Check for updates

ECOLOGY

The true scale of global wildlife trade is obscured by data gaps

Alice C. Hughes[1]*, Benjamin Michael Marshall[1,2]*, Daniel W. S. Challender[3], David P. Edwards[4], Evan A. Eskew[5], Julie L. Lockwood[6], Oscar Morton[7], Kelly Malsch[8], Caroline Fukushima[9,10], Amy Hinsley[11], Vincent Nijman[12,13], Shai Meiri[1], Sharon Baruch-Mordo[14], Michael F. Tlusty[15,16], Rodrigo Oyanedel[17,18], Jacqueline Jürgens[19], Samuel Pironon[20,21], Alyson T. Pavitt[8], Nazli Demirel[22], Molly R. C. Brown[23], Oliver J. S. Tallowin[23], Kim Friedman[24,25], Rishi Sharma[26], Neil D. Burgess[8,26]

Copyright © 2026 The Authors, some rights reserved; exclusive licensee American Association for the Advancement of Science. No claim to original U.S. Government Works. Distributed under a Creative Commons Attribution NonCommercial License 4.0 (CC BY-NC).

Overexploitation of wildlife is one of the greatest global drivers of biodiversity loss. Yet, despite this well-established risk, data on extraction and trade are both incomplete and highly fragmented. The IPBES Global analysis estimated 50,000 species to be in trade, yet our review of wildlife trade monitoring programs found at least double that, at 107,356 species in use and trade globally. This included up to 47,685 animal species, covering 42% of all described vertebrate species. Most countries lack any systematic data on trade for species not listed in Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), with the exception of the US-specific dataset Law Enforcement Management Information System, which frequently had higher diversity of species in trade than global databases. This highlights the importance of national monitoring efforts and the need for standardized collation of wildlife trade data beyond CITES-listed species. Without these changes, global indicators on trade meant to guide sustainability and conservation will continue to focus on less than 2% of traded species.

INTRODUCTION

Unsustainable collection of wildlife for trade is one of the greatest threats to species survival around the globe (*1*, *2*). The sustainable use of biodiversity is important to human livelihoods and is a pillar of the Convention on Biological Diversity (CBD). Assessing sustainability of trade relies on data covering which species are in trade and in what form, from where they originate, in what quantities, how they are sourced (e.g., wild versus captive bred/propagated), and, if from the wild, the status of the populations, and the impact of collection on these populations. For species for which population-level data exist, traded populations suffer on average 50 to 60% loss in abundance relative to untraded populations (*3*, *4*). This encompasses a range of trends, from local extirpation to population increases in traded species populations [e.g., (*5*)], yet the lack of systematic data collection means that population changes may not be detected, undermining the ability to implement effective interventions to manage and conserve species. Such interventions are required, given that wildlife trade is estimated to have contributed, directly or indirectly, to the global extinction of 294 species, the extinction in the wild of 25 species, and 192 local extinctions (*6*). Yet, for most species, the data required to assess the impact of trade does not exist, precluding accurate assessments of extinction risk (*6*).

While management interventions designed to regulate and control trade often focus on illegal trade, most detected or observed trade (an estimated 99.99%) is legal (based on cross-taxa data for the United States, as well as global assessments for reptiles, amphibians, and arachnids, though unseized illegal trade remains challenging to estimate). Legal trade is estimated to be worth around US$ 220 to 300 billion annually (*7*–*9*), approximately 5.6 to 10.6 times larger in value than the illegal wildlife trade, estimated at US$ 28.4 to 39.5 billion annually (*10*). Assessing the availability and representativeness of data on wildlife trade is crucial if the continued loss of species and the loss of the key ecosystem services they provide are to be halted (*11*). However, understanding the availability of data on trade, especially across the spectrum of uses, from timber and fisheries to fashion and ornamental uses, remains limited. Furthermore, although the volumes of legal trade far outstrip illegal trade for most taxa, assessing the sustainability of legal trade remains challenging because data are lacking

[1]School of BioSciences, University of Melbourne, Royal Parade, Melbourne, Victoria, Australia. [2]School of Biodiversity, One Health and Veterinary Medicine, University of Glasgow, Glasgow, UK. [3]Interdisciplinary Centre for Conservation Science (ICCS) and Oxford Martin Programme on Wildlife Trade, Department of Biology and Oxford Martin School, University of Oxford, Oxford, UK. [4]Department of Plant Sciences, Centre for Global Wood Security, and Conservation Research Institute, University of Cambridge, Cambridge, UK. [5]Institute for Interdisciplinary Data Sciences, University of Idaho, Moscow, ID, USA. [6]Rutgers Climate and Energy Institute and Department of Ecology, Evolution, and Natural Resources, Rutgers University, New Brunswick, NJ, USA. [7]School of Biosciences, University of Sheffield, Sheffield, UK. [8]United Nations Environment Programme World Conservation Monitoring Centre (UNEP-WCMC), Cambridge, UK. [9]The Biodiversity and Sustainability Solutions (BISONS) Lab, Department of Biodiversity Sciences, University of Turku, Turku 20014, Finland. [10]Centre for Ecology, Evolution and Environmental Changes (cE3c), Laboratory for Integrative Biodiversity Research (LIBRe), CHANGE - Global Change and Sustainability Institute, Faculdade de Ciências, Universidade de Lisboa, Lisboa 1749-016, Portugal. [11]Interdisciplinary Centre for Conservation Science, Wildlife Conservation Research Unit, Oxford Martin Programme on Wildlife Trade, Department of Biology, University of Oxford, Oxford, UK. [12]Oxford Wildlife Trade Research Group, Oxford Brookes University, Oxford, UK. [13]EcoVerde Global Consulting, Oxford, UK. [14]TRAFFIC International, Cambridge, UK. [15]School for the Environment, University of Massachusetts Boston, Boston, MA, USA. [16]Global Ocean Conservation Program, Monterey Bay Aquarium, Monterey, CA, USA. [17]MAR FUTURA, Navidad, Chile. [18]Instituto Milenio en Socio-Ecología Costera (SECOS), Santiago, Chile. [19]German Federal Agency For Nature Conservation, Bonn, Germany. [20]School of Biological and Behavioural Sciences, Queen Mary University of London, London, UK. [21]Royal Botanic Gardens, Kew, Richmond, UK. [22]Institute of Marine Sciences and Management, Istanbul University, Istanbul, Turkiye. [23]International Union for Conservation of Nature (IUCN), Cambridge, UK. [24]Fisheries and Aquaculture Division (NFI), Assessment & Management Team (NFIFM), Food and Agriculture Organization of the United Nations (FAO), Rome, Italy. [25]The University of Western Australia Oceans Institute, Crawley, Western Australia, Australia. [26]Centre for Macroecology, Evolution and Climate (CMEC), University of Copenhagen, Copenhagen, Denmark.
*Corresponding author. Email: Alice.c.hughes@unimelb.edu.au (A.C.H.); benjaminmichaelmarshall@gmail.com (B.M.M.)

Downloaded from https://www.science.org on October 30, 2026

for many species and systems (*12*). The CBD recognizes the importance of "sustainable use," with the "Kunming-Montreal Global Biodiversity Framework" (KM-GBF) including two targets on the use and trade of wild species, namely, target 5 (impacts of trade on biodiversity) and target 9 (benefits from trade) [CBD/COP/DEC/15/5, Annex I; (*13*)]. However, the only headline indicator for target 5, "Proportion of fish stocks within biologically sustainable levels," focuses on the sustainability of harvest of marine fish stocks and thus fails to reflect trade for other taxa and ecosystems. Furthermore, while well-managed, sustainable use and trade can deliver critical benefits for people and species, including funding and motivating conservation efforts, diversifying income and increasing food security (*14*, *15*), and incentivizing long-term stewardship for wild populations (*16*), a failure to assess impacts can inevitably threaten species. Reaching these sustainable goals requires recognizing, assessing, and monitoring the full extent of the wildlife trade.

Assessing the most basic dimensions of global wildlife trade has remained a persistent issue. The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) notes that approximately 50,000 species are in international trade (*1*), yet other analyses have demonstrated that a lack of systematic monitoring means that the actual number of species is far higher, potentially by tens of thousands of species (*17*). Crucially, no comprehensive global system exists to monitor all international wildlife trade. Existing global-scale databases focus on subsets of taxa based on provisions in Multilateral Environment Agreements (MEAs). For example, the United Nations (UN) Food and Agriculture Organization (FAO) monitors fisheries and fishing data, with a principal focus on commercially valuable fish for food, fish oil, fishmeal, and stocks that are important for small-scale fisheries and local communities (*18*). The FAO [and the International Tropical Timber Organization (ITTO)] also measures timber production, though may fail to record key details on species or sourcing (*19*). The Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) primarily monitors and regulates the legal international trade in at-risk species listed under the Convention (a binding treaty established in 1975) to ensure that it does not threaten survival of these species (*20*). Similarly, the Convention on Migratory Species (CMS) has binding provisions for prohibiting the collection of CMS Appendix I species (strictest control of trade), but data on the use and trade of CMS-listed species are not systematically tracked unless species are also CITES-listed (and then monitoring only covers international trade) (*21*). While all trade data feeding into these programs are ultimately generated via national reporting systems, outside these targeted MEAs, there is no dedicated program to compile global data to help monitor the wider trade in wildlife.

These existing global data sources paint a fragmented and incomplete picture of the full scope of species present in trade. For example, CITES covers around 9.5% of reptile species, compared with more than 45% in international trade [4047 species; (*22*, *23*)]. Similarly, the number of butterfly species in trade (*24*) exceeds the IPBES estimate for all traded terrestrial invertebrate species (*1*, *17*). Reactive interventions, such as listing species in the CITES Appendices, frequently rely on scant trade and trade impact data [because data are often not available before listing, see (*25*)], thus risking waiting until species are already trade threatened to apply measures to reduce the threat and facilitate recovery (*26*, *27*). Despite the recognized threat posed by extraction for trade to thousands of species (*26*) and some assessment through global initiatives (e.g., CITES), there has been little assessment of the coverage of regional and national trade databases.

One exception to the dearth of high-quality, representative wildlife trade data is LEMIS (Law Enforcement Management Information System), the US Fish and Wildlife Service database of wildlife traded internationally into and out of the United States, which collates records for nondomesticated wild animals and is periodically made publicly available. Conversely, the US Department of Agriculture (USDA) covers imported plant materials, and they are rarely recorded in LEMIS. The United States implemented LEMIS to help ensure adequate availability of customs officers at appropriate ports (*28*). Unfortunately, comparable data for other countries remains unavailable. LEMIS alone showed that, since 2000, more than 21,000 wild animal species were traded into the United States (*29*). This estimate is incomplete [particularly for invertebrates (*30*) and fish (*31*)], but it highlights both the scale and diversity of wildlife trade going into a single, albeit large and economically important, country. LEMIS data have allowed wildlife trade into the United States to be fairly well described (*23*, *29*, *32*–*34*), but equivalent efforts for other parts of the world are limited by a lack of data. Further, while the LEMIS data give key insights into the US wildlife market, the quality and reliability of the data have frequently been questioned (*28*, *35*). Thus, although work on the LEMIS dataset highlights the scale and diversity of trade, it also underscores the need to assess the availability and quality of equivalent for other regions to understand what is currently being monitored in national and global wildlife trade markets. Such information can enable sustainable management of trade, as well as the allocation of resources (i.e., training of customs officers, etc.) to where they are most needed.

Previous analyses have examined the trade of various taxa globally (*22*, *30*) or national cross-taxa trade (*23*), but no assessment exists of the systems in place for monitoring the trade of all wildlife at a global scale, nor of their accessibility and coverage. Here, we first assess the systems responsible for monitoring legal and illegal wildlife trade at various scales by compiling a comprehensive list of national authorities, their remits, and the systems in place, and examining the consistency of the number of species recorded in trade across taxa. Second, based on these assessments, we identify key wildlife trade data coverage gaps and evaluate the interoperability of the information collected within these systems. Furthermore, we discuss the types of error and sources of uncertainty within trade data. Considering these analyses, we highlight ways to markedly improve our knowledge of and ability to sustainably manage international, as well as national and local, wildlife trade.

RESULTS

We report on wildlife trade monitoring, including plants, fungi, and animals, at global, regional, and national levels. However, wildlife trade data are generally assembled through national reporting programs that feed into international programs and structures for trade monitoring, while our focus is predominantly on international wildlife trade. Operations to detect and report illegal trade can also include international programs and structures. We first explore the scope of systems monitoring the global legal wildlife trade (such as the CITES Trade Database) and the global commodity trade in timber and fish (through global agencies with a mandate for resource management, such as the FAO), and then we review systems monitoring illegal trade. Last, we assess the landscape of regional and national trade monitoring initiatives.

Downloaded from https://www.science.org on October 30, 2026

Global databases and coverage

Overall scope and coverage of global databases

The most basic system of global trade monitoring is through the harmonized standard of custom codes [harmonized system commodity codes (HS codes/comcodes) in the United Nations Comtrade Database], as well as systems such as the Global Trade Analysis Project. Though HS codes give the product type or physical form being traded (e.g., pieces of reptile leather), they are generally not species specific and thus can normally only be used to quantify broad dimensions of different wildlife-based commodities (*36*, *37*). However, there are instances in which these databases have sufficient resolution to track trade [e.g., European eel, *Anguilla anguilla*; (*38*)]. In addition, in some cases, HS codes can be cross-referenced with LEMIS or CITES data to allow for species-level analysis [e.g., long-tailed macaques, *Macaca fascicularis*; (*39*)], or assumptions made based on species ranges and country of export [e.g., *Anguilla* species; CITES (*40*)—section 6.2], but increasing taxonomic resolution would vastly enhance the ability to use comcodes to understand trade for considerably more species (*41*).

CITES remains the main source of detailed, species-level information on global-scale international wildlife trade (*34*), despite only covering a subset of species in trade. At present (August 2026), approximately 40,980 species are included in CITES Appendices (I, II, and III), of which 6634 (16.2%) are animal species and 34,310 species (83.8%) are plants, with orchids making up more than 70% of the total number of CITES-listed species (Table 1). Approximately 76% of CITES Appendix–listed species appear to be traded, ranging from 42% for plants to 100% for arachnids, with 78% of listed animals overall. Within CITES, international trade in CITES-listed species is reported by Parties in their annual trade reports. These legal trade data are collated and made publicly available via the CITES Trade Database (https://trade.cites.org/; https://tradeview.cites.org/). There are currently (August 2026) more than 29 million records of international legal trade in CITES-listed species dating back to 1975. This database provides details on the species, countries of import and export, and source of the specimen, among other information.

CITES data remain prone to reporting errors and time lags (*42*, *43*); many records still rely on "paper permits" and manual compilation of annual trade reports by CITES authorities (*44*, *45*), with limited standardization or exchange across digital systems, where implemented (e.g., eCITES) (*45*–*47*). The reliance on paper documentation for most legal trade permits within CITES makes it harder to cross-reference records and identify errors and discrepancies (*48*). eCITES is the digital replacement for CITES paper permits, reducing the potential for error, facilitating cross-referencing, and reducing current lags in information submission (which make the detection of discrepancies too slow to enable management interventions) (https://cites.org/eng/prog/eCITES). Electronic permitting (eCITES) may overcome some of the challenges outlined here (*46*); however, there continue to be capacity limitations, and to date, it has been implemented in around only 30 of the 184 countries that have ratified CITES.

For timber and fish, the FAO plays a major role in monitoring global trade, though with a principle focus on food rather than aquaria fish (*49*). Given the importance of fish to humans, the FAO has collected decades of trade data (*19*, *50*) and reports on the proportion of commercially exploited fish stocks that are biologically sustainable (*51*). Fisheries management frameworks are designed to trigger corrective actions before stocks reach sustainability thresholds, with target reference points well above critical sustainability "limit reference points" (B_{LIM}). Despite this, several major fisheries-status syntheses show that some fish stocks have fallen below biological limit reference points—<5% of FAO's recent global assessment are assessed to be below the B_{LIM} (*18*). Global conservation targets related to the wildlife trade under the CBD KM-GBF currently focus on the sustainability of harvested fish species. However, well-known deficiencies in the taxonomic resolution of data (i.e., recording shipments above species level) hinder assessment of volumes and impact of trade at the species level (*52*–*54*). This includes the information recorded

Table 1. Number of species recorded in trade in various databases (note that some taxonomic groupings overlap). "Total all" is the count of unique species detected in any of the data sources, regardless of purpose, quantity, or form. "Total conservative" is the count of unique species that appear in data sources that cannot easily be assigned as non-commercial. These sources include CITES Trade, LEMIS (with scientific purposes removed), TRAFFIC, and Research. CITES and IUCN data come from the respective websites (downloaded October 2025), though it should be noted that many species on CITES Appendices have a zero quota and these specimens cannot be legally traded internationally for commercial purposes (thus, CITES separately lists species within Appendices and those in trade). Numbers for CITES are dominated by orchids for plants (many not in trade) and stony corals for marine invertebrates. For example, breaking down plants, CITES lists 30,051 monocotyledons, of which 11,048 are recorded in trade in CITES, yet only lists 3404 dicotyledons (2732 in use) but 13,747 species are listed as traded in total, with the majority outside CITES. FAO only includes data for fish, with 1963 species listed in the ASFIS dataset. LEMIS data come from Marshall *et al.* (*23*) (plants fall under USDA rather than LEMIS, hence the low number of species). Many of these species are only listed "for scientific use"; however, determining what that entails, if it is biomedical research or in high volumes, is challenging, and the lack of detailed information highlights the challenge of interpretation.

Taxa	Total all	Total conservative	CITES Trade	CITES App	LEMIS	LEMIS (no scientific purposes)	IUCN	TRAFFIC	Research
Amphibia	2007	1261	166	376	1413	606	859	38	1203
Arachnida	1607	1607	37	41	818	628	36	65	1607
Aves	7691	5595	1582	1520	5173	2531	4793	966	5227
Fish	13,973	4348	163	257	3031	1602	11,580	215	2050
Invertebrates	10,618	7502	102	159	4163	2860	2161	158	5746
Lepidoptera	4154	3893	52	50	1208	914	142	26	3556
Mammalia	2749	1481	821	900	2010	1054	1513	581	NA
Plants	59,671	49,723	13,747	33,233	295	228	18,921	697	37,212
Reptilia	4886	4144	888	1160	3047	2063	1666	472	3931

Downloaded from https://www.science.org on October 30, 2026

on both capture production and trade data held by FAO [e.g., (*19*), see text S2 for further information on FAO and related global capture production and trade databases].

The ITTO (*55*) monitors international timber trade and is principally managed to ensure the sustainability of supply chains (with the exception of CITES-listed taxa). For timber, most initiatives focus on certification and tracking to enhance sustainability but may provide little data on exactly which taxa are being traded (*55*), with newer tools aiming to help identify and track illegal trade [e.g., TimberStats, which helps detect illegal timber trade (*56*)]. For timber, the current lack of species-level trade data is increasingly driving independent assessment (World Forest ID) of the Global Priority Wood Species List (*57*).

