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FRONT MATTER

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

Global gaps in wildlife trade data

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], Amy Hinsley[10], Vincent Nijman[11], Shai Meiri[1], Sharon Baruch-Mordo[12], Michael F. Tlusty[13], Rodrigo Oyanedel[14], Jacqueline Jürgens[15], Samuel Pironon[16], Alyson T. Pavitt[8], Nazli Demirel[17], Molly R. C. Brown[18], Oliver J. S. Tallowin[18], Kim Friedman[19], Rishi Sharma[19], Neil D. Burgess[8,21]

[1.] School of BioSciences, University of Melbourne, Royal Parade, Melbourne, Vic alice.c.hughes@unimelb.edu.au.

[2] School of Biodiversity, One Health and Veterinary Medicine, University of Glasgow, UK. [£] Contributed equally.

[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 and Centre for Global Wood Security, University of Cambridge, Cambridge, UK, Conservation Research Institute, University of Cambridge, Cambridge, UK

[5.] Institute for Interdisciplinary Data Sciences, University of Idaho, Moscow, Idaho, USA

[6.] Rutgers Climate and Energy Institute, Rutgers University, New Jersey, USA; Department of Ecology, Evolution, and Natural Resources, Rutgers University, New Jersey, 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 and 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

[10] (Interdisciplinary Centre for Conservation Science; Wildlife Conservation Research Unit; Oxford Martin Programme on Wildlife Trade) Department of Biology, University of Oxford, Oxford, UK

[11] Oxford Wildlife Trade Research Group, Oxford Brookes University, Oxford, UK and EcoVerde Global Consulting, Sacramento, USA and Oxford, UK

[12] TRAFFIC International, Cambridge, UK

[13] School for the Environment, University of Massachusetts Boston, Boston MA, USA and Global Ocean Conservation Program, Monterey Bay Aquarium, Monterey CA USA

[14] MAR FUTURA, Navidad, Chile and Instituto Milenio en Socio-Ecología Costera (SECOS), Santiago, Chile

[15] German Federal Agency For Nature Conservation, Bonn, Germany

[16] School of Biological and Behavioural Sciences, Queen Mary University of London, London, UK & Royal Botanic Gardens, Kew, Richmond, UK

[17] Institute of Marine Sciences and Management, Istanbul University, Istanbul, Turkiye

[18] International Union for Conservation of Nature (IUCN), Cambridge, UK

[19] Fisheries and Aquaculture Division (NFI), Assessment & Management Team (NFIFM), Food and Agriculture Organization of the United Nations (FAO)

[20.] The University of Western Australia Oceans Institute, Crawley, Western Australia, Australia;;
[21.] Centre for Macroecology, Evolution and Climate (CMEC), University of Copenhagen, Denmark.
*Alice C. Hughes. **Email:** Alice.c.hughes@unimelb.edu.au
*Benjamin M. Marshall **Email:** benjaminmichaelmarshall@gmail.com

Abstract

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 CITES, with the exception of the US-specific dataset LEMIS, which frequently had higher diversity of species in trade than global databases. This highlights the importance of national monitoring efforts, and the need for standardised 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 under 2% of traded species.

Teaser

We estimate that the number of species in use and trade is around double previous estimates at 107,356 species, but only 2% are reflected in global biodiversity target indicators.

MAIN TEXT

INTRODUCTION

Unsustainable collection of wildlife for trade is one of the greatest threats to species survival around the globe (IPBES 2022; IPBES 2019). 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 vs. 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 exists, traded populations suffer on average 50-60% loss in abundance relative to untraded populations (Morton et al., 2021; McRae et al., 2022). This encompasses a range of trends, from local extirpation to population increases in traded species populations (e.g., McAllister et al. 2009); 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 (Hinsley et al., 2023). Yet for most species, the data required to assess the impact of trade does not exist, precluding accurate assessments of extinction risk (Hinsley et al., 2023).

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 US, 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 USD 220-300 billion annually (Hughes 2021; Andersson et al., 2021; FAO 2024), approximately 5.6-10.6 times larger in value than the illegal wildlife trade, estimated at USD 28.4-39.5 billion annually (Tow and Carrasco, 2026). 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 (Duckworth et al., 2012). 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 for many species and systems (Hughes et al., 2023). The CBD recognises 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; CBD 2022). 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 (Corey et al., 2017; Sahley et al., 2007), and incentivizing long-term stewardship for wild populations (Abensperg-Traun, 2009), 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 trade (IPBES 2022), 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 (Hughes et al., 2025). 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 Organisation (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 (Sharma et al., 2025). The FAO (and International Tropical Timber Organisation-ITTO) also measure timber production, though may fail to record key details on species or sourcing (FAO 2025). 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 (Wijnstekers 2011). 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) (CMS 1979). Whilst 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 over 45% in trade (4,047 species; Marshall et al., 2025b; Marshall et al., 2020). Similarly, the number of butterfly species in trade (Wang et al., 2024) exceeds the IPBES estimate for all traded terrestrial invertebrate species (IPBES 2022; Hughes et al., 2025). Reactive interventions, such as listing species in the CITES Appendices, frequently rely upon scant trade and trade impact data (since data are often not available prior to listing, see Friedman et al., 2020), thus risking waiting until species are already trade-threatened to apply measures to reduce the threat and facilitate recovery (Challender et al., 2023; Cooney et al., 2021). Despite the recognised threat posed by extraction for trade to thousands of species (Challender et al., 2023) 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 non-domesticated 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 US implemented LEMIS to help ensure adequate availability of customs officers at appropriate ports (Weissgold 2024). Unfortunately, comparable data for other countries remains unavailable. LEMIS alone showed that, since 2000, over 21,000 wild animal species were traded into the US (Marshall et al., 2025a). This estimate is incomplete (particularly for invertebrates; Marshall et al., 2022, and fish; CITES Secretariat and UNEP-WCMC, 2024), but it highlights both the scale and diversity of wildlife trade going into a single, albeit large and economically important, country. LEMIS data has allowed wildlife trade into the US to be fairly well described (Tittensor et al., 2020; Olsen et al., 2021; Harfoot et al., 2018; Marshall et al., 2025a, 2025b), but equivalent efforts for other parts of the world are limited by a lack of data. Further, while the LEMIS data gives key insights into the US wildlife market, the quality and reliability of the data have frequently been questioned (Weissgold 2024; Rhyne et al, 2017). Thus, although work on the LEMIS dataset highlights the scale and diversity of trade, it also underscores the need to assess the availability of equivalent and better data 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 (Marshall et al., 2020; 2022) or national cross-taxa trade (Marshall et al., 2025), 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 dramatically 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 both 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. Finally, we assess the landscape of regional and national trade monitoring initiatives.

