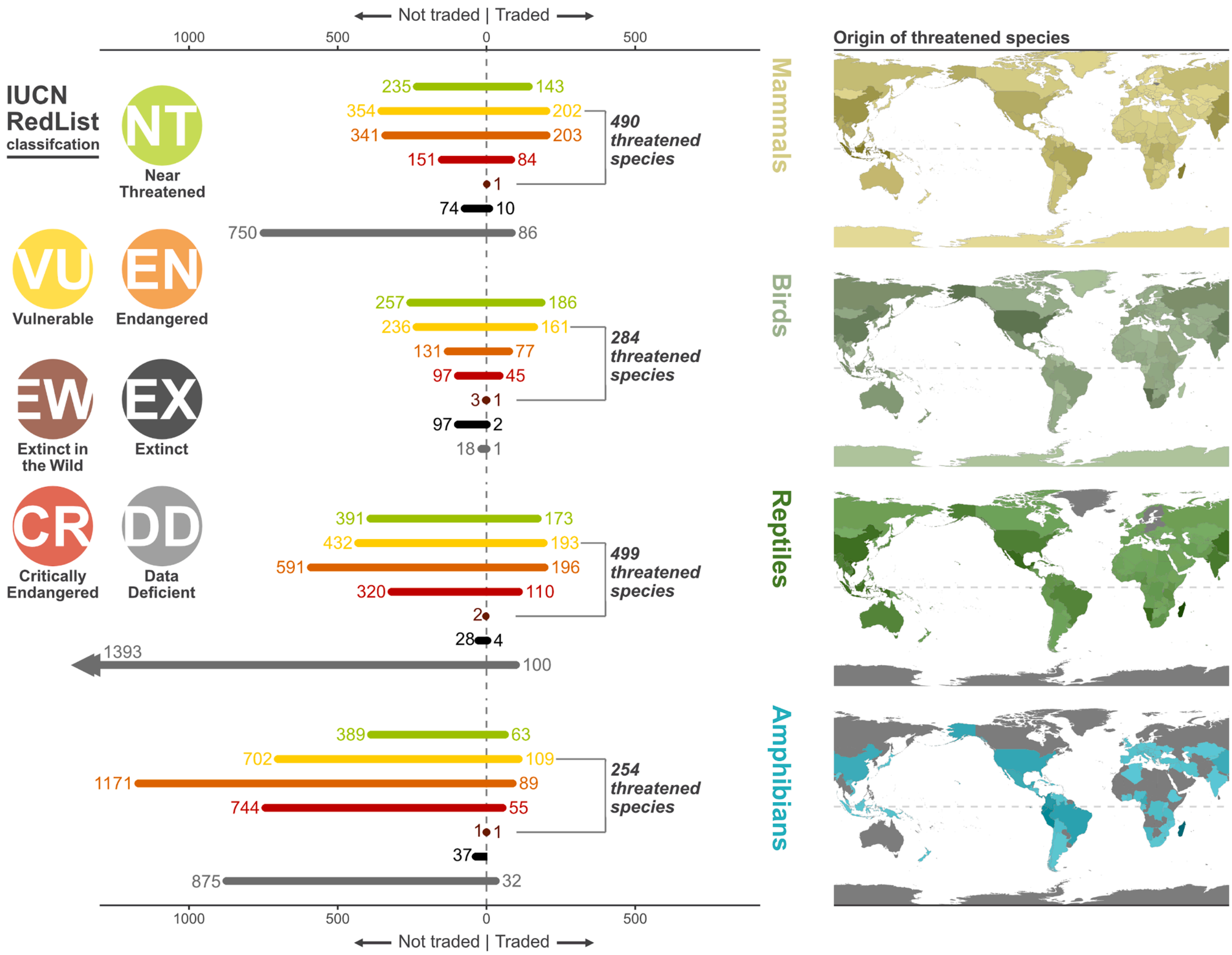

Figure 4. The counts of near-threatened and threatened species (based on IUCN Red List categories) and their detection status in the LEMIS trade data

Counts to the left indicate species not appearing in the LEMIS data, whereas those to the right indicate counts of species listed. Not displayed are species classed as least concern. World maps indicate national-level data about native origin of the threatened species, with darker colors indicating more traded threatened species. See Figures S7 and S8 for purposes and sources of taxa in trade and a synergy of patterns, and Figure S6 for those classed as Extinct or Extinct in the Wild.

(91), with Indonesia (28), Papua New Guinea (27), and the Dominican Republic (25) to lesser extents. For Amphibians, large numbers of endemic species originate from northern South America and Central America (e.g., Ecuador [20] and Mexico [15]). Amphibians also show similar patterns to terrestrial Mammals and Birds, with 26 species coming from Papua New Guinea (50% of resident traded species), as well as the Solomon Islands (17, 81% of resident traded species). Endemic Arachnids have trade hotspots in Ethiopia (5) and Chile (5) but, in general, see fewer species classed endemics traded compared with the other groups.

Threatened species in trade

For most taxonomic groups in trade, only a minority of species are covered by the IUCN Red List; thus, we restricted assessments of Red List status to terrestrial vertebrates to avoid potential "cherrypicking" of listed species in other taxa (i.e., for taxa groups with limited IUCN assessment coverage, existing assessments are likely to be biased toward potentially threatened species).