For illegal trade, at a global level, TRAFFIC and CITES play leading roles, though CITES data are kept confidential in the CITES Illegal Trade Database (https://citesdata.un.org/) (*58*). However, within illegal trade seizure data collection, species-level information is often not recorded (especially for smaller-bodied groups such as invertebrates, fish, etc.), and data based on customs codes can amalgamate the data for many taxa. For example, the EU recorded the seizure of 574 CITES-listed species in 2023, but 45% of entries (of 53,363) did not include species-specific information (*59*). Conversely, dedicated programs systematically collect illegal trade data for specific taxa, e.g., ETIS (Elephant Trade Information System) and MIKE (Monitoring the Illegal Killing of Elephants) for elephants (*60*, *61*). More informal efforts to monitor illegal trade, such as through NGOs, do exist for some taxonomic groups (*62*). Targeted efforts also monitor specific forms of trafficking (i.e., air transit: https://wildlifedashboard.c4ads.org/), though some of these programs are constrained by short-term funding (*63*).

Fragmentation and completeness of wildlife trade data

Global and national databases show different numbers of species in trade for various taxa (Table 1). Overall, we detected 47,685 animal species in trade across these databases. This count includes up to 31,306 vertebrate species, equating to 42% of all currently described vertebrates. An additional 676 animal species were listed in CITES Appendices but not recorded in trade, indicating that they are not legally traded internationally. Scientific studies often show that the numbers captured in global trade databases are greatly underestimated, particularly for taxa in which a smaller proportion of internationally traded species are represented in conventions such as CITES [e.g., reptiles, amphibians, and invertebrates; Fig. 1; (*64*)]. LEMIS uniquely records 27.5% of all traded animal species; within taxonomic groups, it covers between 14 and 54% of traded species not found in other data sources (based on databases of recorded trade; Fig. 1). Invertebrates had the lowest coverage in LEMIS, as until recently, LEMIS has often overlooked their trade [Fig. 2; (*30*)].

Different collations of data can provide very different estimates of the number of species in trade (Table 1 and Fig. 2). Here, we note recorded trade in species based on databases that document direct evidence of legal trade (e.g., LEMIS, CITES, etc.) and illegal trade (TRAFFIC incidents and seizure data), then compare it to a potential estimate where trade and use are listed within International Union for Conservation of Nature (IUCN) Red List assessments. Following cleaning and standardization of names, the highest number of species estimated to be in trade for a single group was for invertebrates (8695 species, 33% only in LEMIS), which increases to 10,618 when data from IUCN Red List assessments are added. The next most traded group (by number of species) was birds (7202 species, approximately 65% of all described extant bird species), yet 25% of these species were only recorded in LEMIS (and 72% of all traded species appear in LEMIS). Thus, given the lack of comparably comprehensive data for other regions of the world, many more bird species may be in trade than we estimate (CITES 2024). Including IUCN Red List data increases the count of bird species in trade to 7691 species. This disparity is similar for fish where 5454 species are in trade, representing 15% of described species, of which 40% are only recorded in LEMIS, while LEMIS includes 55% of all traded fish species (though most of these are not accounted for with their LEMIS harmonized codes). Traded fish species reach up to 13,973 species when IUCN Red List data are included. Reptiles had the next highest count of species in trade at 4620, which represents 37% of all described species, yet 14% were only recorded in LEMIS (and 66% recorded in LEMIS overall). The number of traded reptile species also increases when IUCN Red List data are added, reaching 4886 species. For mammals, 2266 species were recorded in trade (33% of described species, 54% only in LEMIS, and 89% in LEMIS in total), which increased to 2749 species when IUCN Red List data were included. A total of 4122 butterfly species were in trade (14% only in LEMIS, 29% LEMIS overall, and 4154 when IUCN is included) as well as 1607 arachnid species (no species were only listed in LEMIS, but 51% were in LEMIS overall). For amphibians, 1793 species were in trade, with 32% only in LEMIS (79% overall in LEMIS) representing 20% of all described species. This increases further to 2007 species when IUCN Red List data are added.

For most taxa, the US LEMIS dataset included a high percentage of species in trade, despite only representing trade with a single country, highlighting how incomplete our overall knowledge is given the lack of comparable data for other countries. It should also be noted that a considerable number of species may be traded for "scientific" purposes (Table 1 and table S2). This may include samples collected by scientists, animals collected for breeding programs, and animals (such as macaques and various amphibians) traded for biomedical purposes. Given the lack of comparable data for non-CITES species outside the United States, confirming other uses (such as pet trade) in these species remains challenging.

Variation among reported figures for species in trade (Table 1) highlights the fragmentation of existing datasets (Fig. 2), especially the lack of comprehensive global monitoring and the resulting inability to accurately estimate the true number of species in trade. More broadly, while relatively structured systems exist to document trade for subsets of vertebrates and some plant groups, coverage across taxa remains highly uneven. Assessing plant trade is especially challenging, as international recording systems are even less comprehensive than those for animals, and the inclusion of hybrids, cultivars, and varieties further complicates accurate species-level accounting.

Our estimates indicate that at least 49,723 plant species are documented as traded, with previous research indicating the majority of recorded uses related to medicinal applications (26,842 species), followed by uses for materials (13,418 species) (*65*–*67*). Nevertheless, documentation of plant use remains highly incomplete and uneven across regions and use categories, with many uses never formally catalogued (*68*). Combining IUCN, CITES, and TRAFFIC data with data on used plants places the total number of species still higher, reaching 59,671 plant and fungi species in use and trade. Notably, whereas, for animals, we explicitly collate data on trade, much of the data on plants rely on previous papers documenting use because the recording of plant trade is generally weaker and less systematic than

Downloaded from https://www.science.org on October 30, 2026

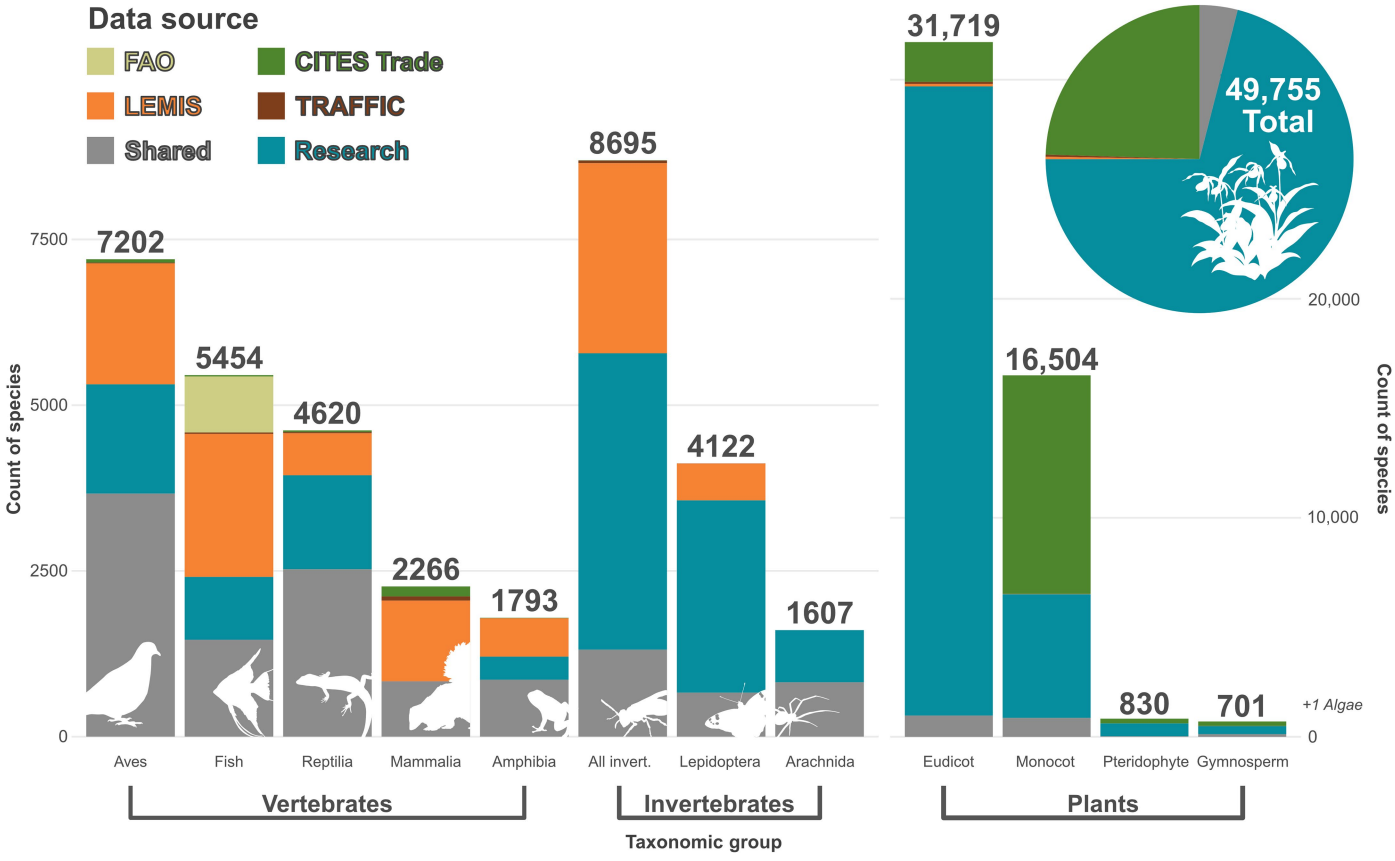


Fig. 1. Number of species in trade for each animal taxa. Summary follows data and name standardization limited to data sources that can be considered confirmed trade. Where species are only listed in a single repository, these are shown, whereas any species listed in trade in at least two separate repositories is listed as "shared." Interactions and coverage within each database as well as species-level CITES Appendices coverage is shown in Fig. 2. "All invertebrates" includes all invertebrate species (including the arachnids, lepidopterans subgroups displayed alongside, as well as other terrestrial and marine invertebrates). Plants are shown separately due to the large numbers in trade (note differing *y* axis). For plants, "research" includes the useful plant dataset and, thus, may reflect local uses, but given the frequent omission of systematized recording of international plant trade for non-CITES species, collating a representative list of species in trade remains challenging. LEMIS recorded species included here covers all purposes and forms.

animal trade. Accurately assessing plant trade for non-CITES species remains almost impossible at present. Furthermore, use and trade of wildlife encompasses a wide spectrum of activities, ranging from subsistence and local construction to commercial exploitation, and therefore does not map directly onto species recorded within dedicated trade databases, which primarily capture formal and often international trade. Species recorded in trade are almost invariably used, and a substantial, though unknown, fraction of used species are likely to enter trade at local, regional, or global scales. As a result, information on plant use provides an important upper bound for estimating the true scale of plant trade. If all documented plant species (and 260 fungal species, according to the IUCN Red List) in use were assumed to be traded, this would imply that more than 107,356 nondomesticated species are in use or trade, and of these, at least 79,554 are likely traded commercially internationally (Table 1).

Only 28% of plant species documented as being used by humans are currently listed under CITES. Among angiosperms, the majority of used species are not listed within the CITES Appendices: 92% of used eudicots and 33% of used monocots fall outside CITES. The comparatively higher representation of monocots reflects the precautionary, family-level listing of orchids, which includes species listed under the look-alike criterion to aid customs and enforcement, as well as species that would likely be threatened by wild-sourced trade if it were to occur. In contrast, CITES coverage is substantially higher for gymnosperms, with 43% of used species being included. These patterns highlight a fundamental mismatch between species in use and the availability of trade data: Some plant species listed under CITES show little or no evidence of use (with many listed as look-alike species), though limited alternative mechanisms for monitoring international trade means that most species in demonstrable use are not formally monitored (Table 1 and Fig. 2). This illustrates one of the major challenges in trying to draw general conclusions from datasets gathered for more specific purposes (e.g., CITES is intended to regulate trade in species that are or may be threatened by international trade; it is not intended as a mechanism to monitor all trade in all species), and little or no data may be available for monitoring at local and national scales. These discrepancies in protection versus use highlight the complexities of trade, especially in assessing what is sustainable, given the different scales and volumes of use.

Regional databases and coverage

The import of wildlife is normally regulated nationally, but, in some instances, may be monitored and regulated for trade blocs. For example, the European Union monitors the trade in animals, animal

Downloaded from https://www.science.org on October 30, 2026

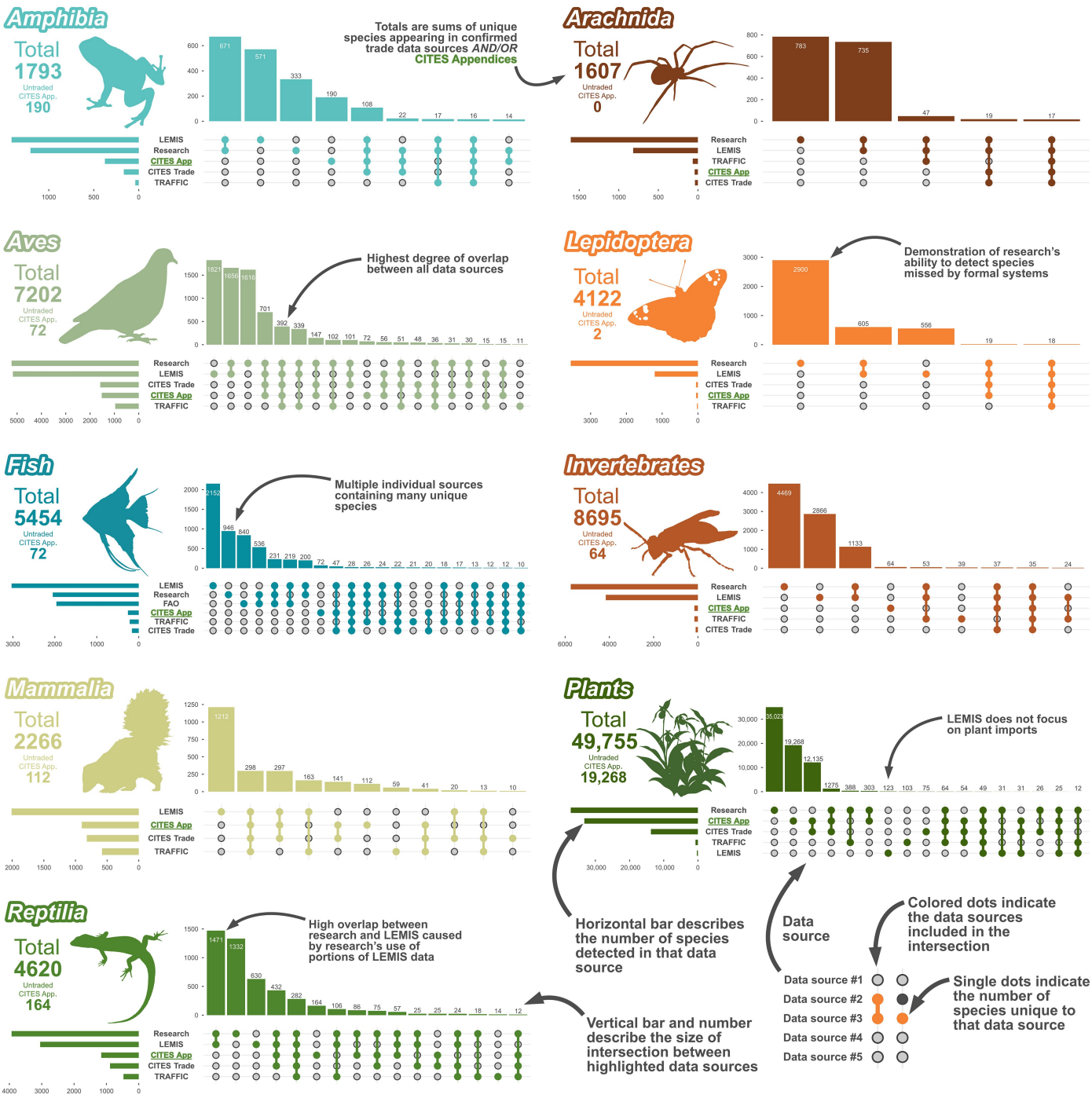


Fig. 2. UpSet plots displaying the overlap between the different sources of trade data. Trade sources are limited to those considered confirmed trade, with counts of untraded CITES Appendices species listed in "CITES App." Overlap is calculated using species-level listings after translation of reported species names to the same standard. The top panels show the size of the intersection between sources, while the below matrix shows which data sources are included in a given comparison. Intersections of less than 10 are not displayed (thus, totals may exceed the sum of shown bars). The left panel shows the total species count after the species conforming process. The Research source is a composite of multiple data sources and is not mutually exclusive with some other data sources (e.g., some research sources included pre-2014 LEMIS data in their species lists). The Invertebrate panel includes all the species listed in Arachnida and Lepidoptera; for the purposes of subsetting the multiple-group data, Invertebrates also includes all classes included in the Lassaline *et al.* (*210*) data.

Downloaded from https://www.science.org on October 30, 2026

products, food and feed of non-animal origin, and plants via the EU-TRACES platform. This was principally developed from a biosafety perspective, and while species are recorded within "CHED-A" (Common Health Entry Document; live animals are recorded in CHED-A, whereas animal products are recorded in CHED-P) within TRACES, these data are not publicly available and have rarely been included in scientific publications [i.e., 1452 fish species, (*69*)]. Species may frequently be listed at higher taxonomic levels or entire shipments may be listed under the first species within a shipment, and, for species imported in water or ice, any weight measure is likely to include the shipment media (i.e., water/ice), making gauging the number of individuals in trade difficult or impossible (*29*, *70*). Regional monitoring also occurs within some fisheries. For example, in North America, food fisheries are monitored by NOAA, whereas USFWS more often covers species traded for ornamental uses (via LEMIS), with systems of recording, the use of harmonized codes, and regulations more broadly, under periodic review [i.e., (*71*)].

At regional levels, various legislative infrastructures also exist. For example, the EU has EUTR and EUDR to monitor timber supply chains (*72*), as well as FLEGT [Forest Law Enforcement, Governance and Trade; (*73*, *74*)], which applies stricter domestic measures for the import of CITES-listed species including timber (*75*). Other platforms and organizations providing regulation and monitoring of timber trade include the US Lacey Act (*76*), the Global Timber Index Platform (https://itto.int/gti/), and the Global Green Supply Chains Secretariat (https://itto-ggsc.org/). Systems to trace trade [e.g., TRASE and Starling verification; https://trase.earth/, (*77*)] have been developed to support new legislation (such as zero-deforestation supply chains under EUDR), supported by mechanisms to verify and certify timber production ["Forestry certification standards"—FSC and Programme for the Endorsement of Forest Certification—PEFC; (*78*), https://pefc.org/].