Global databases and coverage

Overall scope and coverage of global databases

The most basic system of global trade monitoring is through the harmonised standard of custom codes (harmonised system commodity codes [HS codes/comcodes] in the United Nations Comtrade Database), as well as systems such as the Global Trade Analysis Project (GTAP). 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 (Gerson et al., 2008; Davies et al., 2026). However, there are instances in which these databases have sufficient resolution to track trade (e.g., European eel, *Anguilla anguilla*; Kaifu et al., 2019). Additionally, 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*; Hansen et al. 2022), or assumptions made based on species ranges and country of export (e.g. *Anguilla* species; CITES 2025b - section 6.2) but increasing taxonomic resolution would vastly enhance the ability to use comcodes to understand trade for considerably more species (Chan et al., 2015).

CITES remains the main source of detailed, species-level information on global-scale international wildlife trade (Harfoot et al., 2018), despite only covering a subset of species in trade. At present (August 2026), approximately 40,980 species are included in CITES Appendices (I, II, III), of which 6,634 (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. This 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) over 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 remains prone to reporting errors and time lags (Okes and Sant, 2022); many records still rely on “paper permits” and manual compilation of annual trade reports by CITES authorities (Zain 2020; Vural 2026), with limited standardisation or exchange across digital systems, where implemented (e.g. eCITES) (ESCAP et al., 2025; CITES 2024a; Pavitt 2021). The reliance on paper documentation for most legal trade permits within CITES makes it harder to cross-reference records and identify errors and discrepancies (Blundell & Mascia 2005). 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). eCITES may overcome some of the challenges outlined here (CITES 2024), however there continue to be capacity limitations, and to date it has been implemented in around only 30 of the 184 countries which 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 (Tlusty et al., 2013). Given the importance of fish to humans, the FAO has collected decades of trade data (FAO 2025; FAO 2025a) and reports on the proportion of commercially exploited fish stocks that are biologically sustainable (FAO 2026). 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}, (Sharma et. al. 2025). 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 (UNEP-WCMC 2003; Wabnitz et al., 2003; https://aquariumtradedata.org; CITES 2024). This includes the information recorded on both capture production and trade data held by FAO (e.g., FishStatJ: FAO 2025d, see **Text S2** for further information on FAO and related global capture production and trade databases).

The International Tropical Timber Organisation (ITTO 2025) 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 (ITTO 2025), with newer tools aiming to help identify and track illegal trade (e.g., TimberStats which helps detect illegal timber trade-TRAFFIC 2024). 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 (GPWSL) (Richardson et al., 2023).

For illegal trade, at a global level TRAFFIC and CITES play leading roles, though CITES data is kept confidential in the CITES Illegal Trade Database (https://citesdata.un.org/) (CITES 2025d). 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 species in 2023, but 45% of entries (of 53,363) did not include species-specific information

(TRAFFIC 2023). Conversely, dedicated programs systematically collect illegal trade data for specific taxa, e.g., the Elephant Trade Information System (ETIS) and MIKE (Monitoring the Illegal Killing of Elephants) for elephants; (TRAFFIC 2025; ETIS 2025). More informal efforts to monitor illegal trade, such as though NGOs do exist for some taxonomic groups (Catbyte 2026). 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 (TRAFFIC 2022).

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 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; Figure 1, CITES 2022). 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; Figure 1). Invertebrates had the lowest coverage in LEMIS, as until recently LEMIS has often overlooked their trade (Marshall et al., 2022; Figure 2).

Different collations of data can provide very different estimates of the number of species in trade (Table 1; Figure 2). Here we note recorded trade in species based on databases which 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 IUCN Red List assessments. Following cleaning and standardisation 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, approx. 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 5,454 species are in trade, representing 15% of described species, of which 40% are only recorded in LEMIS, whilst LEMIS includes 55% of all traded fish species, (though most of these are not accounted for with their LEMIS harmonised 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, 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, 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; 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 US, 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 (Figure 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) (Díazgranados et al., 2020; Pironon et al., 2024). Nevertheless, documentation of plant use remains highly incomplete and uneven across regions and use categories, with many uses never formally catalogued (Bacchetta et al., 2016). Combining IUCN, CITES and TRAFFIC data with data on utilised 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 relies on previous papers documenting use because the recording of plant trade is generally weaker and less systematic than 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 over 107,356 non-domesticated 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 utilized species remain unlisted within 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 utilized 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, though limited alternative mechanisms for monitoring international trade means that most species in demonstrable use are not formally monitored (Table 1; Figure 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 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, Biondo et al., 2024). 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 (Marshall et al., 2025; UNEP-WCMC 2022). 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 harmonised codes, and regulations more broadly, under periodic review (i.e. NOAA.Fisheries 2025).

At regional levels, various legislative infrastructures also exist. For example, the EU has EUTR and EUDR to monitor timber supply chains (EU-Lex 2016), as well as FLEGT (Forest Law Enforcement, Governance and Trade; EEAS 2020; EUR-Lex 2003), which applies stricter domestic measures for the import of CITES-listed species including timber (EUR-Lex 2026). Other platforms and organisations providing regulation and monitoring of timber trade include the US Lacey Act (Lawson 2015), the Global Timber Index Platform (https://www.itto.int/gti/), and the Global Green Supply Chains Secretariat (https://www.itto-ggsc.org/). Systems to trace trade (e.g., TRASE, Starling verification; https://trase.earth/, Airbus 2025) 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, Programme for the Endorsement of Forest Certification PEFC; Matias et al., 2024, https://www.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 (TRAFFIC 2025). Patchy efforts have been made to collate data on wild meat use (www.wildmeat.org/database/; Willis et al., 2022) and assess regulatory approaches to wild meat (Ingram et al., 2021). Regulatory systems seem largely to have been a focus between 2015-2020, and efforts to assess the use of wild meat have largely been restricted to Africa. Changes in policy are evident elsewhere (e.g., China, Xiao 2024), 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. Antunes et al., 2025), generally under Comtrade harmonised codes (comcodes) (Zamani et al., 2025; Vasisht et al., 2016; Silalahi et al., 2023; Jimoh et al., 2023; Xiang et al., 2022), and rarely includes either species or geographic information. Some programs, such as FairWILD standards and WildCheck (Mosig Reidl et al., 2023), 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 (Figure S1), LEMIS is among the most complete and representative globally. LEMIS includes data on the trade of animal species imported to the US, including both species names and a series of harmonised codes, although these codes often lump together various taxa, such as whole groups of insects or fish (i.e., see Rhyne et al., 2017). 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 (Marshall et al., 2025a). 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 S3). 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., US, Canada). However, CITES-associated regulations also relate to permitting in various African countries, where a high number of species are traded for purposes such as trophy hunting. Notably whilst many of these species may be subject to annual national quotas, 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 sub-national 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 on illegal trade and for CITES), or only information on how permits can be applied for, either for international trade or the collection of wildlife within a country. This lack of standardisation 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 (2022) 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 trade for potentially 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 "utilized plants" analysis include species used for subsistence and other non-commercial purposes and therefore cannot be directly interpreted as species in trade. For animals, we identify up to 47,685 species in international trade, 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 recognised 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 (Liang et al., 2023). 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 employed 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: Ahlers et al., 2017; Lynam et al., 2025; C4ADS, ROUTES: Utermohlen & Baine 2018). Likewise, a transition from paper to the electronic eCITES permits may reduce laundering and improve the accuracy of trade records (Outhwaite 2020). Importantly, 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 (Rose & Smith 2010; Stiles et al. 2013; Van Roon et al. 2019). For other taxa and for national-level data, major gaps exist, and whilst seizure data are useful (i.e. Hu et al., 2024; Tittensor et al., 2020; Stringham et al., 2021; Tow et al., 2025) they only represent the illegal trade that was uncovered, a potentially highly unrepresentative sample. Successful illegal trade thus cannot be directly monitored (Prasad et al., 2022; Tow & Carrasco 2026).