Reptiles show the greatest number of traded threatened species at 499, and also have the highest number of traded Data Deficient species at 100 (Mammals follow at 86; Figure 4). Reptiles also have the highest numbers of traded Endangered species (110). Terrestrial Mammals have the second highest number of traded Threatened species at 490, of which 84 are Endangered/Critically Endangered, followed by Birds, with 284 threatened species (118 Endangered/Critically Endangered and 1 Data Deficient), and finally Amphibians, with 254 Threatened species in trade, of which 144 are Endangered/Critically Endangered and 32 are Data Deficient. Unsurprisingly, when the origins of these species are examined, high percentages of Critically Endangered, Endangered, and often Data Deficient species are exported from tropical regions. Thus, these biodiverse regions have both more and a higher proportion of Threatened species in trade (see Figures S7 and S8).

Do wildlife trade patterns reflect national-level reporting to CITES?

Understanding the relationship between what is listed in a CITES Appendix and traded into the US vs. the total number of species traded into the US according to LEMIS for each country may help us to understand where trade in various taxa is related to regulation to manage that trade. Understanding national-level engagement is also critical (Figure S9), as some countries may not actively engage with management of trade via CITES despite high trade volumes.

We found significant relationships between total trade in LEMIS and CITES listings per country in all taxonomic groups except Arachnids, though it should be noted that for some taxa this is due to a small number of highly listed taxonomic groups (Table S1). The clearest relationship for all trade was in marine Mammals (R^2 = 0.4), followed by Fish (R^2 = 0.34), and Birds (R^2 = 0.32). R^2 for all other taxa was under 0.30. When only the number of species traded declared wild is considered, the relationships get clearer for a number of taxa. Reptiles show the strongest relationship (R^2 = 0.53), followed by marine Mammals, Fish, and then terrestrial Mammals (R^2 = 0.33; the relationship with Birds got weaker). For some taxa, very few species are listed within CITES (especially invertebrate taxa) so trends are unlikely to be indicative, and a re-evaluation of the sustainability of trade is likely needed for these groups, especially given the thousands of species traded. In addition, many of the countries with the highest number of species in CITES may have almost ten times more species traded outside CITES, without data to assess the impacts. Very different patterns of trade also exist in different regions and groups (Figure S9). Not only do most countries have many more species in trade overall than are listed in CITES but also most tropical and arid regions (especially Latin America and Asia) show particularly high number of species in trade overall but low rates of listing in CITES (Figure S9).

Application and reliability of CITES Appendix III

The application of CITES Appendix III clearly varies by region and taxa. We explored which Appendix III species appeared in LEMIS originating from the country that listed them (or with unknown origin), after the listing was in effect, and although most of this is legal, detecting violations or inconsistencies is important to understanding the effectiveness of the application of Appendix III. In terms of the use of Appendix III, within Mammals, Appendix III was often applied to small carnivores in the 1980s, with relatively few species listed since this time. Within Birds, Ukraine listed a large number of species in 2021 (for example, 21 species detected in trade in the US are now Appendix III in Ukraine). Prior to this, Pakistan listed some species in 2014, and various Latin American countries listed species in the 1980s and early 1990s. For Amphibians, only three species were listed (that were recorded in trade in the US). Reptiles are better represented, but, like Birds, one species was listed from Ukraine in 2021 and 15 species from Cuba in 2019, with later listings from Australia (4 species in 2022) and Israel in 2023. Earlier reptile listings were also largely in the 1980s.

In terms of “effectiveness” of these Appendix III listings, there are repeated possible violations for the Cuban endemic *Sphaerodactylus* and *Anolis* species post listing, where LEMIS lists them as wild whereas these same individuals in CITES have different source codes (i.e., pre-convention—even years after listing—and for live specimens, highlighting a likely false declaration, and more rigorous checks are clearly needed to ensure accuracy and consistency). For other species (such as *Daboia russelii*), trade is noted from other Asian countries where it is not native. For Amphibians, one of the three species (*Calyptocephalella gayi*) has mismatches between the dates of CITES and LEMIS data, with, for example, the 2012 CITES record corresponding to the 2022 LEMIS record. For Birds, we have species clearly exported from countries where they are listed as Appendix III but not appearing within CITES (such as *Cephalopterus penduliger*). There are also multiple instances where country codes vary between CITES and LEMIS, as well as instances where XX, G2, or G5 is listed in CITES rather than a country code, and several Appendix III species exported from the wild in countries where they are not native. For mammals, different patterns emerge. For example, the Blackbuck (*Antilope cervicapra*) is listed on Appendix III in India, but the invasive population in Argentina is legally exported in large numbers. Many Appendix III mammals are traded from countries neighboring that in which they are listed, as well as traded from the wild in areas where they are not native, and further efforts are needed to manage these issues.

DISCUSSION

Dimensions of trade

The number of wildlife species in global trade has been estimated at around 50,000 by IPBES, yet the US alone imports around 30,000 species.[2,31] Despite the colossal diversity of species and number of individuals involved in trade, the issue of unsustainable trade is frequently overlooked, with many agencies and researchers assuming that CITES alone provides a fairly complete index of traded species.[37] Yet, CITES only includes a small fraction of species for which trade is known to pose a potential threat and for which overarching controls have been advocated.[38] Although wildlife trade is a global issue, the dimensions of trade vary hugely between taxonomic groups and regions. Furthermore, gauging the impacts and sustainability of trade is impossible without understanding where wildlife is coming from (and if it is from the wild) and in what quantities. Regional patterns have likely shifted across the total period examined,[2] but broad patterns need to be understood as changes are also inevitable in the future, and countries that have become less engaged in trade may reverse such patterns due to political factors.