Many regional systems have been developed to collate seizure information for illegal trade at regional levels often with local government support (e.g., TRAFFIC TWIX networks; see text S1). These programs now have almost global coverage (*63*). Patchy efforts have been made to collate data on wild meat use [www.wildmeat.org/database/; (*79*)] and assess regulatory approaches to wild meat (*80*). Regulatory systems seem largely to have been a focus between 2015 and 2020, and efforts to assess the use of wild meat have largely been restricted to Africa. Changes in policy are evident elsewhere [e.g., China, (*81*)], but these are reflected in national regulations, with little data collated on the use of various taxa. Likewise, work on medicinal plants has focused on tracking the trade of various plant commodities and the growth of the traditional medicine industry [e.g., (*82*)], generally under Comtrade harmonized codes (comcodes) (*83*–*87*), and rarely includes either species or geographic information. Some programs, such as FairWild standards and WildCheck (*88*, *89*), counteract these overarching trends, but they focus on a smaller subset of species and regions.

National databases and coverage

Results from our three different national databases identification approaches were cross-referenced to determine overall patterns of national trade monitoring. This included 155 responses to the questionnaire, spanning 61 countries and several UN bodies. In terms of comprehensiveness at the national level (fig. S1), LEMIS is among the most complete and representative trade databases globally. LEMIS includes data on the trade of animal species imported to the United States, including both species names and a series of harmonized codes, although these codes often lump together various taxa, such as whole groups of insects or fish [see (*35*)]. Further, inconsistencies can exist in recording geographic information in LEMIS. For example, many shipments may list "XX" (unknown) as the origin country, making assessments of sustainability or even the enforcement of CITES Appendix III very challenging (*29*). Its limitations notwithstanding, in our review of databases, the LEMIS system was the only comprehensive and accessible compilation of trade data across taxa from any country (see data S5). Many countries had permitting systems for the import and export of wildlife and some collated seizure information, but almost none had comprehensive data on the trade of species.

Some countries also have permitting regulations for the numbers of individuals of certain species that can be harvested, which may include geographic, seasonal, and other restrictions. Many of these are higher-income economies (e.g., United States and Canada); however, take-related restrictions for CITES-listed species are in place in various African countries, particularly for species traded for purposes such as trophy hunting. It is important to note that many of these species may be subject to annual national harvest quotas, and information on how permits are allocated is less accessible. Other countries, such as Peru and Suriname, also have domestic harvest quotas for various species, as do some other countries at subnational or national levels (which may be managed by CITES management authorities). Indonesia is the only country for which this system extends across all taxa, including an annual "quota" for the harvest and trade for hundreds of species to be traded (including non-CITES species) and includes subdivisions for harvest, but this is once again tied to a system of "permits" rather than actively recording what is traded and harvested. Notably, most systems provide either no information on the databasing of records for legal trade (many countries only collate data for CITES and on illegal trade), or only information on how permits can be applied for, either for international trade or the collection of wildlife within a country. For countries that are party to the CMS, Parties are also required to prohibit the "take" (harvest, use, and trade) of species that are listed in Appendix I of CMS. However, without national, regional, and global tracking systems for tracking harvest and trade in non-CITES species, it is challenging to monitor this for non-CITES species. This lack of standardization and data compilation for non-CITES species represents a major global knowledge gap, as this lack of data precludes the assessment of vulnerability to unsustainable trade and the effective management of vulnerable species.

DISCUSSION

Assessing the adequacy of data on wildlife trade

The IPBES Sustainable Use of Wild Species assessment (*1*) estimated that around 50,000 species were in trade (though it provided little information on species identities). Here, we document 79,554 species confirmed to be in international trade potentially for commercial uses, substantially exceeding the IPBES estimate, and identify evidence that this may still be a considerable underestimate, with up to 107,356 species potentially in use or trade. The 59,671 plant and fungi species identified through the broader "used plants" analysis include species used for subsistence and other noncommercial purposes and therefore cannot be directly interpreted as species in trade. For animals, we identify up to 47,685 species in international trade,

Downloaded from https://www.science.org on October 30, 2026

of which at least 16,829 are confirmed to be traded for commercial uses. These findings highlight major gaps in our knowledge of the scale and composition of global wildlife trade, particularly for plants.

Currently, no "global" database provides an accurate reflection of the overall trade in most taxa, except commercially traded food fish and timber (although these often rely on HS codes that can mask species-specific information). For all other taxa and purposes, global databases fail to accurately reflect trade. Generally, the collation of data, and efforts to quantify trade, have either focused on species traded in large volumes (such as fish and timber), those of high commercial value, those with recognized vulnerability to international trade (i.e., CITES data), and those subject to illegal trade and seizure. In recent years, innovations and new databases, particularly at the regional level, have focused on aggregating data on seizures and court procedures (*90*). Thus, the ability to detect and seize illegally traded wildlife has improved, yet it remains challenging due to the covert nature of the trade and the increasingly complex methods used by smugglers, which includes the use of sophisticated online networks. In addition to new programs (e.g., regional TWIX programs, Aleris, and ASEAN-WEN), new tools to detect and curb illegal trade have been launched [e.g., ForCyt: (*91*, *92*); C4ADS and ROUTES: (*93*)]. Likewise, a transition from paper to the electronic eCITES permits may reduce laundering and improve the accuracy of trade records (*94*). Seizure data are a product of illegal trade volumes and enforcement and reporting efforts (e.g., a country with high seizure numbers may not necessarily experience more wildlife trafficking but may simply have strong enforcement and/or good reporting). Simultaneously, wildlife seizures are just the tip of the iceberg with large parts of the illegal trade remaining unknown (*95*–*97*). For other taxa and for national-level data, major gaps exist, and while seizure data are useful [i.e., (*32*, *98*–*100*)], they only represent the illegal trade that was uncovered, a potentially highly unrepresentative sample. Successful illegal trade thus cannot be directly monitored (*100*, *101*).

Some recent global wildlife trade assessments [such as the IPBES 2022 assessment; (*1*)] have failed to recognize how the dimensions and drivers of trade have changed in recent years, with the growth of the exotic pet market being particularly notable (*22*, *102*). Yet, taxa traded for pets (such as invertebrates and reptiles), as well as plants, represent some of the greatest discrepancies between our estimates of taxa in trade and those noted in global assessments, such as IPBES (*103*, *104*). Furthermore, these taxa, particularly invertebrates and plants, remain particularly challenging to assess, as not only is the ability to transport these taxa undetected easier (i.e., via postal services and shipping), but species identification is more difficult, and they are more likely not to be recorded at the species level. Reconciling these data gaps is especially important given emerging markets for pets, often driven by social media influence [Middle East (*105*), China (*106*), and Japan (*107*, *108*)] or popularization of new taxa [i.e., freshwater taxa (*109*) and lorises (*110*)], with little consideration given to how to manage these issues (text S2 and table S1). In this context, social media influence extends beyond promotion to include platform features that facilitate and simplify access to wildlife trade, for users (*111*). This underscores the need for equivalent data from other regions, as 36% of all vertebrates in trade with available data were only recorded in LEMIS. Furthermore, countries may have unique trade profiles. For example, the patterns of demand for invertebrates and reptiles in Japan represent taxa for which far less demand has been recorded elsewhere (*22*, *112*, *113*). Likewise, Indonesia is one of the largest exporters of wildlife [with many exploited marine and terrestrial species particularly vulnerable; (*114*)], yet despite annual publication of trade quotas, corresponding data on wild populations remain lacking [(*115*); data S5]. The Asian Songbird Crisis (*116*, *117*), and associated national to regional trade, highlights the need for better data and enforcement actions for songbird species in international trade. More broadly, without collating data from all nations, data will remain incomplete.

Collecting robust, species-level trade data remains difficult and resource intensive, yet such information is essential for understanding trade volumes, characterizing trade dynamics, and assessing risks to vulnerable species. In this context, listings at higher taxonomic levels within the CITES Appendices can provide broader protection, particularly for taxa where reliable species-level identification of commodities in trade is challenging due to morphologically similar ("look-alike") species (*118*). Notably, while permitted under CITES provisions, the inclusion of look-alike species further increases monitoring, reporting, and certification requirements for national authorities. This added burden can be substantial and divert capacity and resources from critical trade issues, especially when widely traded and non-threatened species are added to CITES Appendix II (e.g., the blue shark, *Prionace glauca*). While Article II of the CITES Convention allows for inclusion of species given the potential that they may be affected by trade (*119*), in reality, the required two-thirds majority for voting on listing proposals makes having robust trade data a key part of international negotiations. A lack of sufficient trade data may, in some cases, present a barrier to the timely listing of threatened or newly described species (*22*, *120*).

Furthermore, there are more programs to detect and quantify illegal trade events (especially for vertebrates) than to monitor legal trade, including global, regional, and national initiatives. Most new trade-related programs focus on improving monitoring and control of illegal trade, although exceptions exist for medicinal plants [i.e., FairWild standards and WildCheck: (*88*)]. Although the drivers of these trends are increasingly understood (*121*), a persistent failure to develop standards for the collation and sharing of data on the wildlife trade undermines our ability to manage and protect traded species. Furthermore, these gaps also inhibit our ability to predict and manage invasions (*122*, *123*) and zoonoses (*124*).

Assessing the gaps

Fully gauging the extent of illegal trade is hampered by the combination of mis- and disinformation that result from the paucity of data recorded on purportedly legal trade [i.e., (*23*, *33*)]. In addition, the legality of trade for CITES Appendix III species may be challenging to assess if the origin is not disclosed or if a third (intermediary/transit) country is listed, and discrepancies in such information are common in available trade data (*23*). Likewise, while the Lacey Act means that species traded into the United States should be in alignment with national export regulations at the point of origin (i.e., legally sourced and exported), the use of third countries, failure to disclose trade origin, and/or unclear origins make the detection of laundering impossible in many instances. Assessing legality may be further challenged as, even if the origin is known, knowledge of national laws and regulations may be limited when assessed by border staff overseas as a global database on wildlife trade regulations does not currently exist [though efforts are being made to collate national laws related to wildlife trade globally; e.g., (*125*)]. Records of species coming from the wild from countries where they are not native and

Downloaded from https://www.science.org on October 30, 2026

the recognized use of third countries in the trafficking of wildlife (*29*, *126*, *127*) means that until overarching strategies are applied to collating data on all wildlife trade, assessing what trade is illegal will also remain challenging. Other countries, such as Canada, do have similar legislation to the Lacey Act [e.g., WAPPRIITA, (*128*)], and the EU is discussing the development of comparable legislation (*129*).

For trade of commercial fishes, improvements in the quality of data collected, increased taxonomic resolution [a common issue in all forms of fish trade; see (*35*, *130*)], and the inclusion of all harvested fish and fish commodities are needed to support sustainable management of these species (*131*, *132*). Though improved tracking has helped reduce illegal trade (*71*, *133*, *134*), it remains a challenge in fishery (and timber) sectors, which requires constant innovation to address (*135*–*140*). Even for fish species listed in CITES, illegal trade remains an issue. For example, around 37 million seahorses (*Hippocampus* sp.) annually are traded internationally, with 95% of these coming from countries where commercial international trade in wild-sourced specimens has been banned by CITES (*141*). The difficulty countries experience in implementing CITES provisions often results in species trade bans, a regulatory mechanism that is difficult to enforce, and can result in trade moving to more informal channels (*142*). Likewise, trade in European eels (*A. anguilla*) outside EU borders is largely illegal, but the high value of global trade in eels [US$1 billion annually; (*141*)] means other countries emerge as export states, trade switches across species with similar market requirements, or noncompliant CITES trade increases (*143*–*145*). In both these cases, East Asian countries are the primary source of demand [i.e., China represented 55% of global eel demand in 2023 and accounts for more than half of global seahorse seizures; Atlas of economic complexity; (*146*, *147*)], but effective enforcement remains challenging due to laundering and mislabeling tactics (*148*).

While the globalization of wildlife trade has led to the development of monitoring structures in some specific sectors (e.g., fishing and timber), other facets of wildlife trade (such as the pet trade) are frequently overlooked (*23*). More "traditional" elements of trade are being better monitored [potentially to prevent the loss of traditional resources used by communities; FairWild, WildCheck, and Infoods; (*89*, *149*, *150*)]. However, despite the use of more than 30,000 plant species for medicinal or aromatic purposes (*151*), information on harvest patterns is often lacking. Standards for data collection for these medicinal species are rarely developed from a conservation monitoring perspective and often lack key information (e.g., species names, quantities, harvest localities, and user identities). For some taxa, such as tropical fish and insects, particularly high levels of uncertainty persist, as little effort exists to accurately record traded species through official channels and accurate taxon naming also remains a challenge (*31*). Even for well-established elements of fish trade, such as the aquaria trade, calls for better collation of data are ongoing (*114*, *152*). Lessons from timber and fisheries trade have demonstrated the critical importance of understanding geographic patterns of trade to ensure legality (*153*); harmonized codes reduce the ability to conduct detailed trade analysis in these sectors as codes may refer to groups of species in some taxa (*23*).

The challenge of assessing sustainability

To assess sustainability of trade and harvest, nondetriment findings (NDFs) can be used (and must be used for international trade in CITES Appendix I and Appendix II listed species) and are commonly conducted as part of quota setting within CITES. Although there are no guidelines for standardizing key components or content requirements, aside from nonbinding guidelines for NDFs, and NDFs are not required to be made publicly available unless specifically requested through a CITES process. A positive NDF assessment is intended to confirm that trade will not be, or is not, detrimental to the survival of CITES-listed species in the wild. However, outside of CITES, NDFs or comparable sustainability evaluations may not be calculated even for species considered threatened. Systems to develop appropriate quotas for NDFs (or local permits) are needed for accurate quota setting or other forms of management. Some countries have harvest quota systems for nationally protected species (see the "National databases and coverage" section). NDFs should assess the impact of all harvest and mortality associated with trade (*154*). This includes, for instance, any (negative) effect of the harvest on the remaining population, mortality during harvest and transport, and its effect on domestic trade, yet how this is translated into practice varies markedly depending on mechanisms in place for NDF preparation and trade regulation at the national level. In reality, the focus is often only on the international aspects of trade (*155*, *156*). Additional work is being conducted for some taxa, for example, IUCN's Sustainable Use and Livelihoods working group has assessed the potential sustainability of trade for 347 species in 117 countries (SpUD—Species Use Database: https://speciesusedatabase.com/) (*157*). Similar assessments are still needed for the majority of taxa in trade, as this represents less than 0.3% of the species detected in trade.

Recent efforts to reduce the impacts of unsustainable wildlife trade on biodiversity have been developed for some sectors (such as fisheries) where overharvest, especially for international trade, has economic implications (*158*). These assessments require information on both trade volumes/intensity and wild population sizes, together with monitoring of harvesting impacts on wild populations (*12*, *157*). Within fisheries, systems for tracing and certifying sustainability have been developed [(*134*, *159*) Marine Stewardship Council (MSC) certification], underpinned by complex regulatory structures (*160*). Fish certification bodies (i.e., MSC) have a critical role in enabling sustainable supply chains. However, species are not the focus here, rather commercially relevant fisheries are evaluated and certified. Despite this "mismatch" in taxonomic resolution, 331 fish species have been included in supplier lists (*134*), though this likely only reflects vulnerability to overconsumption and not other forms of trade-related use (i.e., aquaria trade).

Given the importance of fish to humans, the FAO has collected decades of trade data (*19*, *50*). Additional data are available to assess pressures on wild populations (*161*, *162*). These data are used to calculate the maximum sustainable yields (MSYs) to inform "safe" fishing levels. Various analyses have estimated global status assessments across a large number of fisheries, with some reporting lower sustainability percentages than the FAO [e.g., (*163*, *164*)], which calculated only 32% of fisheries were in good biological condition. These assessments on the condition of fish stocks reflect the broader concept of overfished/overfishing, rather than estimates that identify fish stocks as severely depleted or crossing a depletion threshold such as B_{LIM} (biological limit reference point). The range of metrics used to describe the status of fisheries can confuse nonexperts, as the various assessment frameworks (*18*, *163*–*165*) reflect different and incomparable measures, some of which can be prone to overestimating the probability of collapse. For example, Edgar *et al.* (*165*) uses a metric based on a hindcast comparison that estimated that 1.29 to 1.85 times more stocks had historically crossed a sustainability

Downloaded from https://www.science.org on October 30, 2026

threshold to become recruitment impaired at some point in their history, than was currently reported. Critically, the often-cited "85% more collapsed stocks" result does not describe the current proportion of assessed stocks that are collapsed or below B_{LIM}. It is a retrospective estimate of how many stocks may have crossed an impairment threshold at some point in their historical time series, after accounting for assessment bias. Consequently, these stocks could have recovered since the time that they had declined below a recruitment-impaired ratio adopted in the Edgar *et al.* (*165*) study.

Accordingly, the FAO SOFIA sustainability estimate, the Costello *et al.* (*163*) overfished/overfishing classifications, the Branch *et al.* (*164*) catch-based collapse discussion, and the Edgar *et al.* (*165*) historical analyses represent different biological reference points, metrics, and time frames and should not be treated as directly comparable estimates of global fisheries stock status. These assessments highlight the challenge of both assessing harvest sustainability and communicating that assessment to nonexperts. Despite extensive data on populations and harvest for some taxa, assessing sustainability remains challenging; this reality highlights the even greater hurdles for accurate assessment of taxa that suffer from a lack of relevant data, given the outstanding challenges within fisheries despite the wealth of data that are not present elsewhere [text S2, (*166*)]. In addition, obtaining accurate estimates of bycatch [e.g., (*167*, *168*)] and harmonizing understanding of ecosystem-wide impacts of harvests on community structure [such as the potential for trophic cascades; (*169*)] add further challenges to the accurate application of models for sustainably managing wild populations. These issues underscore the difficulty of accurate sustainability assessments; however, improved data on what is in trade are undeniably a critical foundation for identifying vulnerable species and understanding where further targeted data are needed.

However, monitoring data alone are insufficient for achieving sustainable management (*12*). Assessing whether trade is sustainable requires moving beyond simple volume tracking and species-specific quotas or limits to incorporate information on species ecology [(*165*, *170*, *171*), text S2]. For instance, in fisheries, adhering to MSY for a target species (e.g., forage fish such as anchovy) may fail to sufficiently account for potential cascading ecological roles of small fish in supporting numerous predator species (e.g., seabirds and marine mammals) (*172*), and thus may overlook key ecosystem functions that could be affected by harvest and trade especially if other pressures are not properly incorporated into assessments.