Some recent global wildlife trade assessments (such as the IPBES 2022 assessment) have failed to recognise how the dimensions and drivers of trade have changed in recent years, with the growth of the exotic pet market being particularly notable (Marshall et al., 2020; Gippet & Bertelsmeier 2021). 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 (De Smedt et al., 2025; Quinlan et al., 2022). 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 - Spee et al., 2019; China – Si et al., 2025; Japan - Digirolamo 2024, Sigaud et al., 2023) or popularisation of new taxa (i.e., freshwater taxa: Dickey et al., 2023; lorises: Nekaris et al. 2013), with little consideration given to how to manage these issues (**Text S2**; 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 (Feddema, et al., 2021). 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 (Marshall et al., 2020; Kubo et al., 2025; Hsu et al., 2025). Likewise, Indonesia is one of the largest exporters of wildlife (with many exploited marine and terrestrial species particularly vulnerable; Watson et al., 2023), yet despite annual publication of trade quotas, corresponding data on wild populations remains lacking (OECD 2019; Data S3). The Asian Songbird Crisis (Lees & Yuda 2022; Fiennes et al., 2024), 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 (CITES Secretariat 2022). 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 (CITES, 1973), 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 (Marshall et al., 2020; Watters & Cassey 2026).

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: Mosig Reidl et al., 2023). Although the drivers of these trends are increasingly understood (Haukka et al., 2026), 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 (Evans et al 2025; Lockwood et al., 2019) and zoonoses (García-Moreno 2023).

Assessing the gaps

Fully gauging the extent of illegal trade is hampered by the combination of mis- and dis-information that result from the paucity of data recorded on purportedly legal trade (i.e. Marshall et al., 2025a; Olsen et al., 2021). 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 trade data (Marshall et al., 2025a). Likewise, while the Lacey Act means that species traded into the US 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. Legal Atlas, 2026). Records of species coming from the wild from countries where they are not native and the recognised use of third countries in the trafficking of wildlife (Gangi et al., 2025; Marshall et al., 2025a; Nijman and Shepherd, 2010) 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, Government of Canada 2025), and the EU is discussing the development of comparable legislation (European Commission, 2025).

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 Rhyne et al., 2012; 2017) and the inclusion of all harvested fish and fish commodities is needed to support sustainable management of these species (Pauly and Zeller, 2016; Zeller et al., 2016). Though improved tracking has helped reduce illegal trade (NOAA 2025; Barendse et al., 2019; MSC 2025), it remains a challenge in fishery (and timber) sectors, which requires constant innovation to address (Andre 2025; Schaafsma et al. 2014; Platts et al. 2023; Mgaza 2022; Datta et al., 2023, 2025). 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 (Basel Institute on Governance 2021). 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 (Friedman et al., 2018). Likewise, trade in European eels (*Anguilla anguilla*) outside EU borders is largely illegal, but the high value of global trade in eels ($1 billion annually; Basel Institute on Governance 2021) means other countries emerge as export states, trade switches across species with similar market requirements, or non-compliant CITES trade increases (Stein et al., 2025; Alonso et al., 2023; Pons-Hernandez 2024). 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 over half of global seahorse seizures; Atlas of economic complexity; Kaifu et al., 2025; Foster et al., 2025), but effective enforcement remains challenging due to laundering and mislabeling tactics (Richards et al. 2020).

While the globalisation of wildlife trade has led to the development of monitoring structures in some specific sectors (e.g., fishing, timber), other facets of wildlife trade (such as the pet trade) are frequently overlooked (Marshall et al., 2025). More 'traditional' elements of trade are being better monitored (potentially to prevent the loss of traditional resources used by communities; FairWild, WildCheck, Infoods; Kew 2025, FAO 2025c). However, despite the use of over 30,000 plant species for medicinal or aromatic purposes (Jenkins et al., 2018), 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, 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 (CITES Secretariat & UNEP-WCMC, 2024). Even for well-established elements of fish trade, such as the aquaria trade, calls for better collation of data are ongoing (Watson et al., 2023; Biondo & Calado 2021). Lessons from timber and fisheries trade have demonstrated the critical importance of understanding geographic patterns of trade to ensure legality (Roberson et al., 2025); harmonized codes reduce the ability to conduct detailed trade analysis in these sectors as codes may refer to groups of species in some taxa (Marshall et al., 2025a).

The challenge of assessing sustainability

To assess sustainability of trade and harvest, non-detriment 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 non-binding 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. But outside of CITES, NDFs or comparable 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 "National databases and coverage"). NDFs should assess the impact of all harvest and mortality associated with trade (CITES 2016). 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 (Jackson et al., 2023; Morton et al., 2024). Additional work is being conducted for some taxa, for example, IUCN's Sustainable Use and Livelihoods (SULI) working group has assessed the potential sustainability of trade for 347 species in 117 countries (SpUD - Species Use Database: https://speciesusedatabase.com/) (Roe et al., 2025). Similar assessments are still needed for the majority of taxa in trade, as this represents under 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 (Nielson et al., 2018). These assessments require information on both trade volumes/intensity and wild population sizes, together with monitoring of harvesting impacts on wild populations (Roe et al., 2025; Hughes et al., 2023). Within fisheries, systems for tracing and certifying sustainability have been developed (Sustainable Fisheries Partnership 2025, 2025a, Marine Stewardship Council [MSC] certification), underpinned by complex regulatory structures (Bellmann et al., 2016). 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 (MSC 2025), though this likely only reflects vulnerability to over-consumption 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 (FAO 2025; FAO 2025a). Additional data are available to assess pressures on wild populations (Mermerzadeh, 2019; Sea Around Us 2025). These data are used to calculate the maximum sustainable yields (MSY) 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. Costello et al., 2016; Branch et. al., 2011), 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 non-experts, as the various assessment frameworks (Sharma et al., 2025, Costello et al., 2016, Edgar et al., 2024 and Branch et al., 2011) reflect different and incomparable measures, some of which can be prone to overestimating the probability of collapse. For example, Edgar et al. (2024) uses a metric based on a hindcast comparison that estimated 1.29 to 1.85 times more stocks had historically crossed a sustainability 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. (2024) study.