Sources of different taxa in trade

We found that highly biodiverse, often lower-income, economies (such as Indonesia) export both larger numbers of individuals and a greater diversity of species for many taxa, which are often resident species sourced from the wild. Conversely, higher-income economies (such as those in Europe, especially Germany) that also export high numbers of species tend to export non-resident species declared as captive bred (and even species declared as wild may not be resident). Countries such as Germany play a major role in the pet trade of various reptiles, exemplified by the Terraristika expo in Hamm, which serves as one of the largest events for this trade.[6,8] However, the lack of equivalent data on trade into Europe (TRACES data are not openly available and often not at the species level) makes understanding the full dynamics of European wildlife trade challenging.

The majority of invertebrate species came from Asia, with high proportions coming from the wild. However, some invertebrate groups were primarily exported from elsewhere, such as Arachnids, which largely came from Europe, especially Germany and Poland.[8] This is important as it highlights two separate issues. First, in the last global arachnid trade analysis,[8] LEMIS rarely recorded Arachnids relative to online trade, thus, the greater trade presence of Arachnids from countries with better reporting suggests that the invertebrate trade in many regions may be underestimated if they rely on postal and courier services, which may not be detected or declared during import into the US (especially for invertebrates, as X-ray will be ineffective). This highlights the second issue, that patterns of Arachnids in trade may reflect changes in reporting patterns, with many countries (such as South American countries) still potentially under-reporting the export of species in trade. This reliance on postal services, commonly referred to as "brownboxing," is also used to circumvent regulations and may facilitate laundering.[39]

For many groups, large numbers of species came from tropical regions (with the exception of marine Mammals). Many vertebrate taxa show increasing levels of captive breeding declared within Europe (e.g., Reptiles).[2] Changes may be due to either changing restrictions in some taxa (such as Birds) and increasing awareness of the disease-associated risk of wild-caught species to captive stocks (e.g., Amphibians; i.e., see Tapley et al.[40]). A transition to predominantly captively bred trade in birds has occurred in Europe following the enactment of the EU wildbird directive, which altered global trade patterns.[21,41] However, it should be noted that interpreting patterns is challenging due to the lack of available data on non-CITES species.[42,43] Some changes may come from updated versions of the Lacey Act and other regulations (US Wildbird Conservation Act), though the implications thereof require further work.[44] Regulatory changes may alter routes and sources of trade, thus careful monitoring is needed.[20,45,46] The role of trade agreements also requires attention as they may alter patterns of risk from wildlife trade.[47]

Although more diverse countries may export higher diversity for some taxa, quantity frequently does not mirror diversity in trade routes, such as pet-trade-related export (such as at exotic animal fairs and expos). For example, high imports of certain taxa into Louisville may relate to regional reptile expos, as well as its longstanding role as a designated port for reptile import.[48] Other ports may act as a source for domestic redistribution. Conversely, high-quantity trades in a small number of species likely represent trade for food or fashion (e.g., green iguanas from El Salvador for meat), which require quantities in bulk, or possibly trophies (i.e., terrestrial mammals).[49] Thus, these different types of trade (differing form, quantity, and purpose) likely require different types of management interventions. Species with smaller ranges, low populations, and slower reproducing clearly cannot withstand high volumes of trade, and thus trade quotas and non-detriment findings need to reflect these factors.

Europe represents a major source of species imported as "pets" to the US (with high exports of various arachnids and herpetofauna), and yet comparable data from Europe (although possibly recorded within TRACES) are not openly available.[16,18] The high exports of Arachnids and Reptiles from European countries are often stated as "wild origin" from non-range states, which highlights misdeclaration, inaccurate recording of source, or potential re-export from other source countries not being reported (see Figures S4 and S5). Thus, although captive breeding programs may offset some demand from wild-sourced individuals, this is only the case for a minority of species in trade. More work is needed to demonstrate this for individual species from more targeted approaches.[50,51]

Threatened species in trade

We found 496 threatened Reptile species traded into the US trade over the course of the study, of which 111 are Critically Endangered and 100 are Data Deficient species, with Asia and Africa representing key sources. Many of these species are traded for commercial purposes and frequently come from the wild (Figures S7 and S8). Other taxonomic groups also have high numbers of Endangered, Data Deficient, and Threatened species in trade. When considering Threatened and Data Deficient vertebrate species, there are many fewer Data Deficient species of Reptiles and Amphibians coming into the US than were shown to be for sale online (primarily in Europe[4,6]). Furthermore, a number of species classed as Extinct or Extinct in the Wild (Figure S6) are traded as trophies or for commercial reasons (especially mammals and Birds), although only in Amphibians are the majority for reintroduction. Various species, such as many poison dart Frogs (Dendrobatidae) and Axolotls, which are legally traded as pets, also facilitates additional illegal and unsustainable trade.[52] New methods to identify the trade of these threatened and endemic species have been developed (e.g., Hinsley et al.[53]), but better systematized tracking is urgently needed to monitor and manage trade. Trade has been linked to the extinction of 511 species, in addition to population declines of 62% in traded populations,[28,54] and many species in trade are newly described, undescribed, or Extinct in the Wild.[6,8,9] Many tropical countries have high levels of endemism, as well as small-ranged, wild-caught species, meaning that trade may pose a particularly significant risk to species survival. For these species, un/under-regulated and unmonitored trade may quickly pose a high risk to survival, with the potential to extirpate species from sites or reduce populations below viable levels without such actions being detected.