Persistent challenges and solutions

The gaps and inconsistencies highlighted here are a major obstacle to understanding and managing wildlife trade. These gaps arise from the fragmentary nature of global monitoring systems (Fig. 2), which can fail to record many species in trade and often lack detailed, species-level information (text S3). Developing more accurate wildlife trade systems is possible, given that most countries already have mechanisms to verify zoosanitary and phytosanitary data, collect customs data on imports, and compile relevant data on exports (and often imports) of CITES-listed species. Aligning existing processes and implementing automation could help overcome issues with species identification and accurate quantification and increase our ability to identify inconsistencies in trade data (text S3), when accompanied by equitable sharing of skills, technology, and resources to build and maintain global capacity. New technologies are needed for monitoring and management for all forms of trade to increase the accuracy of reporting (*173*). However, current monitoring systems are often reliant on harmonizing multiple (up to thousands of) species to a singular code. Building on existing trade systems and using existing records [e.g., sales invoices; (*174*)], increased collection of species-level trade data through technological approaches (e.g., optical character recognition applied to trade invoices, machine learning, and constant communication with taxonomy and trade databases) has revealed a greater extent of biodiversity in trade than is captured by typical national-level reporting systems (*35*). Such systems could automate parts of the process, such as automating invoice digitization (*175*, *176*), or flagging potential mislabeling based on inconsistencies such as price [(*177*, *178*); Fig. 3]. For example, Tlusty *et al.* (*175*) suggested the use of a real-time automated species-level detection system, which uses invoice data as the mechanism to populate import data logs. If the customs declaration was digitized and based on preagreed fields, it could align with biosecurity and customs declarations, as well as linking to a database to provide accurate records of what is in trade. Efforts like these have revealed that species-level data are already available and simply requires efficient digitization (*174*). Furthermore, data can be automatically checked (i.e., direct cross-referencing of fields, against baseline data, using images to check species identity using deep learning algorithms) to ensure that the species listed were the species present within a shipment. This will reduce the demand on local expertise, increase the granularity and accuracy of data, and help identify potential laundering. Such approaches could also help identify and correct units that are incorrect, especially for live animals. These tools could also flag other discrepancies, such as when species are declared as wild but are not native to the declared country of origin, when important information is missing, and when current source countries for species of concern may require additional assessment (Fig. 3). Once these systems are in place, it is paramount that this is followed up by appropriate inspections and, if violations are detected, adequate enforcement actions.

Using established reporting frameworks, such as CITES and LEMIS, a broader set of universal recording standards could be developed, making use of key parameters (e.g., based on invoice data), and uptake encouraged through capacity building measures. This is not to say that these databases are error-free: As noted above, inaccurate taxonomic identification, missing data on shipment/record source and origin, and gaps within these systems will likely require increased scientific capacity and new technological advances to overcome (table S1). Yet, these existing systems provide lessons with broad relevance to other nations and could serve as tentative templates for creating a better process for collating those data without creating entirely new processes. Overarching oversight could fall under existing MEAs such as the CBD with initial funding for implementation provided by the Global Environment Facility. Given that all countries do already have customs authorities, standardizing how we collate data on wildlife, as we already largely do with livestock, is not unachievable but will require a concerted effort, engagement, and adequate resourcing. Starting at a regional level (such as the EU) could provide an initial model for such data collation and help refine the granularity of data needed for monitoring at all scales.

The burden of managing such data may represent a major consideration, especially if done globally. Yet, compared with monitoring other animals, such a data program is not as challenging as it may initially seem. For example, the UK has required electronic tagging of individual sheep and logging of all their movements since

Downloaded from https://www.science.org on October 30, 2026

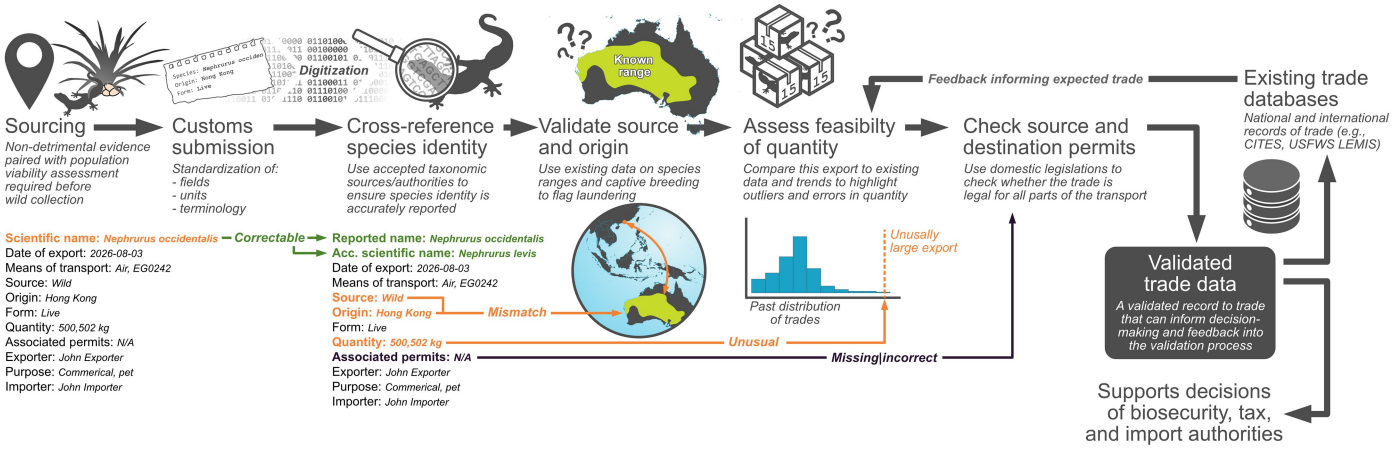


Fig. 3. Potential global trade data collection workflow. A diagram describing potential points of automation and checking that would enhance the collection of global wildlife trade for taxa not encompassed within existing global monitoring processes.

2009 (*179*, *180*), which already includes tracking millions of animals to manage and mitigate disease outbreaks (*181*). This system demonstrates that central reporting, standardized identification of individuals, source tracing, and downstream (e.g., market and resale) identification checking are all possible with current technology, as well as remaining interoperable at super-national levels (*180*). Therefore, such data volumes can clearly be managed; systems like this that track individual provenance provide an example for wildlife trade markets, like the pet trade, to follow. Furthermore, newer approaches, such as Blockchain, provide opportunities to track large volumes of trade globally (*182*).

Comparable examples already exist for some components of wildlife trade. New platforms have already been developed to enable more sustainable use of trees (e.g., https://woodid.info/). Similarly, automated approaches to identify potential wildlife trade are being implemented in shipping, such as Hazcheck and other mechanisms to detect inconsistencies (e.g., in weights) where laundering and misdeclaration may be present (*183*–*185*). However, many efforts either focus on supply chains for major commodities, or on the detection of illegal trade [e.g., (*186*–*189*)] and renewed efforts are needed to more systematically record data for other taxa. Furthermore, for other major dimensions of trade, such as online trade, innovative machine learning approaches that harness timely insights from digital platforms (*190*) and social media data (*191*) now offer the potential for transformative, (near) real-time wildlife trade monitoring. The implementation of lessons from these initiatives is sorely needed more widely across other parts of the trade, as the trade in wildlife outside CITES and the FAO remains a persistent blind spot for governments globally, with virtually none outside the United States providing comprehensive databases of wildlife in trade. These persistent gaps in data collation and the resulting uncertainty around trade and its sustainability have also led to repeated calls for the implementation of reverse-listing approaches [see (*192*)]. However, such proposals would represent a fundamental shift in wildlife trade governance and should be evaluated carefully against considerations of proportionality, feasibility, food security, livelihoods, customary and tenure rights, implementation costs, and the evidentiary burden placed on lower-capacity states and small-scale resource users. Nonetheless, collating sufficient wildlife trade data to provide a basis for decisions must be seen as a priority to enable assessments of sustainability and development of management interventions where appropriate.

Synthesis

Global estimates of taxa in trade are demonstrably incomplete with taxa-specific estimates or single-country estimates exceeding some naive estimates of the global trade for larger groups. Yet, legal wildlife trade, especially of smaller-bodied animals and plants, remains one of the most neglected components of the global biodiversity crisis. Our analysis provides a new, much higher estimate of the total number of species in trade: up to 107,356 species, including plants and fungi, more than double the IPBES (*1*) estimate of 50,000 species. Even though this is likely a considerable underestimate due to a lack of systematic data collection, it already represents 15 to 64% for each taxonomic group of all described vertebrate species.

Despite not being free from issues, the US LEMIS data are periodically made publicly accessible and present a taxonomically comprehensive assessment of animal species imported and exported from the United States (at least 27.4% of traded animal species, including 30% of vertebrates, were only recorded in LEMIS). Comparable data for other countries are urgently needed, yet remain unavailable. While wildlife trade is acknowledged as a major threat to species survival (*1*), even indicators for trade included within global frameworks such as the KM-GBF fail to include data for the majority of taxa in trade, approximately 6 to 11% of internationally traded vertebrate species and 1.8 to 2.5% of species in use and trade reflected by the headline indicator for target 5 on wildlife trade (*23*, *193*). However, it may be considerably lower than this as the indicator focuses on sustainably harvested fish, and while it currently includes around 1000 species, the indicator focuses on stocks rather than species; thus, the number of species with sufficient data remains hard to gauge.

Many countries do have permit systems for the collection or international trade of some wildlife, but there are no standards for collating information from these systems regarding which species can be harvested and traded at different levels. Furthermore, determining what information to include within trade databases and how such data should be shared requires further work. Even within a country, the involvement of multiple agencies or local authorities means that national-level aggregation of such data may remain challenging in

Downloaded from https://www.science.org on October 30, 2026

some jurisdictions. This seriously hampers our ability to monitor progress toward, let alone meet, global conservation targets.

Systems to manage wildlife trade have most frequently been developed to maintain populations of economically valuable species (particularly for species hunted as game or for trophies) or to reduce the risk of invasive species or zoonoses [Wild Bird Conservation Act; EU Wild Bird Directive (*194*, *195*)]. Likewise, limited guidance, legislation, international cooperation, and funding exist for the repatriation of confiscated live animals (*196*, *197*). Many countries have their own mechanisms to legislate elements of trade and collection, but not only does this lag behind current trade patterns, it also fails to reflect the international dimensions of trade (*198*). Likewise, the EU-TRACES program could enable the collation data on wildlife trade for Europe; however, these data are not publicly available and the standards implemented (i.e., taxonomic accuracy and resolution) have been questioned (*17*, *199*). This lack of availability is converse to virtually every other traded commodity (comcodes provide high detail for most exports and livestock trade is increasingly traceable at the level of individual animals). Thus, the lack of comparable progress in wildlife trade monitoring reflects a time when wildlife trade was less diverse than at present, highlighting an urgent need to bring wildlife trade monitoring in line with other elements of commodity trade.

We highlight the urgent need to shift toward collating more representative data across taxa at national and international levels, and to share these data in interoperable formats to lastly enable accurate monitoring of wildlife trade across taxa and scales. Efforts to better understand illegal trade will require continued innovations to detect and disrupt illegal supply chains, but we do have an opportunity to greatly enhance our understanding of legal trade. Legal trade is where our greatest knowledge gaps (particularly in species identity) exist, which precludes a complete understanding of the sustainability of trade. Notably, several targets of the KM-GBF focus on wildlife trade; however, the indicators are insufficient to monitor progress, and any assessment of sustainability of trade is impossible without both accurate trade data and corresponding population data, both of which are currently lacking.

Ultimately, while the threat posed by unsustainable extraction for wildlife trade is well acknowledged, the scale has likely been underestimated. Unless actions are taken to reconcile data gaps, reaching many biodiversity goals will remain virtually impossible, as only through collating the data needed to identify and manage risks can we ensure that wildlife trade is sustainable.

MATERIALS AND METHODS

Scope

In this review of data available on wildlife trade, we focus on international trade (legal and illegal) of wildlife (nondomesticated species). We provide estimates of the number of species in trade based on existing international trade databases, as well as upper estimates based on broader evidence of species use and trade at any geographic scale (though such data is not always recorded). This broadly encompasses timber and wood products (monitored by the FAO, ITTO, and national bodies); fisheries monitored by global (i.e., FAO), regional [such as RFMOs (regional fisheries monitoring organizations)], and national bodies; and wild animals and plants traded for various purposes (i.e., pets, fashion, medicine, food, materials, and ornamental trade). Global, regional, and national, governmental and nongovernmental wildlife trade platforms are examined to understand the data they include and the legal and policy framings they serve. Illegal trade and the intersection between legal and illegal trade are also examined. While monitoring of trade in fungi has also been highlighted as an important gap [i.e., (*200*)], current trade data only include code-aggregated UN Comtrade information, which does not allow for detailed species- or group-level analysis [with a few exceptions, such as long-tailed macaques (*39*) and European eel (*201*, *202*)].

Global monitoring

Data were analyzed in two ways, one to assess actual recorded trade through databases that record species in international trade (see Fig. 1) and include extensive quantities on trade data. Second, we more broadly aggregated data that estimate species that may be used or traded (without the application of a taxonomic backbone), which may include both domestic and international trade, as well as commercial and subsistence uses (see Table 1).

To analyze global patterns of species trade, we first looked at global databases that include information on trade (legal and illegal), with a focus on CITES, the IUCN Red List of Threatened Species, and various FAO databases on the commodity trade of timber and fish, as well as TRAFFIC for illegal trade. All data were downloaded, and analysis was conducted, between 20 October and 5 November 2025 (*203*). For each database, the number of species in trade per major taxa was recorded. For CITES assessments, the CITES checklist was used to assess the number of species listed within various taxonomic groups (https://checklist.cites.org/#/en) while for groups listed at higher taxonomic levels, the number of species was searched independently to assess whether the number listed under the higher taxa is consistent with the published number of species within these taxa. Notably, there are currently no fungi covered within CITES, though three Ascomycetes (Morel mushrooms, white truffles, and *Cordyceps* spp.) and one Basidiomycete (Lacquered bracket fungus) are recorded in TRAFFIC seizures, while 260 species are listed in use by the IUCN. CITES Parties agreed that fungi are covered by the Convention at CoP12 in 2002 (CITES Res. Conf. 12.11), but no fungi species have been listed in the Appendices to date (*204*). Assessing the trade of fungi globally therefore remains exceedingly challenging at present.

For the IUCN Red List data, all categories of "Use and Trade" were selected within an "advanced search" from the Red List website (https://iucnredlist.org/) using the IUCN 2025-2 update (*205*), and the number of species in various taxa was recorded; as quantification of what is in trade through these various channels may reflect specialist group expertise, data availability and thus comprehensiveness may vary depending on the taxa. As this dataset only lists species that may be in trade, it is shown in tabulated data, but not in the figure recording recorded trade. For the FAO data, we relied on ASFIS List of Species for Fishery Statistics Purposes (ASFIS) for Fisheries (*206*) and FAOSTAT-Forestry online database for trees (for the process of tabulation of how species in trade are measured).

Most of the above databases focus on legal trade, whereas TRAFFIC monitors illegal trade (though predominantly seizure and CITES-listed species) and provides incident data via its Wildlife Trade Information System (WiTIS) database. We downloaded WiTIS data [https://wildlifetradeportal.org/incidents (*207*)]. However, other multispecies seizure datasets also exist, but they are not publicly available. For example, the CITES annual illegal trade reports (AITR) are

Downloaded from https://www.science.org on October 30, 2026

typically only made available to governmental authorities or International Consortium on Combating Wildlife Crime partners for global research and analysis [CITES Resolution Conf. 11.17 (Rev. CoP19)]. All assessments listing species-level data were used (49.3% of TRAFFIC seizure entries either did not have species specific data or included a range of taxa) to assess the number of species within each group. It should be noted that as species-specific data are only provided in half of incidences, these will reflect underestimates; nonetheless, it does reflect the trades of taxa for which trade may not be noted in detail elsewhere. Other databases also record seizure data on illegal trade globally [e.g., (*208*); Global Monitoring System Ecosolve: https://ecosolve.eco/dashboard], with increasing effort to aggregate and share global data. Values are assessed to determine the comprehensiveness of monitoring and reporting to determine how complete trade monitoring is and enable targeted action to address gaps. While the Ecosolve analysis is interesting (reflecting adverts, including on Facebook, and trends over time), the initiative only started in 2024, and only 85 animal species have been detected so far (28 mammals, 28 reptiles, 15 birds, 13 fish and marine invertebrates, and 1 amphibian).

To highlight the fragmentation of trade data, we extracted numbers of species in trade from recent publications assessing trade (of taxa with recognized substantial global trade) (Table 1), including all major vertebrate taxa, invertebrates, and plants. We also include the numbers of species recorded in the IPBES sustainable use assessment (*1*) (Table 1), which aimed to provide a comprehensive record of the number of taxa in trade to provide a basis to understand the dimensions of global trade. We then tabulate species noted in use and trade at both global and national levels (Table 1) and assess the total numbers of species within major taxa in international trade based on trade databases (Fig. 1, methods below). These assessments include both global and national (methods below) data to highlight the incompleteness of global analysis.

Given the limited availability of comprehensive data on trade of wild plant species, we additionally compiled information on plant species documented as being used by people from the World Checklist of Useful Plant Species [WCUPS; (*65*–*67*)]. This database records a wide range of human uses, including food, medicine, and materials. We assume that a substantial proportion of plant species documented as used are likely to occur in domestic and/or international trade, although the available data do not allow these pathways to be distinguished. It is important to note that WCUPS is not comprehensive, and many plant taxa that are used, and potentially traded, are not documented. Consequently, estimates derived from this dataset should be interpreted as conservative underestimates.

Determining species overlaps for species in trade

While many separate analyses and compilations exist for trade at international and domestic levels, assessing the actual number of species in trade requires careful processing to synthesize and clean data. Different programs, and papers, use different taxonomic backbones, or include synonyms or even include typos; thus, standardization is needed to accurately assess species in trade. Within this analysis, we use codes S1, S2, and S3 and data S1 and data S2 for this part of analysis.

To resolve this and ensure a fairer estimation of the extent of overlap and differences in species coverage between data sources, we converted the reported names to a standardized taxonomic backbone. We prioritized using the Global Biodiversity Information Facility (GBIF) taxonomic backbone in line with previous research (*23*, *209*–*211*), only deferring to further backbones where no potential for name conversions were found. We used the taxize package [(*212*, *213*); through the gna_verifier function that links to https://globalnames.org/] to query biodiversity data sources. We asked for results from GBIF Backbone Taxonomy, Integrated Taxonomic Information System, and Catalogue of Life, and prioritized accepted answers in that order. Any returned non–species-level name (identified via having two components—genus and species epithet) was discarded and either replaced with a name from the next source or, failing any proper matches, left blank. Notably, as LEMIS data were already cleaned, and the use of codes etc. was used to refine names to maximize species inclusion. In addition, Marshall *et al.* (*23*) have made a name conversion key available, so we reused this key to convert as many remaining names that the taxize process failed to match. We excluded all reported names that were not to the species level. Overall ~5% of the reported names investigated could not be matched to a currently accepted name. For summary statistics comparing the trade extent to the number of described taxa, we used Amphibian Species of the World (*214*), World Bird Names (*215*), Fishbase (*216*), Reptile Database (*217*), and Mammal Diversity (*218*) as the basis for total described species.