Accordingly, the FAO SOFIA sustainability estimate, the Costello et al. (2016) overfished/overfishing classifications, the Branch et al. (2011) catch-based collapse discussion, and the Edgar et al. (2024) historical analyses represent different biological reference points, metrics and timeframes 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 non-experts. 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 which suffer from a lack of relevant data, given the outstanding challenges within fisheries despite the wealth of data which are not present elsewhere (**Text S2,** Richie & Roser 2021). Additionally, obtaining accurate estimates of bycatch (e.g., Gilman et al 2022; Dasnon et al., 2022) and harmonizing understanding of ecosystem-wide impacts of harvests on community structure (such as the potential for trophic cascades; Hočevar & Kuparinen 2021), 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 (Hughes et al., 2023). Assessing whether trade is sustainable requires moving beyond simple volume tracking and species-specific quotas or limits to incorporate information on species ecology (Edgar et al., 2024; Booth et al., 2020; Richardson & Peres, 2016, **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, marine mammals) (Sanchirico & Essington, 2021), 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 (Figure 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 (Brown et al., 2025). 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; Murray et al., 2026), 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

(Rhyne et al. 2017). Such systems could automate parts of the process, such as automating invoice digitisation (Tlusty et al., 2023; Tlusty et al. 2024), or flagging potential mislabeling based on inconsistencies such as price (Nijman & Stein 2022; Stein et al., 2021; Figure 3). For example, Tlusty et al. (2023) 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 digitised and based on pre-agreed 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 digitisation (Murray et al., 2026). 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 (Figure 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 that 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, standardising 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 2009 (Gov.UK 2024, DEFRA 2009), which already includes tracking millions of animals to manage and mitigate disease outbreaks (AHDB 2024). This system demonstrates that central reporting, standardised 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 (DEFRA 2009). Therefore, such data volumes can clearly be managed; systems like this which 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 (Gupta et al., 2025).

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 (WWF 2025; TRAFFIC 2021; Moloney et al., 2026). However, many efforts either focus on supply chains for major commodities, or on the detection of illegal trade (e.g. WWF 2026; GI-TOC 2025; Themis 2022; CGI 2026), 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 (Rinne et al., 2023) and social media data (Fox et al., 2025) 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 US 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 Challender et al., 2026). 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 (2022) estimate of 50,000 species. Even though this is likely a considerable underestimate due to a lack of systematic data collection, it already represents 15-64% for each taxonomic group of all described vertebrate species.

Despite not being free from issues, the US LEMIS data is periodically made publicly accessible and presents a taxonomically comprehensive assessment of animal species imported and exported from the US (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 remains unavailable. While wildlife trade is acknowledged as a major threat to species survival (IPBES 2022), even indicators for trade included within global frameworks such as the KMGBF fail to include data for the majority of taxa in trade, approximately 6-11% of internationally traded vertebrate species and 1.8-2.5% of species in use and trade reflected by the headline indicator for Target 5 on wildlife trade (Hughes & Grumbine 2023; Marshall et al., 2025). 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 some jurisdictions. This seriously hampers our ability to monitor progress towards, 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 EUR-Lex 2009, FWS 2017). Likewise limited guidance, legislation, international cooperation and funding exist for the repatriation of confiscated live animals (Rivera et al., 2021; Saito, 2025). 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 (Vergneau-Grosset et al., 2024). 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 (Hughes et al., 2025; Biondo et al. 2019). 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 towards collating more representative data across taxa at national and international levels, and to share these data in interoperable formats to finally 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, whilst 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

I). Scope.

In this review of data available on wildlife trade, we focus on international trade (legal and illegal) of wildlife (non-domesticated 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 organisations), 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 non-governmental 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. Whilst monitoring of trade in fungi has also been highlighted as an important gap (i.e., Oyanedel et al., 2024) current trade data only include code-aggregated UN Comtrade information, which does not allow for detailed species or group level analysis (with few exceptions, long tailed macaques; Hansen et al., 2022, European eel; Nijman 2017; de Frutos, 2020).

II). Global monitoring

Data were analysed in two ways, one to assess actual recorded trade through databases which record species in international trade (see Figure 1) and include extensive quantities on trade data. Secondly, we more broadly aggregated data which estimates 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 analyse 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 International Union for Conservation of Nature (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 conducted, between 20 October - 5 November 2025. For each database, the number of species in trade per major taxa were 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 if 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, whilst 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 (CITES 2025a). 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://www.iucnredlist.org/) using the IUCN 2025-2 update, and the number of species in various taxa 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 (FAO 2025) 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-based trade) and provides incident data via its Wildlife Trade Information System (WiTIS) database. We downloaded WiTIS data (https://www.wildlifetradeportal.org/incidents). While other multi-species seizure datasets exist, they are not publicly available. For example, the CITES annual illegal trade reports (AITR) are typically only made available to governmental authorities or International Consortium on Combating Wildlife Crime (ICCWC) 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., IWT project 2025; Global Monitoring System Ecosolve: https://www.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. Whilst the Ecosolve analysis is interesting (reflecting adverts, including on Facebook, and trends over time) the initiative only started in 2024, and only 85 species have been detected so far (28 mammals, 28 reptiles, 15 birds, 13 fish and marine invertebrates and one amphibian).

To highlight the fragmentation of trade data we extracted numbers of species in trade from recent publications assessing trade (of taxa with recognised 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 (2022) (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 (Figure 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; Diazgranados et al., 2020; Pironon et al., 2024). 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.

III). Determining species overlaps for species in trade

Whilst 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 synthesise and clean data. Different programs, and papers, use different taxonomic backbones, or include synonyms or even include typos, thus standardisation is needed to accurately assess species in trade.

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 standardised taxonomic backbone. We prioritised using the Global Biodiversity Information Facility (GBIF) taxonomic backbone in line with previous research ((Marshall et al., 2025 and Lassaline et al., 2025; Jürgens et al., 2025), only deferring to further backbones where no potential for name conversions were found. We used the taxize package (Chamberlain, Szocs, 2013; Chamberlain et al., 2020; 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

(ITIS), and Catalogue of Life; and prioritised 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 was already cleaned, and the use of codes etc used to refine names, we have maximised species inclusion. Additionally, Marshall et al., (2025) has made a name conversion key available, so we re-used 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 number of described taxa we used: Amphibian Species of the World (Frost, 2026), World Bird Names (Gill et al., 2025), Fishbase (Fishbase, 2026), Reptile Database (Reptile Database 2026), and Mammal Diversity (Burgin et al., 2025) 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. (2022) on the arachnid trade is included as a research paper source but includes data from pre-2014 LEMIS provided by Eskew et al. (2019; 2020). Similarly, Marshall et al. (2022), and Wang et al. (2023) contributed to the Arachnida or Lepidoptera group counts, as well as to the total Invertebrate group for visualisations. To help promote a fair comparison between sources, we additionally expanded the Invertebrate category used in Marshall et al. (2025) that was provided alongside the LEMIS data to include all classes appearing in Lassaline et al.'s (2025) data.