For marine invertebrates (which have not been examined previously), Indonesia and the Philippines play particularly important roles, which is consistent with the European fish trade, where 44% of ornamental marine fish species came from Indonesia.[55] These highly diverse regions are also threatened by a wide array of other factors (habitat loss and degradation, ocean acidification, etc.[56]). Similarly, a high diversity of wild fish is still coming from Asia (especially Indonesia) and Australia. This is especially notable, as although the ornamental freshwater fish trade is now known to largely come from captivity,[57] this is not the case for tropical marine species sourced from the wild, which may put populations at risk.[58]

The relationship (or lack thereof) between potentially traded species (via LEMIS) and regulated traded species (CITES) could highlight areas (and taxa) in need of greater attention and management interventions (Figure S9). Most countries with high numbers of CITES-listed species have many more non-CITES-traded species, (e.g., African nations have up to eight times more traded non-CITES species). Furthermore, for some taxonomic groups (e.g., invertebrates), so few species are traded via CITES that there is no relationship (e.g., only around 4% of Arachnid species traded into the US are CITES listed), highlighting an urgent need to re-examine what is in trade.

Understanding mismatches between species ranges and declared sources

The US remains one of the few regions that provides broad-scale data of wildlife in trade across taxa. These data highlight the staggering numbers of species in trade, in addition to demonstrating that not only are most species in trade traded outside the remits of CITES but also that a lack of oversight means that many species declared as wild sourced are not resident to the countries they are exported from. The inconsistencies between native origin and wild declarations highlight the need for more rigor in assessing genuine origins of species, and inconsistencies in the system are well known.[32,59] There are many clear cases of either re-export, false declarations (or misrecording), or laundering, given the high number of individuals declared as "wild sourced" despite not being resident, particularly from Canada and European economies. Determining what is creating mismatches requires closer examination of the trade and verification from other data sources (e.g., examination of on- and offline markets) but has the potential to highlight key trade hubs (see Figures S4 and S5 and Methods S1.3).

Multiple uncertainties and errors exist in trade data, including misdeclaration of source countries (either deliberately or through omission); for example, at present, re-exported species may only include the third country (intermediary) rather than the source, obscuring true patterns of trade and requiring attention to improve the quality of data input to enable identification of deliberate misdeclarations. Furthermore, many species noted to originate from "unknown" re-export from the US without the source country declared, and mismatches between wild-sourced individuals originating from countries they are not native to (either indicating the individual is not wild or the original source has not been provided; Figure 2) clearly requires attention to provide accurate recording. At present, the lack of accurate declaration of sources in many cases (for example, unknown is often the top source for many species) is needed even to enforce existing laws, such as the Lacey Act, as determining legal export should require acknowledgment of the source country. In addition, "Exception 4" listings may not include source information. Using exception 4 to avoid providing basic information undermines the ability to monitor and analyze trade, and the ability to list species under this designation should be restricted to where commercial sensitivity (or other mitigating factors) can be proven.

Furthermore, when looking at CITES Appendix III, the impact of managing trade is unclear, given the mismatches between the source (Wild/Captive/Pre-convention) reported in LEMIS and CITES and even mismatches between the countries of origin, highlighting that additional data standards, checking, and validation are obviously needed. In addition, Appendix III species are sometimes traded from the country in which they are listed without being recorded within CITES (and only being noted within LEMIS), the export country is not disclosed, or they are exported from "the wild" in countries in which they are not resident, calling into question the efficacy of CITES Appendix III in some regions. There are many instances in which Appendix III species were exported from countries neighboring the country where they are listed as Appendix III. This could signal laundering over borders to bypass regulations. This is consistent with previous analysis showing that certain regions (parts of Africa and Asia) often show poor compliance with CITES, and levels of reporting vary considerably.[5]

Recent advances in AI, as well as the use of automated systems, could overcome some of the issues (automatic quality checking of input to flag errors immediately, even IDing of species based on images and tracing of supply chains to flag false declarations), but others likely represent a lack of prioritization on issues around wildlife trade and a lack of effort into verifying sources and origins. Increased training and inspection at the points of import could reduce recording errors and therefore make potential violations (and deliberate misdeclarations) more visible. Mismatches may also be indicative of purposeful trafficking or laundering to move species to other countries where export is easier, such as if ports in another country are closer to where species are initially collected or where restrictions are lighter. These issues highlight the need for improvement in data collection and completeness, in addition to areas where greater regulatory scrutiny is required. Determining what is creating mismatches requires closer examination of the trade and verification from other data sources (e.g., examination of on- and offline markets) but has the potential to highlight key trade hubs. Using automated systems to input and check data would reduce the potential for input errors, thus making deliberate acts of attempted laundering and misdeclarations easier to identify and facilitating the enforcement of legislation such as the Lacey Act. Ultimately, improvements in the accuracy of data input, as well as training to identify deliberate misdeclarations and potential laundering, are essential to understand and manage wildlife trade.