The taxonomic groups selected are not mutually exclusive, nor are the data sources (i.e., LEMIS data are also used in the research papers, and arachnids and lepidoptera are also invertebrates). For example, Marshall *et al.* (*30*) on the arachnid trade is included as a research paper source but includes data from pre-2014 LEMIS provided by Eskew *et al.* (*219*, *220*). Similarly, Marshall *et al.* (*30*) and Wang *et al.* (*24*) contributed to the Arachnida or Lepidoptera group counts, as well as to the total Invertebrate group for visualizations. To help promote a fair comparison between sources, we additionally expanded the Invertebrate category used in Marshall *et al.* (*23*) that was provided alongside the LEMIS data to include all classes appearing in Lassaline *et al.*'s (*210*) data. For amphibians, we used the non–mutually exclusive lists from Hughes *et al.* (*221*) and Mohanty and Measey (*222*). For birds, we used Donald *et al.* (*223*) and the Songbirds in Trade Database (*224*).

We used the ComplexUpset package (*225*, *226*), along with the ggplot2 (*227*), legendry (*228*), and patchwork (*229*) packages, to visualize the overlap between data sources. The manipulation and plotting of data was conducted in R version 4.4.2 (*230*), and additionally used the here (*231*), dplyr (*232*), tidyr (*233*), and stringr (*234*) packages. Data on species in trade were then plotted (Fig. 1) to highlight the fragmentation and incompleteness of trade databases, and plotted in detail (Fig. 2). We used Serif's Affinity Publisher 2 to edit figures for final presentation and add animal/plant icons sourced from https://phylopic.org/ (all icons are CC0 Public Domain).

National and regional database collation and policies

To analyze national and regional databases to examine the systems in place for monitoring wildlife trade, we took a three-pronged approach. First, a questionnaire was distributed by IPBES and GEOBON networks, which asked whether any database was present for assessing the trade of non-CITES species and to provide any sources if present. Sources (e.g., organization URLs) were then checked and verified through searching in Google either for the link provided or for the appropriate translated term (if the respondent had claimed a system was present without providing any links) to assess whether national systems to record trade of non-CITES species were present (data S3).

Second, the term "wildlife trade database" was translated into 30 languages (based on the top 25 languages in Google translate and five

Downloaded from https://www.science.org on October 30, 2026

further countries that needed verification following other assessments), and relevant links and passages were collated into a table. Links were copied if they noted biodiversity but were not exclusively focused on CITES. For each language, at least the first three pages (where present) returned by a Google search were interrogated following a Google translation (or Baidu in the case of Chinese) into English. Relevant passages of text referring to databases were also copied (it should be noted that very few of these pertained to national databases, though some referred to systems for issuing hunting licenses and permits). These searches were largely used to cross-reference with other searches and reflect the nuances in trade regulation. In addition, for all countries that stated they had a monitoring database but did not provide any link, specific supplementary searches were then conducted (data S4).

Third, a search was conducted with the assistance of Claude AI with the prompt "I am trying to collate data on national systems for databasing the trade of wildlife, would you be able to run a search where the term 'Wildlife Trade Database' is translated into each official National language and a table collated which includes weblinks, the translated search term, and the key text noting the presence of any National database on trade. Would you be able to run this search for each country within the area defined by the UN as within the ****, and create a single table with all the information, so each component in the compiled data is in a separate column, and the countries are listed in different rows." The **** was replaced with each UN region in turn. Outcomes were copied (data S5) and summaries for each are recorded in text. All outputs were manually checked for consistency with prior searches, as well as the authors' knowledge of the various agencies responsible for environmental governance in various jurisdictions. All URLs listed in the initial search tabulation were then manually checked, and either nonfunctional ones were removed or the keywords were searched for to find updated websites; irrelevant links were also removed. Many countries also listed "N/A" or had no government websites provided by the search. In these cases, we conducted a Google search for "wildlife trade ministry" and the country name. The names of ministries were then translated into the National language and websites of appropriate agencies (involved with wildlife trade, hunting permits, timber, etc.) were searched for, tested, and added to the document. Any countries that initially lacked any government URLs were also searched so that except in cases where ministries had disbanded, all countries had working weblinks for ministries associated with wildlife trade recorded in the table.

To synergize this information, the pdfs for all regions were uploaded into Notebook LM with the query "Could you list all the countries which do have a national system or database for collating the trade of non-CITES species." All listed systems from this search were then searched for independently in Google, and the veracity and coverage of each noted system were independently checked. The results of the search, with the information and URLs used for verification and to deepen the information provided, were then checked and noted below the original summaries in italics. All searched information and verification data are provided in the Supplementary Materials (data S5).

Supplementary Materials

The PDF file includes:

Supplementary Text S1 to S3
Fig. S1
Tables S1 and S2
Legends for data S1 to S5
Legends for code S1 to S3
References

Other Supplementary Material for this manuscript includes the following:

Data S1 to S5
Code S1 to S3

REFERENCES

1. IPBES. Summary for policymakers of the thematic assessment report on the sustainable use of wild species of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, J. M. Fromentin, M. R. Emery, J. Donaldson, M. C. Danner, A. Hallosserie, D. Kieling, G. Balachander, E. S. Barron, R. P. Chaudhary, M. Gasalla, M. Halmy, C. Hicks, M. S. Park, B. Parlee, J. Rice, T. Ticktin, D. Tittensor, Eds. (IPBES Secretariat, 2022). DOI: https://doi.org/10.5281/zenodo.6425599.
2. IPBES. Global assessment report of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, S. Díaz, J. Settele, E. S. Brondízio, E. S., H. T. Ngo, M. Guèze, J. Agard, A. Arneth, P. Balvanera, K. A. Brauman, S. H. M. Butchart, K. A. M. Chan, L. A. Garibaldi, K. Ichii, J. Liu, S. M. Subramanian, G. F. Midgley, P. Miloslavich, Z. Molnár, D. Obura, A. Pfaff, S. Polasky, A. Purvis, J. Razzaque, B. Reyers, R. Roy Chowdhury, Y. J. Shin, I. J. Visseren-Hamakers, K. J. Willis, C. N. Zayas, Eds. (IPBES Secretariat, 2019).
3. O. Morton, B. R. Scheffers, T. Haugaasen, D. P. Edwards, Impacts of wildlife trade on terrestrial biodiversity. *Nat. Ecol. Evol.* **5**, 540–548 (2021).
4. L. McRae, R. Freeman, J. Geldmann, G. B. Moss, L. Kjær-Hansen, N. D. Burgess, A global indicator of utilized wildlife populations: Regional trends and the impact of management. *One Earth* **5**, 422–433 (2022).
5. R. R. J. McAllister, D. McNeill, I. J. Gordon, Legalizing markets and the consequences for poaching of wildlife species: The vicuña as a case study. *J. Environ. Manage.* **90**, 120–130 (2009).
6. A. Hinsley, J. Willis, A. R. Dent, R. Oyanedel, T. Kubo, D. W. S. Challender, Trading species to extinction: Evidence of extinction linked to the wildlife trade. *Camb. Prisms Extinct.* **1**, e10 (2023).
7. A. C. Hughes, Wildlife trade. *Curr. Biol.* **31**, R1218–R1224 (2021).
8. A. A. Andersson, H. B. Tilley, W. Lau, D. Dudgeon, T. C. Bonebrake, C. Dingle, CITES and beyond: Illuminating 20 years of global, legal wildlife trade. *Glob. Ecol. Conserv.* **26**, e01455 (2021).
9. FAO. The State of World Fisheries and Aquaculture 2024. Blue transformation in action. Rome. ISBN: 978-92-5-138763-4 (2024). DOI: 10.4060/cd0683en.
10. J. H. Tow, L. R. Carrasco, A comprehensive reassessment of the global illegal wildlife trade's economic value. *Integr. Conserv.* **5**, 293–305 (2026).
11. J. W. Duckworth, G. Batters, J. L. Belant, E. L. Bennett, J. Brunner, J. Burton, D. W. S. Challender, V. Cowling, N. Duplaix, J. D. Harris, S. Hedges, B. Long, S. P. Mahood, P. J. K. McGowan, W. J. McShea, W. L. R. Oliver, S. Perkin, B. M. Rawson, C. R. Shepherd, S. N. Stuart, B. K. Talukdar, P. P. van Dijk, J-C. Vié, J. L. Walston, T. Whitten, R. Wirth. Why South-east Asia should be the world's priority for averting imminent species extinctions, and a call to join a developing cross-institutional programme to tackle this urgent issue. *S.A.P.I.EN.S.*, **5.2** (2012).
12. A. Hughes, M. Auliya, S. Altherr, B. Scheffers, J. Janssen, V. Nijman, C. R. Shepherd, N. D'Cruze, E. Sy, D. P. Edwards, Determining the sustainability of legal wildlife trade. *J. Environ. Manage.* **341**, 117987 (2023).
13. CBD. Decision 15/5: Monitoring framework for the Kunming-Montreal Global Biodiversity Framework. CBD/COP/DEC/15/5. Adopted at the Fifteenth Meeting of the Conference of the Parties to the Convention on Biological Diversity (COP 15), Montreal, Canada, 19 December 2022 (2022); https://cbd.int/doc/decisions/cop-15/cop-15-dec-05-en.pdf.
14. B. Corey, G. J. W. Webb, S. C. Manolis, A. Fordham, B. J. Austin, Y. Fukuda, D. Nicholls, K. Saalfeld, Commercial harvests of saltwater crocodile *Crocodylus porosus* eggs by Indigenous people in northern Australia: Lessons for long-term viability and management. *Oryx* **52**, 697–708 (2018).
15. C. T. Sahley, J. T. Vargas, J. S. Valdivia, Biological sustainability of live shearing of vicuña in Peru. *Conserv. Biol.* **21**, 98–105 (2007).
16. M. Abensperg-Traun, CITES, sustainable use of wild species and incentive-driven conservation in developing countries, with an emphasis on southern Africa. *Biol. Conserv.* **142**, 948–963 (2009).
17. A. C. Hughes, O. Morton, D. P. Edwards, Urgent policy change is needed to understand the dimensions of legal international wildlife trade to enable targeted management. *Conserv. Lett.* **18**, e13097 (2025).
18. R. Sharma, M. Barange, V. Agostini, P. Barros, N. L. Gutierrez, M. Vasconcellos, D. Fernandez Reguera, C. Tiffay, P. Levontin. *Review of the State of World Marine Fishery Resources—2025* (FAO, 2025).
19. FAO. FishStatJ—Software for Fishery and Aquaculture Statistical Time Series (2025); https://fao.org/fishery/en/statistics/software/fishstatj.
20. W. Wijnstekers. *The Evolution of CITES—9th Edition* (International Council for Game and Wildlife Conservation, 2011).
21. CMS Convention on the Conservation of Migratory Species of Wild Animals. Bonn, 23 June 1979 (1979).

Downloaded from https://www.science.org on October 30, 2026

22. B. M. Marshall, C. Strine, A. C. Hughes, Thousands of reptile species threatened by under-regulated global trade. *Nat. Commun.* **11**, 4738 (2020).
23. B. M. Marshall, A. L. Alamshah, P. Cardoso, P. Cassey, S. Chekunov, E. A. Eskew, C. S. Fukushima, P. García-Díaz, M. L. Gore, J. L. Lockwood, A. L. Rhyne, J. S. Sinclair, C. Thomas Strine, O. C. Stringham, M. F. Tlusty, J. W. Valdez, F. Watters, A. C. Hughes, The magnitude of legal wildlife trade and implications for species survival. *Proc. Natl. Acad. Sci. U.S.A.* **122**, e2410774121 (2025).
24. Z. Wang, W.-P. Chan, N. T. Pham, J. Zeng, N. E. Pierce, D. J. Lohman, W. Meng, One in five butterfly species sold online across borders. *Biol. Conserv.* **283**, 110092 (2023).
25. K. Friedman, M. Braccini, M. Bjerregaard-Walsh, R. Bonfil, C. J. A. Bradshaw, S. Brouwer, I. Campbell, R. Coelho, E. Cortés, W. Dimmlich, M. G. Frisk, I. Kingma, S. R. McCully Phillips, C. O'Criodain, D. Parker, S. Shephard, J. Tovar-Ávila, K. Yokawa, Informing CITES parties: Strengthening science-based decision-making when listing marine species. *Fish Fish.* **21**, 13–31 (2020).
26. D. W. S. Challender, P. J. Cremona, K. Malsch, J. E. Robinson, A. T. Pavitt, J. Scott, R. Hoffmann, A. Joolia, T. E. E. Oldfield, R. K. B. Jenkins, D. A. Conde, C. Hilton-Taylor, M. Hoffmann, Identifying species likely threatened by international trade on the IUCN Red List can inform CITES trade measures. *Nat. Ecol. Evol.* **7**, 1211–1220 (2023).
27. R. Cooney, D. W. S. Challender, S. Broad, D. Roe, D. J. D. Natusch, Think before you act: Improving the conservation outcomes of CITES listing decisions. *Front. Ecol. Evol.* **9**, 631556 (2021).
28. B. J. Weissgold, US wildlife trade data lack quality control necessary for accurate scientific interpretation and policy application. *Conserv. Lett.* **17**, e13005 (2024).
29. B. M. Marshall, C. T. Strine, M. L. Gore, E. A. Eskew, O. C. Stringham, P. Cardoso, S. Chekunov, F. Watters, C. Fukushima, P. García-Díaz, J. S. Sinclair, M. F. Tlusty, R. J. Almeida, J. W. Valdez, A. C. Hughes, Mapping the global dimensions of US wildlife imports. *Curr. Biol.* **35**, 3959–3972.e4 (2025).
30. B. M. Marshall, C. T. Strine, C. S. Fukushima, P. Cardoso, M. C. Orr, A. C. Hughes, Searching the web builds fuller picture of arachnid trade. *Commun. Biol.* **5**, 448 (2022).
31. CITES Secretariat and UNEP-WCMC. International trade in non-CITES listed marine ornamental fish: International trade, conservation status, management and legislation for non-CITES marine ornamental fish in support of the implementation of Decision 18.296 [Updated] (UNEP-WCMC, 2024).
32. D. P. Tittensor, M. Harfoot, C. McLardy, G. L. Britten, K. Kecse-Nagy, B. Landry, W. Outhwaite, B. Price, P. Sinovas, J. Blanc, N. D. Burgess, K. Malsch, Evaluating the relationships between the legal and illegal international wildlife trades. *Conserv. Lett.* **13**, e12724 (2020).
33. M. T. Bager Olsen, J. Geldmann, M. Harfoot, D. P. Tittensor, B. Price, P. Sinovas, K. Nowak, N. J. Sanders, N. D. Burgess, Thirty-six years of legal and illegal wildlife trade entering the USA. *Oryx* **55**, 432–441 (2021).
34. M. Harfoot, S. A. M. Glaser, D. P. Tittensor, G. L. Britten, C. McLardy, K. Malsch, N. D. Burgess, Unveiling the patterns and trends in 40 years of global trade in CITES-listed wildlife. *Biol. Conserv.* **223**, 47–57 (2018).
35. A. L. Rhyne, M. F. Tlusty, J. T. Szczebak, R. J. Holmberg, Expanding our understanding of the trade in marine aquarium animals. *PeerJ* **5**, e2949 (2017).
36. H. Gerson, B. Cudmore, N. E. Mandrak, L. D. Coote, K. Farr, G. Baillargeon, Monitoring international wildlife trade with coded species data. *Conserv. Biol.* **22**, 4–7 (2008).
37. A. Davies, A. A. Andersson, R. O. Martin, S. Inglis, C. Dingle, Using customs data to understand overlooked trade in non-CITES birds between Africa and Asia. *Conserv. Biol.* **40**, e70265 (2026).
38. K. Kaifu, F. Stein, W. Dekker, N. Walker, C. A. Dolloff, K. Steele, A. A. Aguirre, V. Nijman, P. Siriwat, P. Sasal, "Global exploitation of freshwater eels (genus *Anguilla*): Fisheries, stock status and illegal trade," in *Eels Biology, Monitoring, Management, Culture and Exploitation*, A. Don, P. Coulson, Eds. (CABI, GB, 2019), pp. 377–422.
39. M. F. Hansen, M. Gill, E. F. Briefer, D. R. K. Nielsen, V. Nijman, Monetary value of live trade in a commonly traded primate, the long-tailed macaque, based on global trade statistics. *Front. Conserv. Sci.* **3**, 839131 (2022).
40. CITES. Consideration of proposals for amendment of appendices I and II. CoP20 Prop. 35. (2025); https://cites.org/sites/default/files/documents/E-CoP20-Prop-35_1.pdf.
41. H.-K. Chan, H. Zhang, F. Yang, G. Fischer, Improve customs systems to monitor global wildlife trade. *Science* **348**, 291–292 (2015).
42. N. Okes, G. Sant. Missing sharks: A country review of catch, trade and management recommendations for CITES-listed shark species. Traffic (2022); https://www.traffic.org/publications/reports/missing-sharks-a-country-review-of-catch-trade-and-management-recommendations-for-cites-listed-shark-species/.
43. S. Zain, Corrupting trade: An overview of corruption issues in illicit wildlife trade. Targeting Natural Resource Corruption, 4 (2020).
44. Ç. Vural. "Wildlife trafficking: Conservation and illicit trade dynamics," in *Illicit Economies and Security Dynamics* (SAGE Publications, 2026), pp. 168–184.
45. ESCAP, Digital and sustainable trade facilitation: Global report 2025 (2025); https://www.unescap.org/kp/2025/digital-and-sustainable-trade-facilitation-global-report-2025.
46. CITES. eCITES (2024) https://cites.org/eng/prog/eCITES.
47. A. Pavitt, K. Malsch, E. King, A. Chevalier, D. Kachelriess, S. Vannuccini, K. Friedman, *CITES and the Sea: Trade in Commercially Exploited CITES-Listed Marine Species* (FAO, 2021).
48. A. G. Blundell, M. B. Mascia, Discrepancies in reported levels of international wildlife trade. *Conserv. Biol.* **19**, 2020–2025 (2005).
49. M. F. Tlusty, A. L. Rhyne, L. Kaufman, M. Hutchins, G. M. Reid, C. Andrews, P. Boyle, J. Hemdal, F. McGilvray, S. Dowd, Opportunities for public aquariums to increase the sustainability of the aquatic animal trade. *Zoo Biol.* **32**, 1–12 (2013).
50. FAO. "All information collections," in *Fisheries and Aquaculture* [online]. (2026); http://fao.org/fishery/knowledgebase/78/en?status=published.
51. FAO. "Global capture production," in *Fisheries and Aquaculture* [online]. (2026); http://fao.org/fishery/collection/capture/en.
52. UNEP-WCMC, *Global Marine Aquarium Database* (UNEP-WCMC, 2003); https://resources.unep-wcmc.org/products/WCMC_DT004.
53. C. Wabnitz, M. Taylor, E.P. Green, T. Razak, *From Ocean to Aquarium: The Global Trade in Marine Ornamental Species* (UNEP-WCMC, 2003).
54. CITES. AC33 Doc. 44 (Rev. 2) Annex 4 (https://cites.org/sites/default/files/documents/E-AC33-44-R2.pdf, https://cites.org/sites/default/files/documents/E-AC33-44-A4_2.xlsx) (2024).
55. ITTO. Annual Report 2025. International Tropical Timber Organization, Yokohama, Japan (2026); https://www.itto.int/news/2026/08/10/itto_2025_annual_report_another_year_of_positive_impact_for_tropical_forests/.
56. TRAFFIC. Introducing TimberStats: A novel tool to root out illegal timber trade (2024); https://traffic.org/news/introducing-timberstats-a-novel-tool-to-root-out-illegal-timber-trade/.
57. S. B. Richardson, J. C. Simeone, V. Deklerck, The global wood species priority list: A living database of tree species most at risk for illegal logging, unsustainable deforestation, and high rates of trade globally. *Wood Fiber Sci.* **55**, 31–42 (2023).
58. CITES SC78 Doc. 65.1. Report on the implementation of resolution Conf. 10.10 (Rev. CoP19). Seventy-eighth meeting of the Standing Committee (3–8 February 2025) (2025); https://cites.org/sites/default/files/documents/E-SC78-65-01.pdf.
59. TRAFFIC. An overview of seizures of CITES-listed wildlife in the European union: January to December 2021 (2023); https://traffic.org/site/assets/files/27874/2_june_-_last_-_traffic-overview_of_2023_eu_seizures.pdf.
60. TRAFFIC. ETIS. the Elephant Trade Information System (2025); https://traffic.org/what-we-do/thematic-issues/trade-monitoring/elephant-trade-information-system/.
61. CITES. Monitoring the Illegal Killing of Elephants (MIKE) (2025); https://cites.org/eng/prog/mike/index.php/portal.
62. Catbyte (2026); https://catbyte.org/about-catbyte/.
63. TRAFFIC. USAID ROUTES Partnership; Reducing Opportunities for Unlawful Transport of Endangered Species (2022); https://traffic.org/what-we-do/thematic-issues/private-sector-guidance/routes/.
64. CITES. Representation of songbirds (Passeriformes) in the Cites appendices and their prevalence in trade. Nineteenth meeting of the Conference of the Parties Panama City (Republic of Panama), 14–25 November 2022 (2022); https://birdlife.org/wp-content/uploads/2022/11/CITES-InfDoc-REPRESENTATION-OF-SONGBIRDS-PASSERIFORMES-IN-THE-CITES-APPENDICES-submitted-to-CITES-1.pdf.
65. M. Diazgranados, B. Allkin, N. Black, R. Cámara-Leret, C. Canteiro, J. Carretero, R. Eastwood, S. Hargreaves, A. Hudson, W. Milliken, M. Nesbitt, I. Ondo, K. Patmore, S. Pironon, R. Turner, T. Ulian, World Checklist of Useful Plant Species, KNB Data Repository (2020); https://doi.org/10.5063/F1CV4G34.
66. S. Pironon, I. Ondo, M. Diazgranados, R. Allkin, A. C. Baquero, R. Cámara-Leret, C. Canteiro, Z. Dennehy-Carr, R. Govaerts, S. Hargreaves, A. J. Hudson, R. Lemmens, W. Milliken, M. Nesbitt, K. Patmore, G. Schmelzer, R. M. Turner, T. R. Van Andel, T. Ulian, A. Antonelli, K. J. Willis, The global distribution of plants used by humans. *Science* **383**, 293–297 (2024).
67. S. Pironon, I. Ondo, M. Diazgranados, R. Allkin, A. C. Baquero, R. Cámara-Leret, C. Canteiro, Z. Dennehy-Carr, R. Govaerts, S. Hargreaves, A. J. Hudson, R. Lemmens, W. Milliken, M. Nesbitt, K. Patmore, G. Schmelzer, R. M. Turner, T. R. van Andel, T. Ulian, A. Antonelli, K. J. Willis, The global distribution of plants used by humans datasets: List of utilised species, occurrence data and model outputs at 10 arc-minutes spatial resolution, Zenodo (2024); https://doi.org/10.5281/ZENODO.10345634.
68. L. Bacchetta, F. Visioli, G. Cappelli, E. Caruso, G. Martin, E. Nemeth, G. Bacchetta, G. Bedini, A. Wezel, T. Van Asseldonk, L. Van Raamsdonk, F. Mariani, On Behalf Of The Eatwild Consortium, A manifesto for the valorization of wild edible plants. *J. Ethnopharmacol.* **191**, 180–187 (2016).
69. M. V. Biondo, R. P. Burki, F. Aguayo, R. Calado, An updated review of the marine ornamental fish trade in the European Union. *Animals* **14**, 1761 (2024).
70. UNEP-WCMC. International Trade in Non-CITES Listed Marine Ornamental Fish: International Trade, Conservation Status, Management and Legislation for Non-CITES Marine Ornamental Fish in Support of The Implementation of Decision 18.296 (UNEP-WCMC, 2022).
71. NOAA Fisheries. Harmonized Tariff Codes and Other Resources for the Marine Mammal Protection Act Import Prohibitions. December 04, 2025 (2025); https://www.fisheries.