We used the ComplexUpset package (Krassowski, 2020; Lex et al., 2014), along with the ggplot2 (Wickham, 2016), legendry (van den Brand, 2026), and patchwork (Pedersen, 2025) packages, to visualise the overlap between data sources. The manipulation and plotting of data was conducted in R version 4.4.2 (R Core Team, 2024), and additionally used the here (Müller 2020), dplyr (Wickham 2023), tidyr (Wickham 2024), and stringr (Wickham, 2023) packages. Data on species in trade was then plotted (Figure 1) to highlight the fragmentation and incompleteness of trade databases, and plotted in detail (Figure 2).

IV). National and regional database collation and policies

To analyse 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 if any database was present for assessing the trade of non-CITES species and to provide any sources if present. Sources (e.g., organisation 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 if national systems to record trade of non-CITES species were present (Data S1).

Second, the term 'wildlife trade database' was translated into 30 languages (based on the top 25 languages in Google translate and five further countries that needed verification following other assessments), and relevant links and passages 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 S2).

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 S3) and summaries for each are recorded in text. All outputs were 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 non-functional ones either removed or the keywords 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 synergise 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 was 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 Supplements.

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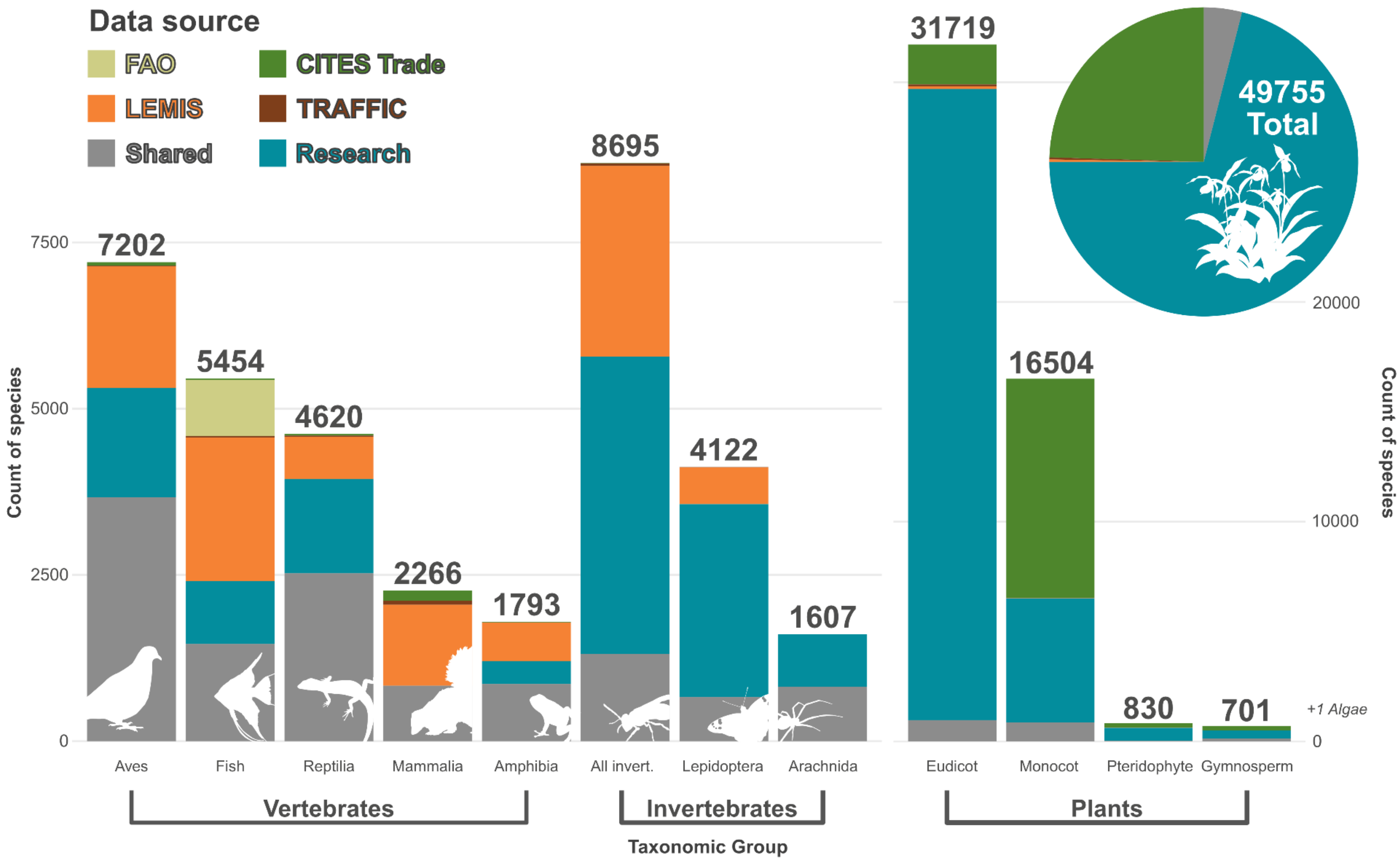
Competing interests: The Authors declare no conflicting interests

Data, code, and materials availability: All data has been made available in supplements. DOI is: 10.26188/33194898