Moving forward

Under-regulated and virtually unmonitored wildlife trade continues to pose a major threat to species survival. Our knowledge of global trade remains fragmented because of a lack of data availability, data collation, standards, and verification. Moving forward, more countries should collate and disclose wildlife trade data using clear and interoperable standards, similar to LEMIS and CITES, and make data available in a timely manner to enable tracking of changing trends. Without such data, reaching biodiversity goals, such as targets 5 and 9 of the Kunming-Montreal Global Biodiversity Framework, will be impossible.[60] This is particularly true for Europe, which has TRACES but, in addition to questionable standards (frequent use of higher taxonomic levels), is inaccessible for analysis and therefore does not enable large-scale monitoring.

Although "sustainable use" is a pillar of multiple conventions (CITES, CBD, etc.), unsustainable trade remains a major driver of biodiversity loss.[31] Counteracting these pervasive threats requires better data and interventions to manage trade sustainably (such as NDFs [non-detriment findings] for vulnerable groups; Reaser[61]). The lack of correlation between the use of CITES vs. the trade in LEMIS for many invertebrates (in particular) and weak relationships overall highlights that CITES lags potential trade vulnerabilities, as has been noted previously.[62] Furthermore, clear violations of CITES Appendix III are present when these two data sources are compared. Thus, the use of Appendix III could be seen as a stopgap before listing to Appendixes I or II if it is not to potentially enable laundering of species via a third country, and disclosure of source countries should be essential.

Although patterns of trade inevitably vary by taxa, better monitoring and clearer identification of the true origin of species "from the wild" being exported from countries in which they are not resident are needed. For example, unknown is often the top source for many species and basic origin information is required to enforce existing laws such as the Lacey Act. Listing only the country of export as the origin can mask locations and areas with high levels of collection. With better automation, and the introduction of ePermitting via eCITES, tools for standardizing the digital databasing of trade are becoming more widely used. Furthermore, the use of eCITES could allow flagging of errors and mismatches. Advances in supply-chain tracking for zero-deforestation and fishery supply chains should enable tracing of all trade via the application of similar technologies, and parallel approaches could be applied to wildlife trade. In addition, major import hubs (e.g., Memphis, which hosts FedEx headquarters; Memphis International Airport[63]) and areas where mismatches were greatest could be targeted for added training and capacity to minimize possible errors and identify laundering. Such programs would likely require considerable funding,[64] but by providing training to build capacity in export hubs,[65] paired with better ways to accurately collate species data on import, we could develop the means to not only understand the dimensions of trade but also to regulate trade sustainably.

In addition to regulatory change, growing consumer awareness is reshaping the exotic pet trade in some regions. Enthusiasts are increasingly seeking captive-bred animals due to their health advantages, superior temperament, and ethical sourcing.[66] Critically Endangered species, such as poison dart frogs, are now being bred extensively in Europe to help reduce the impact of wild collection.[40,67] The crested gecko exemplifies this change; once thought extinct, it is now one of the most common species in the pet industry, bred exclusively in captivity with diverse morphs commanding high prices.[68] This consumer-driven shift is pushing the industry toward more ethical and sustainable practices, but certification standards and bodies may be necessary for enforcement and validation of claims for sourcing (e.g., if genuinely captive bred). This entails involving multiple sectors to develop approaches that reflect the complex challenges and developing collaborative and pragmatic approaches to enable more sustainable trade.[69] For example, in the US amphibian pet trade, recent collaborations between businesses and researchers have resulted in initiatives to formalize pathways for disease surveillance, reporting, and risk mitigation in the trade (e.g., Healthy Trade Institute[70] healthytrade.org). These partnerships emerged as a direct response to the 2016 listing of salamanders as "injurious" under the Lacey Act (18 U.S.C. § 42), and seek to provide centralized resources and support for both sellers and consumers to engage in sustainable trade practices. This increasingly shared recognition of the importance of sustainable trade across diverse stakeholders[71,72] may serve as a model for effective bottom-up strategies to mitigate risks associated with the trade that would otherwise be exacerbated or insufficiently addressed by traditional top-down regulatory approaches. Building on these efforts both in taxonomic scope and geographic coverage (such as in Europe) is urgently needed to reduce the multifaceted negative impacts of wildlife trade on species survival.

Ultimately, the diverse drivers of international wildlife trade, as well as the scope and scale, have continued largely neglected by the international community. The standardized collation and sharing of trade data, as well as mechanisms to better regulate trade (including mechanisms to detect errors such as false disclosures), are urgently needed. Without them, unsustainable, but legal, wildlife trade will remain a major threat to species' survival around the planet.

RESOURCE AVAILABILITY

Lead contact

Further information can be directed to, and fulfilled by, the lead contact, Alice C. Hughes (alice.c.hughes@unimelb.edu.au).

Materials availability

The original dataset is available as part of Marshall et al.,[2,73] (https://doi.org/10.6084/m9.figshare.25041584.v1), which expanded upon data curated by Eskew et al.,[74,75] (https://doi.org/10.5281/zenodo.3565869).

Data and code availability

Any additional information required to reanalyze the data reported in this paper is available from the lead contact and first author upon request. We have made all code used to summarize these data available at https://github.com/BenMMarshall/mapTradeLEMIS and archived at Zenodo: https://doi.org/10.5281/zenodo.14982543. We have made the data with additional distribution fields available at Zenodo: https://doi.org/10.5281/zenodo.14982583, alongside the GBIFIDs of all used occurrence data points.