Downloaded from https://www.science.org on October 30, 2026

noaa.gov/resource/outreach-materials/harmonized-tariff-codes-seafood-trade-monitoring-programs.
72. EU-LEX. Consolidated version of the Treaty on the Functioning of the European Union. Part three—Union policies and internal actions. title ii - free movement of goods. Chapter 3—Prohibition of quantitative restrictions between member states. Article 37 (ex Article 31 TEC). Document 12016E037 (2016); https://eur-lex.europa.eu/eli/treaty/tfeu_2016/art_37/oj/eng.
73. EEAS. Forest Law Enforcement, Governance and Trade in ASEAN (FLEGT ASEAN) (2020); https://eeas.europa.eu/eeas/forest-law-enforcement-governance-and-trade-asean-flegt-asean_und_en.
74. EUR-LEX. Commission Regulation (EC) No 1497/2003 of 18 August 2003 amending Council Regulation (EC) No 338/97 on the protection of species of wild fauna and flora by regulating trade therein (2003); https://eur-lex.europa.eu/eli/reg/2003/1497/oj/eng.
75. EUR-LEX. Consolidated text: Council Regulation (EC) No 338/97 of 9 December 1996 on the protection of species of wild fauna and flora by regulating trade therein (2026); https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A01997R0338-20230520.
76. S. Lawson. *The Lacey Act's Effectiveness in Reducing Illegal Wood Imports* (Union of Concerned Scientists, 2015).
77. Airbus. Airbus fosters Barry Callebaut's efforts to develop a deforestation-free supply chain. Press Release 09 December 2025 (2025); https://airbus.com/en/newsroom/press-releases/2025-12-airbus-fosters-barry-callebauts-efforts-to-develop-a-deforestation-free-supply-chain.
78. G. Matias, F. Cagnacci, L. M. Rosalino, FSC forest certification effects on biodiversity: A global review and meta-analysis. *Sci. Total Environ.* **908**, 168296 (2024).
79. J. Willis, D. J. Ingram, K. Abernethy, D. Kemalasari, U. Muchlish, Y. Sampurna, D. Midoko Iponga, L. Coad, WILDMEAT interventions database: A new database of interventions addressing unsustainable wild meat hunting, consumption and trade. *Afr. J. Ecol.* **60**, 205–211 (2022).
80. D. J. Ingram, L. Coad, E. J. Milner-Gulland, L. Parry, D. Wilkie, M. I. Bakarr, A. Benítez-López, E. L. Bennett, R. Bodmer, G. Cowlishaw, H. R. El Bizri, H. E. Eves, J. E. Fa, C. D. Golden, D. M. Iponga, N. V. Minh, T. Q. Morcatty, R. Mwinyihali, R. Nasi, V. Nijman, Y. Ntiamoa-Baidu, F. Pattiselanno, C. A. Peres, M. Rao, J. G. Robinson, J. M. Rowcliffe, C. Stafford, M. Supuma, F. N. Tarla, N. Van Vliet, M. Wieland, K. Abernethy, Wild meat is still on the menu: Progress in wild meat research, policy, and practice from 2002 to 2020. *Annu. Rev. Env. Resour.* **46**, 221–254 (2021).
81. L. Xiao, E. Pagani-Núñez, X. Han, P. Zhao, X. Li, Y. Hong, R. Hu, X. Zhao, G. Sun, C. Wardhana, Z. Lu, A mixed black and whitelist approach for wildlife trade regulation in China: Biodiversity conservation is made of shades of gray. *Conserv. Sci. Pract.* **6**, e13062 (2024).
82. A. P. Antunes, P. de Araujo Lima Constantino, J. E. Fa, D. P. Munari, T. Q. Morcatty, M. C. M. Jacob, B. W. Nelson, M. F. Cassino, E. A. R. Carvalho, A. Ickowitz, L. Coad, R. E. Bodmer, P. Mayor, C. Richard-Hansen, J. Valsecchi, J. V. Campos-Silva, J. C. B. Pezzuti, M. Aparício, E. M. von Muhlen, M. A. Oliveira, M. J. de Paula, N. C. Pimenta, M. A. R. de Mattos Vieira, M. A. Santos Junior, A. V. Nunes, J. P. Boubli, L. M. G. Suruí, E. C. S. Paumari, A. V. C. Paumari, J. L. V. S. Paumari, G. C. Paumari, A. P. L. R. Katukina, D. Baniwa, V. S. M. Baniwa, W. S. L. Baniwa, A. O. F. Baniwa, A. B. Baniwa, I. J. S. Baniwa, Y. Waura, J. S. Apurinã, V. S. S. Apurinã, J. O. G. Tikuna, E. P. A. L. Tikuna, J. L. Kaxinauá, K. B. Kuikuro, J. T. Penaforth Kaixana, G. H. Rebelo, D. Torquato, V. S. F. Apurinã, M. Antúnez, P. E. Perez-Peña, T. G. Fang, P. E. Puertas, R. M. Aquino, L. Maranhão, G. Longin, C. K. M. Lopes, H. R. El Bizri, Healthy forests safeguard traditional wild meat food systems in Amazonia. *Nature* **648**, 625–633 (2025).
83. S. Zamani, M. Fathi, M.-T. Ebadi, Á. Máthé, Global trade of medicinal and aromatic plants. A review. *J. Agric. Food Res.* **21**, 101910 (2025).
84. K. Vasisht, N. Sharma, M. Karan, Current perspective in the international trade of medicinal plants material: An update. *Curr. Pharm. Des.* **22**, 4288–4336 (2016).
85. K. Dürbeck, T. Hüttenhofer, "International trade of medicinal and aromatic plants," in *Medicinal and Aromatic Plants of the World*, Á. Máthé, Ed. (Springer Netherlands, 2015), vol. 1, pp. 375–382.
86. M. A. Jimoh, M. O. Jimoh, S. A. Saheed, S. O. Bamigboye, C. P. Laubscher, L. Kambizi, "Commercialization of medicinal plants: Opportunities for trade and concerns for biodiversity conservation," in *Sustainable Uses and Prospects of Medicinal Plants*, L. Kambizi, C. Bvenura, Eds. (CRC Press, ed. 1, 2023), pp. 309–332.
87. L. Xiang, Z. Chen, S. Wei, H. Zhou, Global trade pattern of traditional Chinese medicines and China's trade position. *Front. Public Health* **10**, 865887 (2022).
88. P. M. Reidl, S. B. Ferguson, S. Zadek, M. Doncel, M. Atouguia. Legal and sustainable wild species trade: Learnings and implications for nature market governance. Taskforce on Nature Markets and TRAFFIC (2023); https://traffic.org/publications/reports/naturefinance-legal-and-sustainable-wild-species-trade/.
89. TRAFFIC. FairWild. Promoting sustainable harvesting, use and trade of wild plants (2025); https://traffic.org/what-we-do/thematic-issues/promoting-sustainable-trade/fairwild/.
90. D. Liang, X. Giam, S. Hu, L. Ma, D. S. Wilcove, Assessing the illegal hunting of native wildlife in China. *Nature* **623**, 100–105 (2023).
91. N. Ahlers, J. Creecy, G. Frankham, R. N. Johnson, A. Kotze, A. Linacre, R. McEwing, M. Mwale, J. J. Rovie-Ryan, F. Sitam, L. M. I. Webster, 'ForCyt' DNA database of wildlife species. *Forensic Sci. Int. Genet. Suppl. Ser.* **6**, e466–e468 (2017).
92. A. J. Lynam, D. T. Cronin, S. A. Wich, J. Steward, A. Howe, N. Kolla, M. Markovina, O. Torrico, V. Reyes, K. Sophalrachana, X. Stevens, E. Schmidt, H. Cox, The rising tide of conservation technology: Empowering the fight against poaching and unsustainable wildlife harvest. *Front. Ecol. Evol.* **13**, 1527976 (2025).
93. M. Utermohlen, P. Baine. In Plane Sight. Wildlife Crimes in the Air Transport Sector (2018); https://globalinitiative.net/wp-content/uploads/2018/08/In-Plane-Sight-Wildlife-Trafficking-in-the-Air-Transport-Sector-C4ADS-ROUTES-2018.pdf.
94. W. Outhwaite. Addressing corruption in CITES documentation processes (2020); https://traffic.org/publications/reports/new-study-lifts-the-lid-on-addressing-corruption-in-cites-documentation-processes/#:~:text=They%20range%20from%20permit%20fraud,corruption%20that%20facilitates%20wildlife%20trafficking.
95. G. E. Rosen, K. F. Smith, Summarizing the evidence on the international trade in illegal wildlife. *Ecohealth* **7**, 24–32 (2010).
96. D. Stiles, I. Redmond, D. Cress, C. Nellemann, R. K. Formo. Stolen Apes—The Illicit Trade in Chimpanzees, Gorillas, Bonobos and Orangutans. A Rapid Response Assessment (2023); https://wedocs.unep.org/handle/20.500.11822/32463?show=full.
97. A. Van Roon, M. Maas, D. Toale, N. Tafro, J. Van Der Giessen, Live exotic animals legally and illegally imported via the main Dutch airport and considerations for public health. *PLOS ONE* **14**, e0220122 (2019).
98. S. Hu, Z. Liang, D. Liang, Y. Liu, J. Zhong, Q. Wei, T. M. Lee, Quantifying species biases among multidata sources on illegal wildlife trade and its implications for conservation. *Conserv. Biol.* **38**, e14351 (2024).
99. O. C. Stringham, S. Moncayo, E. Thomas, S. Heinrich, A. Toomes, J. Maher, K. G. W. Hill, L. Mitchell, J. V. Ross, C. R. Shepherd, P. Cassey, Dataset of seized wildlife and their intended uses. *Data Brief* **39**, 107531 (2021).
100. J. H. Tow, T. P. L. Nghiem, J. Choo, S. Chng, M. Rao, L. R. Carrasco, Two decades of changes in the global network of illegal wildlife trade. *Conserv. Biol.* **40**, e70196 (2026).
101. R. Prasad, G. Rausser, D. Zilberman, The economics of wildlife trade and consumption. *Annu. Rev. Resour. Econ.* **14**, 355–377 (2022).
102. J. M. W. Gippet, C. Bertelsmeier, Invasiveness is linked to greater commercial success in the global pet trade. *Proc. Natl. Acad. Sci. U.S.A.* **118**, e2016337118 (2021).
103. P. De Smedt, N. T. Jones, B. Kästle, J. Robla, I. S. C. Filho, S. Sfenthourakis, S. Taiti, K. Verheyen, K. Szlavecz, Rise of terrestrial isopods in the pet trade and the need for their inclusion in trade regulation. *Conserv. Biol.* **40**, e70166 (2026).
104. M. M. Quinlan, J. D. Mumford, S. Messori, W. R. Enkerlin, J. Shimura, L. Smith, B. Dass, C. F. Oliva, C. Nelson, R. Chand, G. Torres, Issues and gaps in international guidance and national regulatory systems affecting international live insect trade. *Rev. Sci. Tech.* **41**, 198–210 (2022).
105. L. B. Spee, S. J. Hazel, E. Dal Grande, W. S. J. Boardman, A.-L. Chaber, Endangered exotic pets on social media in the Middle East: Presence and impact. *Animals* **9**, 480 (2019).
106. H. Si, A. Hausmann, Z. Li, The exotic pet craze on Chinese social media: Trends, community dynamics, and conservation implications. *Biol. Conserv.* **311**, 111420 (2025).
107. R. Digirolamo, Understanding pet reptile preferences in Japan: An analysis using Yahoo! Chiebukuro and Google Trends. *Herpetological J* **35**, 146–154 (2025).
108. M. Sigaud, T. Kitade, C. Sarabian, Exotic animal cafés in Japan: A new fashion with potential implications for biodiversity, global health, and animal welfare. *Conserv. Sci. Pract.* **5**, e12867 (2023).
109. J. W. E. Dickey, C. Liu, E. Briski, C. Wolter, S. Moesch, J. M. Jeschke, Identifying potential emerging invasive non-native species from the freshwater pet trade. *People Nat.* **5**, 1948–1961 (2023).
110. K. A.-I. Nekaris, N. Campbell, T. G. Coggins, E. J. Rode, V. Nijman, Correction: Tickled to death: Analysing public perceptions of 'cute' videos of threatened species (slow lorises – *Nycticebus* spp.) on web 2.0 sites. *PLoS ONE* **8**, e69215 (2013).
111. K. Feddema, P. Harrigan, S. Wang, The dark and light sides of engagement: An analysis of user-generated content in wildlife trade online communities. *AJIS* **25**, 36 (2021).
112. T. Kubo, T. Mieno, S. Uryu, S. Terada, D. Veríssimo, Banning wildlife trade can boost the unregulated trade of threatened species. *Conserv. Lett.* **18**, e13077 (2025).
113. C.-H. Hsu, J. Kang, X. Zhao, S. Uryu, H. Imagawa, T. Endo, T. Kubo, Conservation implications from a decade of online wildlife trade for land hermit crabs. *Glob. Ecol. Conserv.* **62**, e03722 (2025).
114. G. J. Watson, S. Kohler, J.-J. Collins, J. Richir, D. Arduini, C. Calabrese, M. Schaefer, Can the global marine aquarium trade (MAT) be a model for sustainable coral reef fisheries? *Sci. Adv.* **9**, eadh4942 (2023).
115. OECD. *The Illegal Wildlife Trade in Southeast Asia: Institutional Capacities in Indonesia, Singapore, Thailand and Viet Nam, Illicit Trade* (OECD Publishing, 2019).
116. A. C. Lees, P. Yuda, The Asian songbird crisis. *Curr. Biol.* **32**, R1063–R1064 (2022).
117. S. Fiennes, N. Hardianto, S. D. Ansari, A. A. Dwiyahreni, T. Jackson, G. Holmes, C. Birchall, C. Hassall, Rethinking extinction "crises": The case of Asian songbird trade. *Camb. Prisms Extinct.* **2**, e15 (2024).