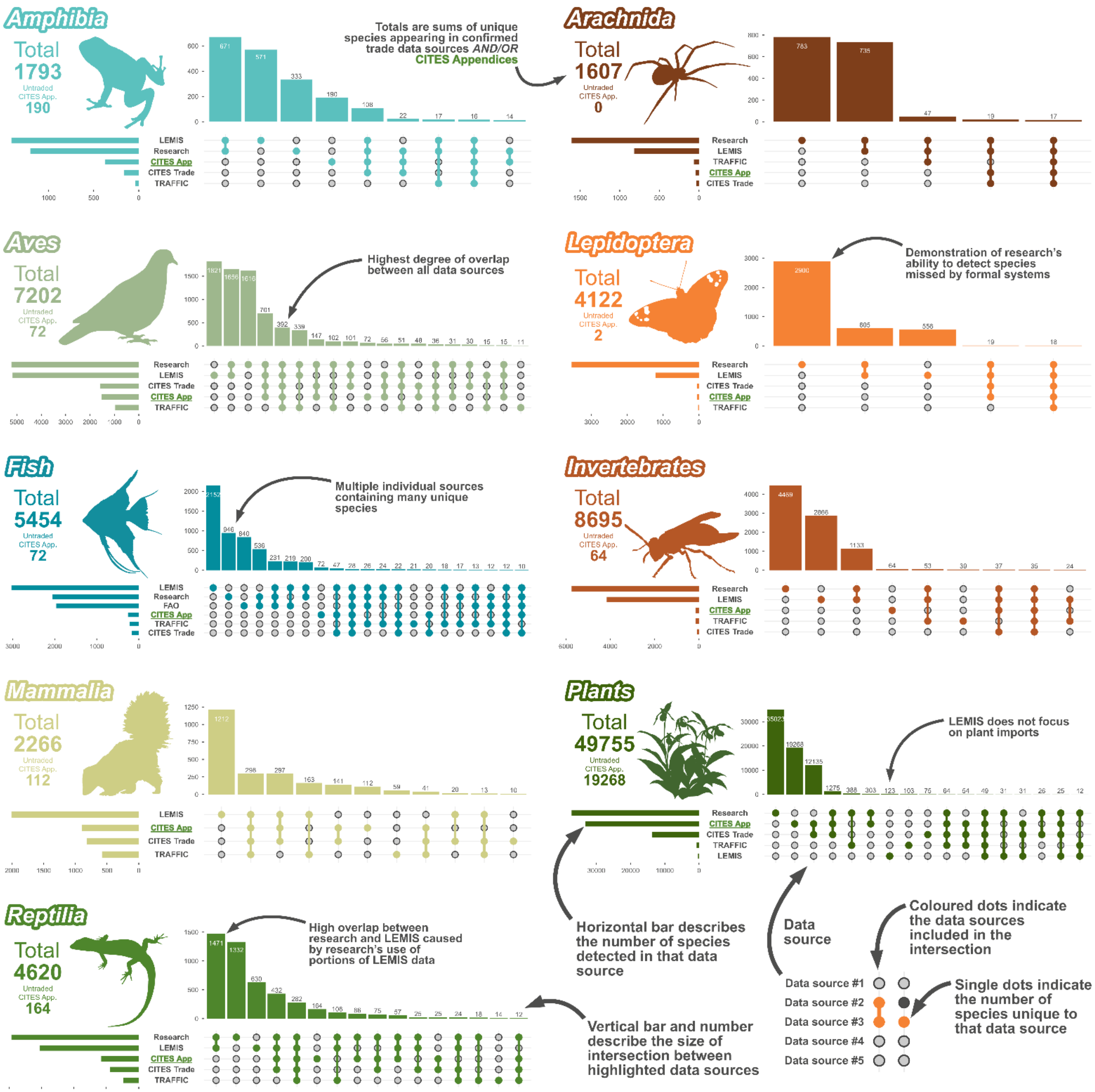
Data used to summarise species counts, and to generate figures is available at https://doi.org/10.26188/33194898. The data files each contain a list of traded species and which trade data sources they are detected in (1 - detected, 0 - not present). The data is split into (not mutually exclusive) taxonomic groups: amp = Amphibians, ara = Arachnids, bir = Aves, but = Lepidoptera, fis = Fish, inv = Invertebrates, mam = Mammals, pla = Plants, rep = Reptiles.

Figures and Tables



Data source
FAO
CITES Trade
LEMIS
TRAFFIC
Shared
Research
7202
5454
4620
2266
1793
8695
4122
1607
31719
16504
830
701
49755
Total
+1 Algae
Count of species
7500
5000
2500
0
20000
10000
0
Aves
Fish
Reptilia
Mammalia
Amphibia
All invert.
Lepidoptera
Arachnida
Eudicot
Monocot
Pteridophyte
Gymnosperm
Vertebrates
Invertebrates
Plants
Taxonomic Group

Figure 1. Number of species in trade for each animal taxa following 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 Figure 2. “All invertebrates” includes all invertebrate species (including the arachnids, lepidopterans sub-groups 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 systematised 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.



Amphibia
Total 1793
Untraded CITES App. 190
LEMIS
Research
CITES App
CITES Trade
TRAFFIC
Totals are sums of unique species appearing in confirmed trade data sources AND/OR CITES Appendices
Arachnida
Total 1607
Untraded CITES App. 0
Research
LEMIS
TRAFFIC
CITES App
CITES Trade
Aves
Total 7202
Untraded CITES App. 72
Research
LEMIS
CITES Trade
CITES App
TRAFFIC
Highest degree of overlap between all data sources
Lepidoptera
Total 4122
Untraded CITES App. 2
Research
LEMIS
CITES Trade
CITES App
TRAFFIC
Demonstration of research's ability to detect species missed by formal systems
Fish
Total 5454
Untraded CITES App. 72
LEMIS
Research
FAO
CITES App
TRAFFIC
CITES Trade
Multiple individual sources containing many unique species
Invertebrates
Total 8695
Untraded CITES App. 64
Research
LEMIS
CITES App
TRAFFIC
CITES Trade
Mammalia
Total 2266
Untraded CITES App. 112
LEMIS
CITES App
CITES Trade
TRAFFIC
Plants
Total 49755
Untraded CITES App. 19268
Research
CITES App
CITES Trade
TRAFFIC
LEMIS
LEMIS does not focus on plant imports
Reptilia
Total 4620
Untraded CITES App. 164
Research
LEMIS
CITES App
CITES Trade
TRAFFIC
High overlap between research and LEMIS caused by research's use of portions of LEMIS data
Horizontal bar describes the number of species detected in that data source
Vertical bar and number describe the size of intersection between highlighted data sources
Data source
Coloured dots indicate the data sources included in the intersection
Single dots indicate the number of species unique to that data source
Data source #1
Data source #2
Data source #3
Data source #4
Data source #5

Figure 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. (2025) data.

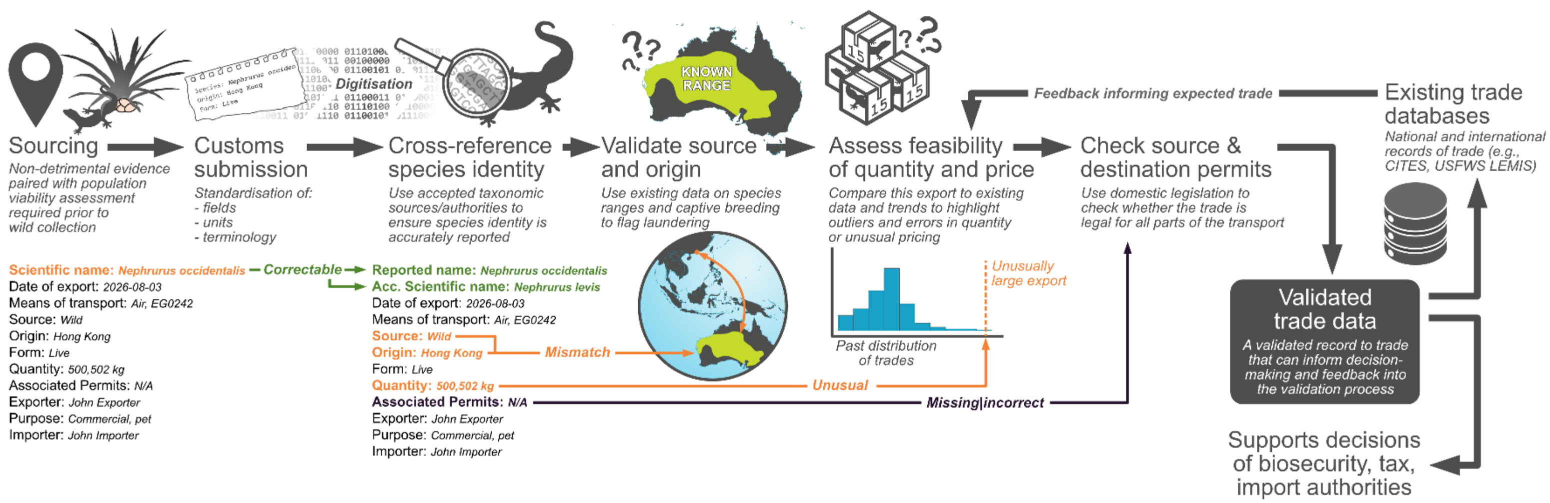


Figure 3. Potential workflow for automating and checking the collection of global wildlife trade for taxa not encompassed within existing global monitoring processes.