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AUTHOR CONTRIBUTIONS

Conceptualization, A.C.H. and B.M.M.; methodology and analysis, B.M.M. and A.C.H.; supervision, A.C.H.; writing – original draft, A.C.H. and B.M.M.; writing – review and editing, A.C.H., B.M.M., C.T.S., M.L.G., E.A.E., O.C.S., P.C., S.C., F.W., C.F., P.G.-D., J.S.S., M.F.T., R.J.A., and J.W.V.

DECLARATION OF INTERESTS

The authors declare no competing interests.

STAR★METHODS

Detailed methods are provided in the online version of this paper and include the following:

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SUPPLEMENTAL INFORMATION

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STAR★METHODS

KEY RESOURCES TABLE

REAGENT or RESOURCE	SOURCE	IDENTIFIER
Deposited data		
LEMIS data	Marshall et al.[2]; https://doi.org/10.1073/pnas.2410774121	https://doi.org/10.6084/m9.figshare.25041584.v1
Eskew et al.[75]	Heinrich et al.[76]	https://doi.org/10.5281/zenodo.3565869
IUCN Amphibian	AmphibiaWeb[77]	Distributions
IUCN Reptile	Uetz et al.[78]	Distributions
IUCN Bird	Bird Life International[79]	Distributions
IUCN Mammal	Mammal Diversity Database[80]	Distributions
Arachnid	WSC[81] and Arel-Bundock et al.[82]	Distributions
World Administrative Boundaries	https://public.opendatasoft.com/api/explore/v2.1/catalog/datasets/world-administrative-boundaries/exports/shp	Administrative boundaries for GIS mapping
CITES listing	https://checklist.cites.org/#/en	Species listed within CITES Appendices
CITES Appendix III listing	https://speciesplus.net/	Appendix III listings
Data and code	https://github.com/BenMMarshall/mapTradeLEMIS	Our data and code
Data and code	https://doi.org/10.5281/zenodo.14982543	Our data and code
Software and algorithms		
R v.4.2.2	R Core Team[83]	N/A
‘countrycodes’ - R	Arel-Bundock et al.[84]	N/A
ArcMap 10.8	https://www.esri.com/en-us/arcgis/products/arcgis-desktop/overview	N/A
tidyverse v.v.2.0.0	Wickham et al.[85]	N/A
glue v.1.7.0	Hester et al.[86]	N/A
ggplot2 v.3.5.1	Wickham[87]	N/A
strings	Pebesma[88]	N/A
sf v.1.0.16	Pebesma and Bivand[89]	N/A
colorspace v.2.1.0	Stauffer et al.[90] and Zeileis et al.[91,92]	N/A
patchwork v.1.2.0	Pedersen[93]	N/A
ggmap v.4.0.0	Kahle and Wickham[94]	N/A
ggimage v.0.3.3	Yu[95]	N/A
ggtext v.0.1.2	Wilke and Wiernik[96]	N/A
CoordinateCleaner v.3.0.1	Zizka et al.[97]	N/A
rgbif v.3.8.0	Chamberlain et al.[98]	N/A
taxize v.0.9.100	Chamberlain et al.[99]	N/A
here v.1.0.1	Müller[100]	N/A
readr v.2.1.5	Wickham et al.[101]	N/A
targets v.1.6.0	Landau[102]	N/A
tarchetypes v.0.9.0	Landau[103]	N/A
rmarkdown v.2.27	Xie et al.[104,105] and Allaire et al.[106]	N/A
tinytex v.0.51	Xie[107,108]	N/A
knitr v.1.47	Xie[109–111]	N/A
grateful v.0.2.4	Rodriguez-Sanchez and Jackson[112]	N/A

(*Continued on next page*)

Continued		
REAGENT or RESOURCE	SOURCE	IDENTIFIER
Other		
Fishbase	Froese[113]	Fish taxonomic correction
Global Lepidoptera Names Index	Beccaloni et al.[114]	Butterfly taxonomic correction
World Spider Catalogue	WSC[81]	Spider taxonomic correction

EXPERIMENTAL MODEL AND STUDY PARTICIPANT DETAILS

Identifying species in trade

We retrieved wildlife trade data from Marshall et al.,[2] which curated and summarised approximately 20 years of LEMIS-derived trade data, constituting animal and some plant trade into the US. During this summation, several data cleaning processes were undertaken. Chief amongst them were efforts to unify scientific names to a consistent taxonomic backbone and address spelling errors. Largely the names were made to conform to the GBIF taxonomic backbone, but other taxonomic authorities were required for some groups (e.g., Fishbase,[113] The Global Lepidoptera Names Index,[114] World Spider Catalogue[81]). Marshall et al.[2] name corrections aimed to alter the original name in the LEMIS data as little as possible. In addition to correcting names, the species were sorted into 15 broad categories (Amphibians; Arachnids; Birds; Bryozoa and Squirts; Crustaceans and Molluscs; Echinoderms and Cnidaria; Fish; Insecta and Myriapoda; Lepidoptera; Marine Mammals; Reptiles; Other Invertebrates; Plants; Porifera Sponges; Terrestrial Mammals). We retained those categories for summaries herein. This name-corrected dataset was used for overall summaries of species numbers and origins.