Downloaded from https://www.science.org on October 30, 2026

118. CITES. Seventy-fourth meeting of the Standing Committee Lyon (France), 7–11 March 2022. Missing sharks: A country review of catch, trade and management recommendations for CITES-listed shark species (2022); https://cites.org/sites/default/files/eng/com/sc/74/Inf/E-SC74-Inf-024.pdf.
119. CITES. Convention on International Trade in Endangered Species of Wild Fauna and Flora—Convention Text. Washington, D.C. (1973). https://cites.org/eng/disc/text.php.
120. F. Watters, P. Cassey, Fifty years of CITES listings: Evolving criteria, trends, and listing outcomes. *Biodivers. Conserv.* **35**, 35 (2026).
121. A. Haukka, J. Jürgens, J. Staerk, A. Lehikoinen, S. Bruslund, A. Santangeli, Aesthetic values predict bird trade, but the association varies across product types and trade regions. *Biol. Conserv.* **313**, 111572 (2026).
122. L. J. Evans, J. A. Baecher, B. R. Scheffers, Invasion risk posed by the pet trade. *Front. Ecol. Environ.* **23**, e2825 (2025).
123. J. L. Lockwood, D. J. Welbourne, C. M. Romagosa, P. Cassey, N. E. Mandrak, A. Strecker, B. Leung, O. C. Stringham, B. Udell, D. J. Episcopio-Sturgeon, M. F. Tlusty, J. Sinclair, M. R. Springborn, E. F. Pienaar, A. L. Rhyne, R. Keller, When pets become pests: The role of the exotic pet trade in producing invasive vertebrate animals. *Front. Ecol. Environ.* **17**, 323–330 (2019).
124. J. García-Moreno, Zoonoses in a changing world. *Bioscience* **73**, 711–720 (2023).
125. Legal Atlas. Legal Atlas (2026); https://legal-atlas.com/.
126. J. Gangi, G. A. Petrossian, M. Sosnowski, The role of transit countries in global wildlife trafficking. *Trends Organ. Crim.*, 10.1007/s12117-025-09572-6 (2025).
127. V. Nijman, C. R. Shepherd, The role of Asia in the global trade in CITES II-listed poison arrow frogs: Hopping from Kazakhstan to Lebanon to Thailand and beyond. *Biodivers. Conserv.* **19**, 1963–1970 (2010).
128. Government of Canada. Legality and sustainability (2025); https://natural-resources.canada.ca/forest-forestry/sustainable-forest-management/legality-sustainability.
129. European Commission. DG Environment Study on the need for, added value, and feasibility of (Lot 2) criminalising all trade in illegal wildlife across the EU. Reference Number: ENV/2023/OP/0017 (2025); https://circabc.europa.eu/ui/group/3f466d71-92a7-49eb-9c63-6cb0fadf29dc/library/13062c04-a41e-434a-837b-65e5ed2bda9f/details.
130. A. L. Rhyne, M. F. Tlusty, P. J. Schofield, L. Kaufman, J. A. Morris, A. W. Bruckner, Revealing the appetite of the marine aquarium fish trade: The volume and biodiversity of fish imported into the United States. *PLOS ONE* **7**, e35808 (2012).
131. D. Pauly, D. Zeller, Catch reconstructions reveal that global marine fisheries catches are higher than reported and declining. *Nat. Commun.* **7**, 10244 (2016).
132. D. Zeller, M. L. D. Palomares, A. Tavakolie, M. Ang, D. Belhabib, W. W. L. Cheung, V. W. Y. Lam, E. Sy, G. Tsui, K. Zylich, D. Pauly, Still catching attention: *Sea Around Us* reconstructed global catch data, their spatial expression and public accessibility. *Mar. Policy* **70**, 145–152 (2016).
133. J. Barendse, A. Roel, C. Longo, L. Andriessen, L. M. I. Webster, R. Ogden, F. Neat, DNA barcoding validates species labelling of certified seafood. *Curr. Biol.* **29**, R198–R199 (2019).
134. MSC. Find a supplier (2025); https://www.msc.org/en-au/for-business/supply-chain/find-sustainable-seafood-suppliers.
135. A. Standing. TAKING STOCK—Online Transparency of Fisheries Management Information. 2024 Summary Assessment Report | Republic Of Indonesia. Fisheries Transparency Initiative (2025); https://fiti.global/wp-content/uploads/2025/07/FiTI_IDN_TaSo_SummaryAssessmentReport_EN_20250721.pdf.
136. M. Schaafsma, N. D. Burgess, R. D. Swetnam, Y. M. Ngaga, R. Kerry Turner, T. Treue, Market signals of unsustainable and inequitable forest extraction: Assessing the value of illegal timber trade in the Eastern Arc Mountains of Tanzania. *World Dev.* **62**, 155–168 (2014).
137. P. J. Platts, M. Schaafsma, R. K. Turner, N. D. Burgess, B. Fisher, B. P. Mbilinyi, P. K. T. Munishi, T. H. Ricketts, R. D. Swetnam, A. Ahrends, B. B. Ashagre, J. Bayliss, R. E. Gereau, J. M. H. Green, R. E. Green, L. Jeha, S. L. Lewis, R. Marchant, A. R. Marshall, S. Morse-Jones, S. Mwakalila, M. A. Njana, D. D. Shirima, S. Willcock, A. Balmford, Inequitable gains and losses from conservation in a global biodiversity hotspot. *Environ. Resource Econ.* **86**, 381–405 (2023).
138. A. Mgaza. TNRC Practice Note | Tracking the trade: Increasing efficiency and transparency in Tanzania's timber sector. TRAFFIC – East Africa (2022); https://assets.worldwildlife.org/www-prd/documents/7kwlmro4p9_Tanzania_Timber_Tracker_Final_.pdf.
139. D. Datta, N. Self, J. Simeone, A. Meadows, W. Outhwaite, L. Walker, N. Elmqvist, N. Ramakrishnan, TimberSleuth: Visual anomaly detection with human feedback for mitigating the illegal timber trade. *Inf. Vis.* **22**, 223–245 (2023).
140. D. Datta, J. C. Simeone, A. Meadows, W. Outhwaite, H. Keong Chen, N. Self, L. Walker, N. Ramakrishnan, Combating trade in illegal wood and forest products with machine learning. *PLOS ONE* **20**, e0311982 (2025).
141. Basel Institute on Governance. Wildlife crime—Understanding risks, avenues for action Part 4: Corruption in marine wildlife trafficking. Basel: Basel Institute on Governance (2021); https://baselgovernance.org/publications/wildlife-crime-series.
142. K. Friedman, S. Gabriel, O. Abe, A. Adnan Nuruddin, A. Ali, R. B. R. Hassan, S. X. Cadrin, A. Cornish, T. De Meulenaer, Dharmadi, Fahmi, L. H. T. Anh, D. Kachelriess, L. Kissol, T. Krajangdara, A. R. Wahab, W. Tanoue, C. Tharith, F. Torres, W. Wanchana, S. Win, K. Yokawa, Y. Ye, Examining the impact of CITES listing of sharks and rays in Southeast Asian fisheries. *Fish Fish.* **19**, 662–676 (2018).
143. F. M. Stein, V. Nijman, M. C. W. Lau, W. Dekker, Inclusion of all *Anguilla* eel species in CITES Appendix II will support their sustainable management across the globe. *Aquat. Conserv.* **35**, e70238 (2025).
144. A. I. Alonso, D. P. Van Uhm, The illegal trade in European eels: Outsourcing, funding, and complex symbiotic-antithetical relationships. *Trends Organ. Crim.* **26**, 293–307 (2023).
145. M. Pons-Hernandez, Inside the slippery world of glass eel trafficking: Lessons learned from Spain to prevent the illegal trade of European eels. *Eur. J. Crim.* **21**, 908–928 (2024).
146. K. Kaifu, Y.-S. Han, H. Shiraishi, Global consumption of threatened freshwater eels revealed by integrating DNA barcoding, production data, and trade statistics. *Sci. Rep.* **15**, 29968 (2025).
147. S. J. Foster, S. J. Ascione, F. Santaniello, T. N. Phelps Bondaroff, Using online reports of seahorse seizures to track their illegal trade. *Conserv. Biol.* **39**, e70047 (2025).
148. J. L. Richards, V. Sheng, C. W. Yi, C. L. Ying, N. S. Ting, Y. Sadovy, D. Baker, Prevalence of critically endangered European eel (*Anguilla anguilla*) in Hong Kong supermarkets. *Sci. Adv.* **6**, eaay0317 (2020).
149. C. Schindler, E. Heral, E. Drinkwater, A. Timoshyna, G. Muir, S. Walter, D.J. Leaman, U. Schippmann. Wildcheck—Assessing the Risks and Opportunities of Trade in Wild Plant Ingredients (FAO, 2022); http://fao.org/documents/card/en/c/cb9267en.
150. U.R. Charrondiere, B. Stadlmayr, F. Grande, A. Vincent, M. Oseredczuk, S. Sivakumaran, P. Puwastien, K. Judprasong, D. Haytowitz, P. Gnagnarella. *FAO/INFOODS Evaluation Framework to Assess the Quality of Published Food Composition Tables and Databases—User Guide* (FAO, 2023).
151. M. Jenkins, A. Timoshyna, M. Cornthwaite. Wild at Home: Exploring the global harvest, trade and use of wild plant ingredients (2018); https://traffic.org/site/assets/files/7339/wild-at-home.pdf.
152. M. V. Biondo, R. Calado, The European Union is still unable to find Nemo and Dory—Time for a reliable traceability system for the marine aquarium trade. *Animals* **11**, 1668 (2021).
153. L. Roberson, G. Hosch, C. Wilcox, R. M. Domiguez-Martinez, G. Sant, C. Klein, A new seafood import policy for nations to combat illegal fishing. *Conserv. Lett.* **18**, e13091 (2025).
154. CITES. Conf. 16.7 (Rev. CoP17) Non-detriment findings (2016); https://cites.org/eng/node/134704.
155. A. Jackson, D. P. Edwards, O. Morton, National spatial and temporal patterns of the global wildlife trade. *Glob. Ecol. Conserv.* **48**, e02742 (2023).
156. O. Morton, V. Nijman, D. P. Edwards, International wildlife trade quotas are characterized by high compliance and coverage but insufficient adaptive management. *Nat. Ecol. Evol.* **8**, 2048–2057 (2024).
157. D. Roe, A. Timoshyna, P. Aust, J. Compton, O. Dar, J. Donaldson, N. Dudley, T. Grillo, C. Hiller, R. Hoffmann, J.-M. Kilian, C. Lippai, N. Long, J. MacGregor, S. Marsh, D. Natusch, M. K. S. Pasha, A. Taylor, F. Vorhies, O. Wilson-Holt, Fifty shades of sustainability? A new five-dimensional framework for assessing sustainability of wild species use. *PLOS Sustain. Transform.* **4**, e0000196 (2025).
158. J. R. Nielsen, E. Thunberg, D. S. Holland, J. O. Schmidt, E. A. Fulton, F. Bastardie, A. E. Punt, I. Allen, H. Bartelings, M. Bertignac, E. Bethke, S. Bossier, R. Buckworth, G. Carpenter, A. Christensen, V. Christensen, J. M. Da-Rocha, R. Deng, C. Dichmont, R. Doering, A. Esteban, J. A. Fernandes, H. Frost, D. Garcia, L. Gasche, D. Gascuel, S. Gourguet, R. A. Groeneveld, J. Guillén, O. Guyader, K. G. Hamon, A. Hoff, J. Horbowy, T. Hutton, S. Lehuta, L. R. Little, J. Lleonart, C. Macher, S. Mackinson, S. Mahevas, P. Marchal, R. Mato-Amboage, B. Mapstone, F. Maynou, M. Merzéréaud, A. Palacz, S. Pascoe, A. Paulrud, E. Plaganyi, R. Prellezo, E. I. Van Putten, M. Quaas, L. Ravn-Jonsen, S. Sanchez, S. Simons, O. Thébaud, M. T. Tomczak, C. Ulrich, D. Van Dijk, Y. Vermard, R. Voss, S. Waldo, Integrated ecological–economic fisheries models—Evaluation, review and challenges for implementation. *Fish Fish.* **19**, 1–29 (2018).
159. Sustainable Fisheries Partnership. Year in Review; Highlights from 2025 (2025); https://sustainablefish.org/about-us/years-in-review/2025-year-in-review/.
160. C. Bellmann, A. Tipping, U. R. Sumaila, Global trade in fish and fishery products: An overview. *Mar. Policy* **69**, 181–188 (2016).
161. M. Memarzadeh, G. L. Britten, B. Worm, C. Boettiger, Rebuilding global fisheries under uncertainty. *Proc. Natl. Acad. Sci. U.S.A.* **116**, 15985–15990 (2019).
162. D. Pauly, D. Zeller, M. L. D. Palomares, Eds. Sea Around Us Concepts, Design and Data (seaaroundus.org) (2020).
163. C. Costello, D. Ovando, T. Clavelle, C. K. Strauss, R. Hilborn, M. C. Melnychuk, T. A. Branch, S. D. Gaines, C. S. Szuwalski, R. B. Cabral, D. N. Rader, A. Leland, Global fishery prospects under contrasting management regimes. *Proc. Natl. Acad. Sci. U.S.A.* **113**, 5125–5129 (2016).
164. T. A. Branch, O. P. Jensen, D. Ricard, Y. Ye, R. Hilborn, Contrasting global trends in marine fishery status obtained from catches and from stock assessments. *Conserv. Biol.* **25**, 777–786 (2011).
165. G. J. Edgar, A. E. Bates, N. C. Krueck, S. C. Baker, R. D. Stuart-Smith, C. J. Brown, Stock assessment models overstate sustainability of the world's fisheries. *Science* **385**, 860–865 (2024).