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 comes 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 30051 monocotyledons, of which 11048 are recorded in trade in CITES, yet only lists 3404 dicotyledons (2732 in use) but 13747 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 comes from Marshall et al., 2025 (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	13973	4348	163	257	3031	1602	11580	215	2050
Invertebrates	10618	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	59671	49723	13747	33233	295	228	18921	697	37212
Reptilia	4886	4144	888	1160	3047	2063	1666	472	3931

Supplementary Materials

This PDF file includes:

Supplementary Text

Text S1-S3

Figures. S1

Tables S1 - S2

Other Supplementary Materials for this manuscript include the following:

Data S1 to S4

Code S1 to S3

Supplementary Text

Text S1: Illegal trade detection networks

Many regional networks exist to detect and attempt to prevent illegal wildlife trade. TRAFFIC has launched various regional TWIX (Trade in Wildlife Information eXchange) networks to support monitoring and the collation of seizure data, including for Southern Africa (SADC-TWIX https://www.sadc-twix.org/), Central Africa (AFRICA-TWIX https://www.africa-twix.org/), Eastern Africa (Eastern Africa-Twix: https://www.easternafrica-twix.org/), Western Africa (West Africa-TWIX https://www.westafrica-twix.org/) and the European Union (EU-TWIX https://www.eu-twix.org/). TWIX networks normally include a selection of regional partnerships with TRAFFIC, which can include regional and national governmental authorities. However, it should be noted that the species monitored by the regional TWIX networks (CITES listed species, regionally protected species, other endangered species) varies and remains a source of discussion, with likely differing inclusion of species within different regions and countries (EU Commission 2022, Armstrong et al., 2023). Other networks include ALERIS in Latin America and the Caribbean (https://www.aleris.earth/); however, this effort is led by conservation biologists rather than governments, making the completeness and sustainability of the platform difficult to gauge. Similarly, the ASEAN Wildlife Enforcement Network (ASEAN-WEN) is a regional inter-agency and inter-governmental initiative that aims to enhance enforcement of wildlife protection laws across ASEAN member states (Southeast Asian Nations) (**Text S2**).

Other dimensions of sustainability are also rarely accounted for in discussions of trade. For example, methods for harvesting a wild species can have destructive collateral effects (for example in the case of selective logging; Ellis et al., 2019), a factor entirely absent from trade statistics. These methods may include deliberate or incidental impacts including degradation of habitats due to harvesting (such as the harvest of Cordyceps fungus in the Himalayas; (Upadhaya et al., 2025) or from practices aiming to increase production. For example, harvesters sometimes intentionally set fire to native old-growth forests to increase the growth of morels (Morchella spp.) in Chile, despite scientific evidence that this practice does not effectively stimulate production (Pildain et al., 2014). Therefore, true sustainability assessment necessitates integrating trade data with comprehensive ecological information on trophic interactions, population-level impacts on non-target species, and the wider system-level effects of harvest practices.

Another key facet of trade that is often neglected is the guidelines and funding for the repatriation of confiscated live specimens. This challenge represents a further governance gap that intersects with many of the issues identified here (Saito 2025; Rivera et al., 2021). Although CITES lists repatriation as one of the recommended management options for confiscated live animals (CITES 2022), practical implementation remains limited, and requires mechanisms for transport, temporary housing and funding which rarely exist (i.e. Leupen 2018). At present repatriation is seldom pursued largely because national authorities face unclear procedures and limited channels for cooperation with source countries (Saito 2025). Existing guidance further highlights barriers related to welfare risks, disease screening and the suitability of release sites (IUCN 2019). As a result, most confiscated animals are placed in zoos, museums, rescue centres or approved private facilities (CITES 2022a). In fact, long-term captive placement remains the most common outcome for live seizures (Gray et al. 2017). Even when repatriation is explored, climate suitability, health concerns, and uncertain post-release capacity often prevent return (Gomes Destro et al. 2019). At present housing in a zoo is often a “best case scenario”, with many instances of animals being killed, often with few welfare considerations (i.e. see Brownell 2024) upon confiscation. Gaps in legislation pertaining to, and funding mechanisms to support repatriation represent a further example of how the threat of wildlife trade is neglected.

Text S2-B Sustainability in Marine fish production

The FAO Global Capture Production Database provides critical baseline data for monitoring fishery data (FAO 2026). Notably, FAO FISHSTATJ is the longest time series of any known database at a species and global level resolution that can display trends by differing areas since 1950, and is the basis of all known reconstructions (FAO 2025d). FAO also collates data of marine harvest, normally at the species level (FAO 2025d), and includes extended data to allow the assessment of temporal trends (though quantities are measured in weights rather than organism counts and may be difficult to interpret) (Sustainable Fisheries Partnership 2025). Although, FishStat (which has been monitoring Fisheries and Aquaculture since the 1950s) shows an improvement in the taxonomic resolution of data collected (660 species items in the early 1950s to about 3600 species items in 2022; FAO 2024), around 20% of production does not have species-level information and only quotes broad categories (e.g., “finfish”) (Fisheries FAO 2024).

Likewise, NOAA collates and releases global fish trade data for food fish from 1950 to the present (https://www.fisheries.noaa.gov/foss/), but not all entries are listed at the species level.

Text S3. Technical challenges in accurately recording taxa in trade

Many trade databases do not record trade at a species level, instead using broader groupings or "harmonised codes", which may make calculating species level patterns difficult or impossible. For example, around 98% of snapper imports to the US are only recorded at the family level (Lutjanidae), despite the family having 113 species (Tlusty et al., 2024). Similarly, >99% of marine ornamental fish traded between 2005-2014 in LEMIS were listed as "Tropical fish (marine sp.)" and lacked any further species information (CITES Secretariat and UNEP-WCMC, 2024). Likewise, genera with only some species listed in CITES may not be recorded at the species level to avoid scrutiny during imports or because of challenges in species identification (Tlusty et al., 2023; Marshall et al., 2025). For instance, large numbers of handicrafts and furniture with CITES Appendix II-listed chambered nautilus (*Nautilus pompilius*) shell inlays are exported annually from Indonesia, with exporters merely declaring them as shell inlays (HS code 96019090 "handicraft items made from animal materials, such as bone or shell") (Nijman et al. 2025). Likewise, harmonised code systems such as the system used within LEMIS may aggregate multiple species within a single code: an analysis of invoices showed that 2,300 species of marine fish only constituted a single LEMIS HS code (Rhyne et al., 2017). In the EU, the TRACES system may only record the first species recorded within a shipment of fish, regardless of the number of species present (Schaff pers comm).