For examination of trade quantity, Marshall et al.[2] had to address data quality issues. Consistent summations of quantity using volumes and weights proved difficult, so examinations of quantity focused instead on organism counts. Count data consisted of traded items that could be considered to represent a “whole” individual. This definition of whole individual meant that data was filtered to only include trade where the LEMIS description code was "BOD" (bodies), "EGL" (live eggs), "DEA" (dead specimen), "LIV" (live), "SPE" (specimen), "SKI" (skin), or "TRO" (trophy). We retain this definition for this paper, and, for calculations of trade quantity, additionally filtered data such that counts (number) of whole individuals was the only unit present (the unit field = “NO” in the LEMIS dataset). This secondary filter removed specimens that were traded as liquids, or volumes. Despite this restriction to whole individuals, there was evidence of extreme outlying trade counts. To prevent these outlying extreme counts from dominating overall patterns, Marshall et al.[2] applied a filter on a genus-by-genus basis to remove outlier shipments that: 1) exceeded other trades in that genus by an order of magnitude, and 2) exceeded an absolute count of 10,000. The groups Insecta and Myripoda and Other Invertebrates also exhibited outlying trades not detected by the genus-level filter. Both groups had a second trade volume filter applied, removing trades over 40 million individuals, which appeared to constitute anomalous clusters. We use the same outlier filters for our examinations of trade origins here, as we directly use the whole individual filtered dataset provided by Marshall et al.[2] We also applied an additional filter to only examine “live” organism imports to explore and compare the proportion of live trade relative to total trade.

METHOD DETAILS

Identifying origins of species traded into the US

We summarised trade into the US in a number of ways (Methods S1.0). The first was via counts of species per taxonomic group (e.g., reptiles, fish, etc.). We summarised the trade by counting the number of species (i.e., excluding all trade that could not be identified to the species level; Marshall et al.[2]) appearing in trades between countries and US ports, and as originating from each country. These summaries were further subdivided, splitting the source of the traded species, whether being declared as originating from the wild, captivity, or were captured from the wild as eggs or juveniles then raised in captivity (termed ‘ranched’). For the number of whole individuals, we again summarised by taxonomic groups, country to US port and overall from country of origin, and the listed origin country and source (wild vs captive) of the trade. To visually represent trade, we mapped the results of the above analyses as connections between countries of origin and US ports for each taxonomic group (Methods S1.1 for route diversity validation, Methods S1.2 for assessments of dynamics of different quantities). For broader in-text summaries, we refer to tropical and non-tropical countries. We treated any country whose centroid falls between -23.5 to 23.5 latitude as a tropical country.

Does the provenance match the range of species listed as “wild”

To further strengthen the datasets from Marshall et al.,[2] we retrieved species distribution data for the traded vertebrate groups which were included in the threat assessments as well as arachnids (See Methods S1.3). We elected to focus our efforts on these taxonomic groups because they have the most consistent and readily available distribution data based on the IUCN assessments (and prior trade-based analyses). As LEMIS data only lists trade origin to a country level, we examined species distributions at the same resolution. We primarily used the distribution data provided by the IUCN.[115] First, we used the ‘taxize’ R package[99] to identify GBIF backbone names equivalent to the IUCN species names.[116] We then matched the resulting species names to country data supplied by the IUCN, creating a list of ISO 3166-1 alpha-2 country codes for each species. We limited our analyses to countries where the species was classed as "Extant" or "Possibly Extant". To supplement this distributional data, we used the 'rgbif' package[98] to query GBIF[117] for up to 10,000 research-grade species observations for each species. We then used the CoordinateCleaner package[97] to remove points located at unusual coordinates (e.g., zeroes, equal coordinates), and country centroids (within 1 km), those centred on capital cities (within 1 km), those that appeared to be misconversions to decimal degrees, and those that were deemed to be outliers by distance. Outliers were defined as points exceeding 5 interquartile ranges of the minimum distances to the next neighbours. Once cleaned, we randomly selected up to 1,000 points for each species and determined the country they fell within to bolster IUCN data which can miss major parts of the range.[118] We added this distributional data to the IUCN range data. A final additional source of distribution data was obtained for each group (Amphibians: [77]; Reptiles: [78]; Birds: [79]; Mammals: [80]; Arachnids: [81,82]). We combined all these data sources together to produce as generous an estimate of a species distribution as possible. This resulted in 99% of traded vertebrate species and 83% of traded arachnid species having established range data at the country level. If a species only had a single country listed, we classed them as endemic and conducted separate summaries of endemic species origins (see Methods S1.3). Our efforts to maximise distribution data comprehensiveness by combining IUCN, GBIF, and taxon-specific data sources should have mitigated this source of error. However, despite these efforts the available distribution data on the traded species may be incomplete and the traded species may in fact be resident to the exporting country (or animals listed as wild-sourced may be misdeclared and actually be captive bred; Morton et al.[11] and Weissgold et al.[32]).

We compared this distributional data to LEMIS-provided data on the country of origin of "wild"-sourced trades (as noted prior) to identify mismatches between species' known distributions and where they had been reportedly wild-sourced for trade. For this comparison, we used the 'countrycodes' package[84] to ensure all country data was in a consistent ISO 3166-1 alpha-2 country code format. A trade was classed as mismatched if the LEMIS origin country code did not appear in the list of known resident countries for that species.