Downloaded from https://www.science.org on October 30, 2026

166. H. Ritchie, M. Roser, M. "Fish and Overfishing," published online at OurWorldinData.org (2021); https://ourworldindata.org/fish-and-overfishing.
167. E. Gilman, M. Hall, H. Booth, T. Gupta, M. Chaloupka, H. Fennell, M. J. Kaiser, D. Karnad, E. J. Milner-Gulland, A decision support tool for integrated fisheries bycatch management. *Rev. Fish Biol. Fish.* **32**, 441–472 (2022).
168. A. Dasnon, K. Delord, A. Chaigne, C. Barbraud, Fisheries bycatch mitigation measures as an efficient tool for the conservation of seabird populations. *J. Appl. Ecol.* **59**, 1674–1685 (2022).
169. S. Hočevar, A. Kuparinen, Marine food web perspective to fisheries-induced evolution. *Evol. Appl.* **14**, 2378–2391 (2021).
170. H. Booth, S. Pooley, T. Clements, M. I. H. Putra, W. P. Lestari, S. Lewis, L. Warwick, E. J. Milner-Gulland, Assessing the impact of regulations on the use and trade of wildlife: An operational framework, with a case study on manta rays. *Glob. Ecol. Conserv.* **22**, e00953 (2020).
171. V. A. Richardson, C. A. Peres, Temporal decay in timber species composition and value in Amazonian logging concessions. *PLOS ONE* **11**, e0159035 (2016).
172. J. N. Sanchirico, T. E. Essington, Direct and ancillary benefits of ecosystem-based fisheries management in forage fish fisheries. *Ecol. Appl.* **31**, e02421 (2021).
173. M. R. C. Brown, V. K. Wells, C. M. Beale, Assessing the integration of social marketing principles in ivory demand management interventions in China and Southeast Asia. *Conserv. Biol.* **40**, e70191 (2026).
174. J. M. Murray, S. R. Alewijnse, O. Harrod, D. Hughes, I. MacMillan, C. Popham, E. Roebuck, A high-resolution species-level dataset of global marine ornamental imports into the United Kingdom. *Sci. Data* 10.1038/s41597-026-07852-6 (2026).
175. M. F. Tlusty, D.-M. Cawthorn, O. L. B. Goodman, A. L. Rhyne, D. L. Roberts, Real-time automated species level detection of trade document systems to reduce illegal wildlife trade and improve data quality. *Biol. Conserv.* **281**, 110022 (2023).
176. M. F. Tlusty, P. Cassey, A. L. Rhyne, D. A. Omrow, P. Stoett, Species-level, digitized wildlife trade data are essential for achieving biodiversity targets. *Proc. Natl. Acad. Sci. U.S.A.* **121**, e2306869121 (2024).
177. V. Nijman, F. M. Stein, Meta-analyses of molecular seafood studies identify the global distribution of legal and illegal trade in CITES-regulated European eels. *Curr. Res. Food Sci.* **5**, 191–195 (2022).
178. F. M. Stein, J. Frankowski, V. Nijman, C. Absil, I. Kranendonk, W. Dekker, Chinese eel products in EU markets imply the effectiveness of trade regulations but expose fraudulent labelling. *Mar. Policy* **132**, 104651 (2021).
179. Gov.UK. Keeping sheep and goats in England (2024); https://gov.uk/government/collections/keeping-sheep-and-goats-in-england.
180. DEFRA. Electronic identification (EID) in sheep. Your technical guide (2009); https://assets.publishing.service.gov.uk/media/5a79e592e5274a684690ce13/pb13616-sheep-eid-technical-guide-091127.pdf.
181. AHDB. UK cattle and sheep populations continue to contract in Defra's June survey: Beef and lamb market update (2025); https://ahdb.org.uk/news/uk-cattle-and-sheep-populations-continue-to-contract-in-defra-s-june-survey-beef-and-lamb-market-update.
182. T. Gupta, R. Bashyal, M. Anagnostou, S. Dhanda, J. Djagoun, L. M. Feitosa, C. E. R. Hatten, S. B. Hunter, T. S. Mutezo, W. Nurbandi, A. Pizarro Choy, H. N. K. Sackey, E. Milner-Gulland, T. E. E. Oldfield, D. W. S. Challender, Resolving uncertainties in the legality of wildlife trade to support better outcomes for wildlife and people. *Conserv. Lett.* **18**, e13110 (2025).
183. WWF. From algorithms to action: Disrupting wildlife trafficking in maritime supply chains. WWF Bhutan (2025); www.wwfbhutan.org.bt/?390375/From-Algorithms-to-Action-Disrupting-Wildlife-Trafficking-in-Maritime-Supply-Chains.
184. TRAFFIC. How to spot the warning signs of wildlife crime in the maritime industry (2021); https://traffic.org/publications/reports/how-to-spot-the-warning-signs-of-wildlife-crime-in-the-maritime-industry/.
185. G. K. Moloney, N. M. Shute, G. G. Brien, J. Moloney, A.-L. Chaber, Combining detection dogs with air extraction methodology to expose wildlife trafficking in containerized cargo. *Conserv. Biol.* **40**, e70225 (2026).
186. WWF. Countering wildlife trafficking through automated detection at ports (2026); https://worldwildlife.org/our-work/wildlife/wildlife-crime/countering-wildlife-trafficking-through-automated-detection-at-ports/.
187. GI-TOC. Monitoring illegal wildlife trade: Maritime and marine dimensions. Global Initiative Against Transnational Organized Crime (2025); https://globalinitiative.net/wp-content/uploads/2025/06/Monitoring-illegal-wildlife-trade-Maritime-and-marine-dimensions-GI-TOC-June-2025.pdf.
188. Themis. Project IWT: Illegal wildlife trade toolkit (2022); https://wearethemis.com/uk/resources/project-iwt/project-illegal-wildlife-trade.
189. CGI. Project SEEKER—An AI model to detect illegal wildlife trafficking at borders (2026); https://cgi.com/uk/en-gb/case-study/aerospace/project-seeker-ai-model-detect-illegal-wildlife-trafficking-borders.
190. J. Rinne, R. Kulkarni, A. Soriano-Redondo, R. Correia, E. Di Minin, Using automated content analysis to monitor global online trade in endemic reptile species. *Divers. Distrib.* **31**, e13771 (2025).
191. N. Fox, E. Di Minin, N. Carter, S. Tomkins, D. Van Berkel, Balancing accessibility and security: Safeguarding citizen-sourced biodiversity data in the age of AI and open-sourced software. *Eco. Inform.* **92**, 103443 (2025).
192. D. W. S. Challender, A. C. Hughes, M. T. Sas-Rolfes, A. Hinsley, Assessing a reverse approach to protecting traded species. *Nat. Ecol. Evol.* **10**, 1582–1584 (2026).
193. A. C. Hughes, R. E. Grumbine, The Kunming-Montreal Global Biodiversity Framework: What it does and does not do, and how to improve it. *Front. Environ. Sci.* **11**, 1281536 (2023).
194. EUR-LEX. Directive 2009/147/EC of the European Parliament and of the Council of 30 November 2009 on the conservation of wild birds (Codified version) (2009); https://eur-lex.europa.eu/eli/dir/2009/147/oj/eng.
195. FWS. Wild Bird Conservation Act (2017). https://fws.gov/law/wild-bird-conservation-act.
196. S. N. Rivera, A. Knight, S. P. McCulloch, Surviving the wildlife trade in Southeast Asia: Reforming the 'disposal' of confiscated live animals under CITES. *Animals* **11**, 439 (2021).
197. A. Saito, Where the wild things are...stored? The management and return of seized wildlife. *Front. Conserv. Sci.* **5**, 1489314 (2025).
198. C. Vergneau-Grosset, R. Watanabe, M. V. Smith, I. Sladakovic, Legislative differences governing exotic animal practice. *Vet. Clin. North Am. Exot. Anim. Pract.* **27**, 465–487 (2024).
199. M. V. Biondo, R. P. Burki, Monitoring the trade in marine ornamental fishes through the European Trade Control and Expert System TRACES: Challenges and possibilities. *Mar. Policy* **108**, 103620 (2019).
200. R. Oyanedel, M. Levi, G. Furci, A call to include fungi in wildlife trade research and policy. *Conserv. Biol.* **38**, e14340 (2024).
201. V. Nijman, North Africa as a source for European eel following the 2010 EU CITES eel trade ban. *Mar. Policy* **85**, 133–137 (2017).
202. P. De Frutos, Changes in world patterns of wild edible mushrooms use measured through international trade flows. *For. Policy Econ.* **112**, 102093 (2020).
203. CITES. CITES trade portals (2025); https://trade.cites.org/, https://tradeview.cites.org/.
204. CITES. Twentieth meeting of the Conference of the Parties Samarkand (Uzbekistan), 24 November – 5 December 2025 Committee I Draft decisions on resolving the implementation of the CoP12 decision that the Convention applies to fungi (2025); https://cites.org/sites/default/files/documents/E-CoP20-Com-I-01.pdf.
205. IUCN. The IUCN Red List of Threatened Species. Version 2025-2 (2025). https://iucnredlist.org.
206. CWP (Coordinating Working Party on Fishery Statistics Secretariat). ASFIS list of species for fishery statistics purposes. v.2020.1 (2020); http://fao.org/.
207. TRAFFIC International. Wildlife Trade Portal (2026); www.wildlifetradeportal.org.
208. IWT Project. IWT Project Map & Database (2025); https://illegalwildlifetradeprojects.org/project-map-and-database/.
209. J. Jürgens, J. Staerk, S. Bruslund, R. O. Nielsen, D. A. Conde, CITES Appendix III matters: Hidden impacts of CITES deletions on global bird trade. *Biol. Conserv.* **310**, 111365 (2025).
210. C. R. Lassaline, A. Toomes, E. Fagan-Jeffries, P. Cassey, From forest floor to market door: The global terrestrial invertebrate trade. *Biol. Conserv.* **308**, 111266 (2025).
211. GBIF Secretariat. GBIF Backbone Taxonomy. Checklist dataset (2023); https://doi.org/10.15468/39omei.
212. S. Chamberlain, E. Szocs, taxize: Taxonomic search and retrieval in R. *F1000Res.* **2**, 191 (2013).
213. S. Chamberlain, E. Szoecs, Z. Foster, Z. Arendsee, C. Boettiger, K. Ram, I. Bartomeus, J. Baumgartner, J. O'Donnell, J. Oksanen, B. G. Tzovaras, P. Marchand, V. Tran, M. Salmon, G. Li, M. Grenié, Taxize: Taxonomic Information from around the Web (2020); https://github.com/ropensci/taxize.
214. D. R. Frost, Amphibian Species of the World: An Online Reference (2026).
215. IOC. IOC World Bird List (v13.1). F. Gill, D. Donsker, P. Rasmussen, Eds. (2025) https://www.worldbirdnames.org/new/ioc-lists/master-list-2/.
216. FishBase. World Wide Web electronic publication. R. Froese, D. Pauly, Eds. (2026); www.fishbase.org.
217. Reptile Database. The Reptile Database. P. Uetz, P. Freed, R. Aguilar, F. Reyes, J. Kudera, J. Hošek, Eds. (2026); http://reptile-database.org.
218. C. J. Burgin, J. S. Zijlstra, M. A. Becker, H. Handika, J. M. Alston, J. Widness, S. Liphardt, D. G. Huckaby, N. S. Upham, How many mammal species are there now? Updates and trends in taxonomic, nomenclatural, and geographic knowledge. bioRxiv 640393 [Preprint] (2025). https://doi.org/10.1101/2025.02.27.640393.
219. E. A. Eskew, A. M. White, N. Ross, K. M. Smith, K. F. Smith, J. P. Rodríguez, C. Zambrana-Torrelio, W. B. Karesh, P. Daszak, United States LEMIS wildlife trade data curated by EcoHealth Alliance, version 1.1.0, Zenodo (2019); https://doi.org/10.5281/ZENODO.3565869.
220. E. A. Eskew, A. M. White, N. Ross, K. M. Smith, K. F. Smith, J. P. Rodríguez, C. Zambrana-Torrelio, W. B. Karesh, P. Daszak, United States wildlife and wildlife product imports from 2000–2014. *Sci. Data* **7**, 22 (2020).
221. A. C. Hughes, B. M. Marshall, C. T. Strine, Gaps in global wildlife trade monitoring leave amphibians vulnerable. *eLife* **10**, e70086 (2021).

Downloaded from https://www.science.org on October 30, 2026

222. N. P. Mohanty, J. Measey, The global pet trade in amphibians: Species traits, taxonomic bias, and future directions. *Biodivers. Conserv.* **28**, 3915–3923 (2019).
223. P. F. Donald, E. Fernando, L. Brown, M. Busana, S. H. M. Butchart, S. Chng, A. De La Colina, J. M. Ferreira, A. Jain, V. R. Jones, R. Lapido, K. Malsch, A. McDougall, C. Muccio, D. Nguyen, W. Outhwaite, S. O. Petrovan, C. Stafford, W. J. Sutherland, O. Tallowin, R. Safford, Assessing the global prevalence of wild birds in trade. *Conserv. Biol.* **38**, e14350 (2024).
224. SiTDB. Songbirds in Trade Database v1.0 (2025); https://sitdb.org/frm_display/search/?common=&scientific=&redlist=&EiT=Yes&PWC=&CCDT=&CCIT=&RPDTT=&LDCB=&CBE=&SBAP=&KAS=.
225. Krassowski M. krassowski/complex-upset. Zenodo (2020); http://doi.org/10.5281/zenodo.3700590.
226. A. Lex, N. Gehlenborg, H. Strobelt, R. Vuillemot, H. Pfister, UpSet: Visualization of intersecting sets. *IEEE Trans. Visual. Comput. Graphics* **20**, 1983–1992 (2014).
227. H. Wickham. *ggplot2: Elegant Graphics for Data Analysis* (Springer-Verlag, 2016).
228. T. Van Den Brand, legendry: Extended Legends and Axes for "ggplot2" (2024); https://doi.org/10.32614/CRAN.package.legendry.
229. T. Pedersen. patchwork: The Composer of Plots. R package version 1.3.2 (2025); https://CRAN.R-project.org/package=patchwork.
230. R Core Team. _R: A Language and Environment for Statistical Computing_. R Foundation for Statistical Computing, Vienna, Austria (2024); https://R-project.org/.
231. K. Müller. _here: A Simpler Way to Find Your Files_. R package version 1.0.1 (2020); https://CRAN.R-project.org/package=here.
232. H. Wickham, R. François, L. Henry, K. Müller, D. Vaughan, Dplyr: A Grammar of Data Manipulation (2026); https://CRAN.R-project.org/package=dplyr.
233. H. Wickham, D. Vaughan, M. Girlich, Tidyr: Tidy Messy Data (2025); https://CRAN.R-project.org/package=tidyr.
234. H. Wickham, Stringr: Simple, Consistent Wrappers for Common String Operations (2025); https://CRAN.R-project.org/package=stringr.
235. A. Hughes, B. M. Marshall, D. W. S. Challender, D. P. Edwards, E. A. Eskew, J. Lockwood, O. Morton, K. Malsch, C. S. Fukushima, A. Hinsley, V. Nijman, S. Meiri, S. Baruch-Mordo, M. F. Tlusty, R. Oyanedel, J. Jürgens, S. Pironon, A. T. Pavitt, N. Demirel, M. R. C. Brown, O. J. S. Tallowin, K. Friedman, R. Sharma, N. D. Burgress, Appearance of species in trade data sources: Supplementary data for The true scale of global wildlife trade is obscured by data gaps (2026), doi:10.26188/33194898. https://figshare.com/s/b05b15f87a58dd65eb1e.
236. EU Commission. Commission staff working document. Evaluation of the EU action plan against wildlife trafficking. Accompanying the document. Communication from the commission to the European parliament, the council, the European economic and social committee and the committee of the regions. Revision of the EU action plan against wildlife trafficking. {COM(2022) 581 final} - {SWD(2022) 355 final} (2022); https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:52022SC0354.
237. O. H. Armstrong, R. Wong, A. Lorenzo, A. Sidik, G. Sant, S. C. L. Chng. Illegal Wildlife Trade: Baseline for monitoring and law enforcement in the Sulu-Celebes Seas. TRAFFIC, Petaling Jaya, Malaysia (2023).
238. P. W. Ellis, T. Gopalakrishna, R. C. Goodman, F. E. Putz, A. Roopsind, P. M. Umunay, J. Zalman, E. A. Ellis, K. Mo, T. G. Gregoire, B. W. Griscom, Reduced-impact logging for climate change mitigation (RIL-C) can halve selective logging emissions from tropical forests. *For. Ecol. Manag.* **438**, 255–266 (2019).
239. S. Upadhaya, B. Poudyal, C. Tumpach, Integrating divergent stakeholder perspectives for sustainable management of high-altitude ecosystems: Insights from cordyceps harvesting in the Himalayas. *Sustain Sci.* **20**, 207–217 (2025).
240. M. B. Pildain, S. B. Visnovsky, C. Barroetaveña, Phylogenetic diversity of true morels (*Morchella*), the main edible non-timber product from native Patagonian forests of Argentina. *Fungal Biol.* **118**, 755–763 (2014).
241. CITES. Disposal of illegally traded and confiscated specimens of CITES listed species in CITES CoP19 (Resolution conf. 17.8 (Rev. CoP19)) (2022); https://cites.org/eng/imp/Disposal_of_confiscated_specimen [accessed November 2025].
242. B. T. C. Leupen. Black Spotted Turtle in Asia II: A Seizure Analysis. TRAFFIC, Petaling Jaya, Selangor, Malaysia (2018).
243. IUCN. Guidelines for the management of confiscated, live organisms. Gland, Switzerland: IUCN. iv + 38 pp. (2019); https://iucn.org/resources/publication/guidelines-management-confiscated-live-organisms [accessed November 2025].
244. T. N. E. Gray, N. Marx, V. Khem, D. Lague, V. Nijman, S. Gauntlett, Holistic management of live animals confiscated from illegal wildlife trade. *J. Appl. Ecol.* **54**, 726–730 (2017).
245. G. F. G. Destro, V. De Fernandes, A. F. A. De Andrade, P. De Marco, L. C. Terribile, Back home? Uncertainties for returning seized animals to the source-areas under climate change. *Glob. Change Biol.* **25**, 3242–3253 (2019).
246. B. Brownell. Remember when a dutch airline put 440 squirrels into a giant shredder? When you have too many squirrels around, just feed them by hand into a wood chipper (2024); https://jalopnik.com/remember-when-a-dutch-airline-put-440-squirrels-into-a-1851573516/.
247. V. Nijman, M. Campera, E. Sintya, D. K. T. Sukmadewi, N. G. M. Putra, Kuntayuni, R. A. Widiaswari, C. R. Shepherd, I. N. A. D. Payuse, J. Chavez, Policies, law enforcement and sustainable use of nautilus shells in Indonesia and the effect of the 2017 CITES Appendix II listing on their trade. *Discov. Conserv.* **1**, 17 (2024).
248. D. L. Roberts, A. Hinsley, The seven forms of challenges in the wildlife trade. *Trop. Conserv. Sci.* **13**, 1940082920947023 (2020).
249. CITES. AC34 Doc. 23. Thirty-fourth meeting of the Animals Committee. Geneva (Switzerland), 13–17 July 2026. Regulation of trade. Trade in stony corals (*Scleractinia* spp.); https://cites.org/sites/default/files/documents/AC/34/agenda/E-AC34-23.pdf.
250. CITES. Notif. 2025/21Guidelines for the preparation and submission of CITES annual reports (February 2025); https://cites.org/eng/node/142528.

Acknowledgments

Funding: N.D.B. was supported by the European Union's Horizon Europe Research and Innovation Programme under grant agreement no. 101133983, project more4nature. **Author contributions:** Conceptualization: A.C.H., N.D.B., J.L.L., R.S., D.P.E., M.F.T., and N.D. Methodology: B.M.M. and A.C.H. Investigation: A.C.H., B.M.M., K.F., S.M., V.N., R.S., and N.D. Validation: A.C.H., B.M.M., K.F., V.N., D.W.S.C., R.S., and M.F.T. Formal analysis: B.M.M., A.C.H., R.S., and D.W.S.C. Resources: A.C.H., K.F., N.D.B., S.M., and S.P. Data curation: B.M.M., A.C.H., and K.F. Writing—original draft: A.C.H., B.M.M., N.D.B., K.F., A.H., O.M., and R.S. Writing—review and editing: A.C.H., B.M.M., N.D.B., K.F., A.H., S.M., K.M., V.N., J.L.L., R.O., C.F., M.R.C.B., D.W.S.C., A.T.P., O.M., R.S., O.J.S.T., D.P.E., J.J., S.P., S.B.-M., M.F.T., E.A.E., and N.D. Visualization: B.M.M., A.C.H., M.F.T., V.N., J.L.L., and D.W.S.C. Supervision: A.C.H. Project administration: A.C.H. and K.F. Funding acquisition: A.C.H. **Competing interests:** V.N. directs EcoVerde Global Consulting and D.W.S.C. has consulted for Jamma Conservation and Communities; neither of these affected analysis or interpretation of data, or provided funds but are being disclosed to provide full transparency. All other authors declare that they have no competing interests. **Data, code, and materials availability:** All data and code needed to evaluate and reproduce the results in the paper are present in the paper and/or the Supplementary Materials. This study did not generate new materials. Preharmonized lists of species from the data sources are available as data S1 and are additionally available at Figshare (*235*). Derived species list and their appearance in data sources are all available as data S2 and are additionally available at Figshare (*235*): https://figshare.com/s/b05b15f87a58dd65eb1e. All other summarized data are provided as Supplementary Materials (data S3 to S5). Code used to harmonize names and present key results is available as Supplementary Materials (codes S1 to S3). Original data used to create combined lists can be obtained from the original sources: https://doi.org/10.1038/s41467-020-18523-4 (*22*); https://doi.org/10.1073/pnas.2410774121 (*23*); https://doi.org/10.1016/j.biocon.2023.110092 (*24*); https://doi.org/10.1038/s42003-022-03374-0 (*30*); https://tradeview.cites.org/ (*203*); https://iucnredlist.org (*205*); http://fao.org/ (*206*); www.wildlifetradeportal.org (*207*); https://doi.org/10.1016/j.biocon.2025.111266 (*210*); https://doi.org/10.5281/ZENODO.3565869 (*219*); https://doi.org/10.1038/s41597-020-0354-5 (*220*); https://doi.org/10.7554/eLife.70086 (*221*); https://doi.org/10.1007/s10531-019-01857-x (*222*); https://doi.org/10.1111/cobi.14350 (*223*); and https://sitdb.org/frm_display/search/?common=&scientific=&redlist=&EiT=Yes&PWC=&CCDT=&CCIT=&RPDTT=&LDCB=&CBE=&SBAP=&KAS= (*224*).

Submitted 25 April 2026
Accepted 1 October 2026
Published 30 October 2026
10.1126/sciadv.aei3504

Downloaded from https://www.science.org on October 30, 2026

ScienceAdvances

The true scale of global wildlife trade is obscured by data gaps

Alice C. Hughes, Benjamin Michael Marshall, Daniel W. S. Challender, David P. Edwards, Evan A. Eskew, Julie L. Lockwood, Oscar Morton, Kelly Malsch, Caroline Fukushima, Amy Hinsley, Vincent Nijman, Shai Meiri, Sharon Baruch-Mordo, Michael F. Tlusty, Rodrigo Oyanedel, Jacqueline Jürgens, Samuel Pironon, Alyson T. Pavitt, Nazli Demirel, Molly R. C. Brown, Oliver J. S. Tallowin, Kim Friedman, Rishi Sharma, and Neil D. Burgess

Sci. Adv. **12** (44), eaei3504. DOI: 10.1126/sciadv.aei3504

View the article online
https://www.science.org/doi/10.1126/sciadv.aei3504
Permissions
https://www.science.org/help/reprints-and-permissions

Downloaded from https://www.science.org on October 30, 2026

Use of this article is subject to the Terms of service

Science Advances (ISSN 2375-2548) is published by the American Association for the Advancement of Science. 1200 New York Avenue NW, Washington, DC 20005. The title *Science Advances* is a registered trademark of AAAS.

Copyright © 2026 The Authors, some rights reserved; exclusive licensee American Association for the Advancement of Science. No claim to original U.S. Government Works. Distributed under a Creative Commons Attribution NonCommercial License 4.0 (CC BY-NC).