Identifying species is particularly challenging when wildlife products are traded in a highly processed or aggregated form, such as dried, mixed mushroom products or blended fishmeal and fish oil. Such products create an unavoidable analytical bottleneck, making species-level identification and accurate volume quantification functionally impossible for customs officials, regardless of the sophistication of the monitoring system (Roberts & Hinsley 2020). At present, assessing the numbers of individuals in trade for any given species, and overall, represents a persistent challenge due to a combination of different units (e.g., trade reported by weight or by individual items), the lack of whole organism equivalence for many traded terms (e.g., skin and timber 'pieces' and manufactured products), and the potential for duplication when various body-parts or components (e.g., skin, skull, and skeleton) could be counted separately when originating from a single animal (Hughes et al., 2025). Quantities can be further complicated by the inclusion of storage mediums or differing preservation methods that alter reported measures (e.g., dried products).

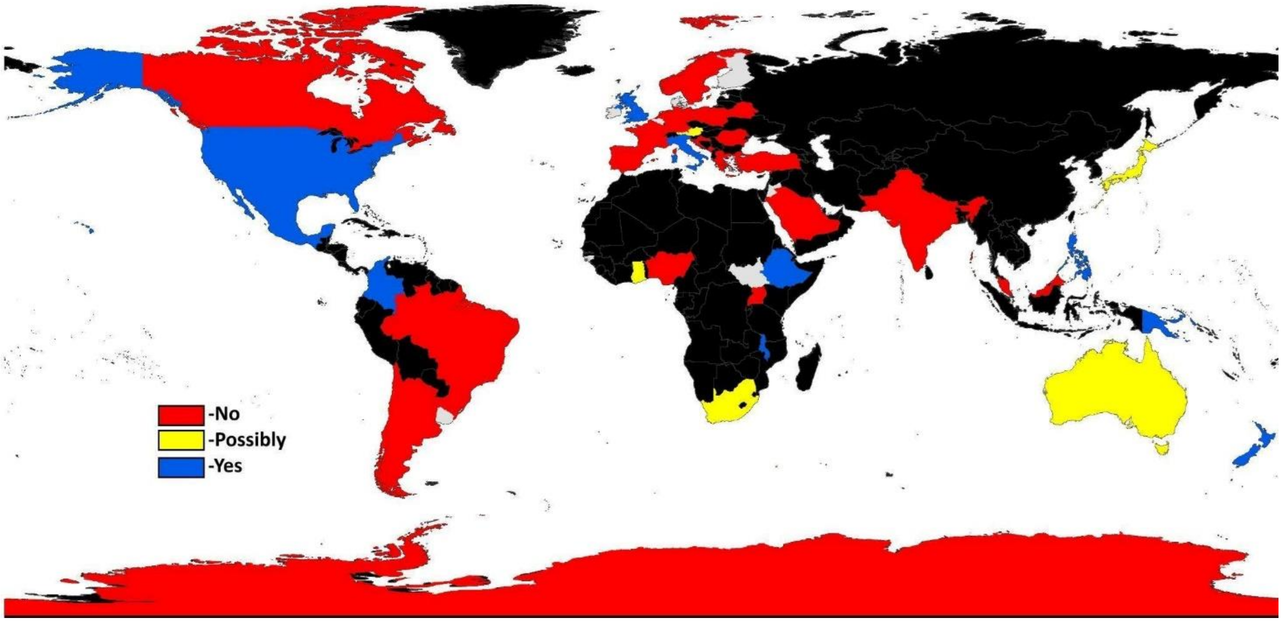


Figure S1.

Self-reported legal wildlife trade databasing (outside species recorded by CITES or FAO, or seizures) from the questionnaire, for “yes” - has a system, “possibly”- may have a system (i.e. conflicting responses). “No” does not have a system. Although the level of detail and accessibility of data varies. Furthermore, some regions are part of regional data collations, for example the EU also has the TRACE system, though the quality of data (and taxonomic resolution) may vary.

Table S1. Potential data limitations in wildlife trade databases.

Limitations and inconsistencies	**Example**	**Mitigation**
Limited taxonomic resolution (not listed at species level)	Depending on regulations trade can be conducted with varying levels of detail, listing contents only to genus, family or even order level. With several exceptions (e.g., stony corals, CITES 2013 (Notif 2013/035)), all	Implement minimum standards for approving initial custom declarations.

	trade in CITES taxa should be reported in CITES annual reports at the species level, however specimens may not always be identifiable to this resolution.	
Limited taxonomic resolution (listed at shipment level, i.e. "Tropical Fish")	In LEMIS (and possibly TRACES), certain groups are listed at the shipment level even when multiple species are included (i.e tropical fish, "lep").	List each species individually and implement minimum standards for initial custom declarations which will normally have species specific listings.
Name mismatches	In databases such as LEMIS without inbuilt taxonomic backbones, competing names/synonyms may be added for a species; e.g., *Bufo marinus* vs *Rhinella marina* both referring to the same species.	Make use of existing name checking systems that use agreed upon taxonomic backbones. Process is a likely candidate for automation. For example, taxonomy in the CITES Trade Database is automatically reconciled to accepted names based on the Checklist of CITES Species (underpinned by the official standard nomenclature references), but this may not entirely align with records for the same items within LEMIS.
Name mismatches between species name and other names (common name, harmonised code)	LEMIS has a harmonised code system, but some of these refer to multiple species (likewise common names)	Inspect shipment to ensure scientific naming is correct
Partial route reporting	Reporting of transit ports or countries rather than the origin of the trade , or reporting indirect trade without any transit or origin country (which would be erroneously interpreted as trade exported directly from the country of origin).	Shift to digital record keeping ensuring trade details follow shipment its entire route.
Unconventional or diluted quantity reporting	Animals transported in a medium, and the medium included in shipped weight.	Separate reporting of wildlife weight prior to shipping and enforce consistent use of SI units. Checking of units and sizes could be integrated with an automated outlier detection system. Where animals are live, use quantities from invoice.

Delays in reporting	Mismatches in shipping dates and import dates, (e.g. trade reported in different years due to year-end exports).	Shift to digital record keeping, and near instant communication to import authorities.
Loss in transit	Mismatches in the exported number and the import number, where both are reported.	Consistent reporting standards at export and import locations allowing for comparison and flagging of inconsistencies. Digital transmission of export records to import location will allow for immediately comparisons and checks.
Discrepancies between systems	Different codes used to denote purpose of trade.	A creation of a unifying glossary of accepted terms compatible with current trade regulations (e.g., CITES). See, for example, the Guidelines for the preparation and submission of CITES annual reports (CITES Notif. 2025/21 Annex 1), with which LEMIS is partially aligned.
Obfuscation	Commercial censorship	Create clearer guidelines on what can be censored to remove discretionary use and abuse.

Table S2. Counts of species that only appear in the LEMIS trade data and are only listed as being traded for Scientific purposes.

Taxa	Count of only purpose S species
Amphibia	523
Arachnida	0
Aves	1604
Lepidoptera	230
Fish	1105
Invertebrates	1193
Mammalia	784
Plants	30
Reptilia	474