It should be noted that because the declaration of wildlife origin in LEMIS is subject to error (e.g., "wild" may be listed when no source information is provided),[32,119] mismatches could indicate either false declarations (disinformation, Tlusty et al.[22]) or only a lack of diligence and quality control in some parts of the data collection process (misinformation, Tlusty et al.[22]). Nonetheless, whilst LEMIS was in part developed so that adequate staffing of agents could be allocated to different US ports based on import volumes, a further justification for the formation of LEMIS was to ensure the legality of wildlife imports (in accordance with the Lacey Act).[120,121] Therefore, accurate recording of provenance is crucial, and we consider misleading provenance to be an important issue that signals the need for better means of data validation. Similarly, we report rates where the listed origin of trade was "XX", indicating unknown (unreported), redacted, or the high seas.

All data analysis was completed in R v.4.2.2[83] via RStudio v.2023.12.0.369.[122] We used tidyverse v.v.2.0.0[85] to manipulate data, with aid from glue v.1.7.0[86] for strings, and sf v.1.0.16[88,89] for spatial data and mapping. We used a combination of ggplot2 v.3.5.1,[87] colorspace v.2.1.0,[90–92] patchwork v.1.2.0,[93] ggmap v.4.0.0,[94] ggimage v.0.3.3,[95] and ggtext v.0.1.2[96] for creating figures. We used countrycode v.1.6.0[84] to convert country ISO codes, rgbif v.3.8.0[98] to retrieve species distribution data, CoordinateCleaner v.3.0.1[97] to clean distribution data, and taxize v.0.9.100[99] to help determine name mismatches. We used here v.1.0.1,[100] readr v.2.1.5,[101] targets v.1.6.0, and tarchetypes v.0.9.0[102,103] to manage directory addresses and saved objects. We used rmarkdown v.2.27,[104–106] tinytex v.0.51,[107,108] and knitr v.1.47[109–111] packages to generate type-set outputs. We generated R package citations with the aid of grateful v.0.2.4.[112]

We have made all code used to summarise these data available at https://github.com/BenMMarshall/mapTradeLEMIS and archived at Zenodo: https://doi.org/10.5281/zenodo.14982543, and the original dataset is available as part of Marshall et al.,[2,73] (https://doi.org/10.6084/m9.figshare.25041584.v1), which expanded upon data curated by Eskew et al.,[74,75] (https://doi.org/10.5281/zenodo.3565869). We have made the data with additional distribution fields available at Zenodo: https://doi.org/10.5281/zenodo.14982583, alongside the GBIFIDs of all used occurrence data points.

Threatened vertebrates in trade

We downloaded IUCN RedList data from IUCN[115] that included the RedList category, as well as synonyms (ensuring species are not double counted due to the use of junior-synonyms in some listings) and distribution data for mammals, amphibians, reptiles and birds. We focused on these taxonomic groups because all others have considerably lower IUCN Red List coverage. We used string matching to link the Red List category against the species identity present in the LEMIS trade data. Where we did not get a direct match, we used the synonym names supplied by the IUCN to improve the chances of detecting a species in the LEMIS data. We classed those Red List species appearing in the LEMIS data as Traded, whereas all others species were classed as Not Traded. We summarised the counts of species per RedList category for each of the taxonomic groups examined and explored what type of trade taxa were involved in (e.g., commercial, scientific, etc.). These summaries were only conducted at the species level, so all trade with only genus-or-higher information was excluded. Breakdowns of threatened species, as well as focused analysis of Extinct in the Wild (EW) and Critically Endangered (CR) species was also examined separately.

Understanding the use of CITES Appendix III

CITES Appendix III is sometimes advocated as a solution to the trade in endemic species (e.g., [76]), especially during intersessional periods. Therefore, we decided to explore the use of Appendix III, if there were species following Appendix III listing that were still only recorded within LEMIS but not CITES, if origins were provided accurately (i.e., if there were discrepancies between LEMIS and CITES or if "XX" or a code was given), and if these species were reported as exported from the wild in countries to which they were not native, especially if these species were endemic to the country listing them. To do this, we downloaded the Appendix III list from CITES, added the dates of listing from Species+ (https://speciesplus.net/), then compared the trade patterns post-Appendix III listing in LEMIS and CITES. This analysis was conducted only for terrestrial vertebrates.

QUANTIFICATION AND STATISTICAL ANALYSIS

Mapping patterns of trade

The origins of species in trade, if they were resident to countries of origin, and the quantities were assessed as listed above (see Methods S1), the relationship between CITES listing and overall levels of wild trade are detailed in Figure S9 and noted in Table S1.

The relationship between trade in all species versus those listed in CITES

There are many motivations for listing a species to CITES, but often it is an attempt to enable sustainable trade for a species that is in commercial demand where trade poses a major risk to species survival. However, for species which are viewed as less commercially valuable, are not charismatic, or are native to countries which profit less from the wildlife trade, it is possible there is little incentive for CITES listing. Therefore, comparing actual trade (to the US) with the engagement with CITES provides a means of assessing which taxa are frequently traded yet are overlooked by international wildlife trade regulations, which could be used to identify species for further review (i.e. conducting an NDF) to determine the sustainability of trade. We assessed the number of species recorded in LEMIS for each taxonomic group for each country to the number of species listed in CITES within each taxonomic group for each country to assess if there was a strong and proportional relationship, and how this varied between taxa. The number of species listed within CITES for each region was explicitly based on CITES data on their distributions (https://checklist.cites.org/#/en) to determine a count that was fully consistent with CITES data and compared at a national level to the level of trade within LEMIS based on the methods noted above. The relationships were analysed using simple linear regression.