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

Alice C. Hughes[1£], Benjamin Michael Marshall[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[20]

[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.] United Nations Environment Programme World Conservation Monitoring Centre (UNEP-WCMC), Cambridge, UK & 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

Author Contributions: ACH Drafted the initial manuscript and conducted the global database assessments, BMM collated and standardised the species data and quantified the species in trade. All authors edited text, with each providing specialism for different components of the paper

Competing Interest Statement: The Authors declare no conflicting interests

Classification: Biological Sciences: Environmental Sciences; Sustainability Science

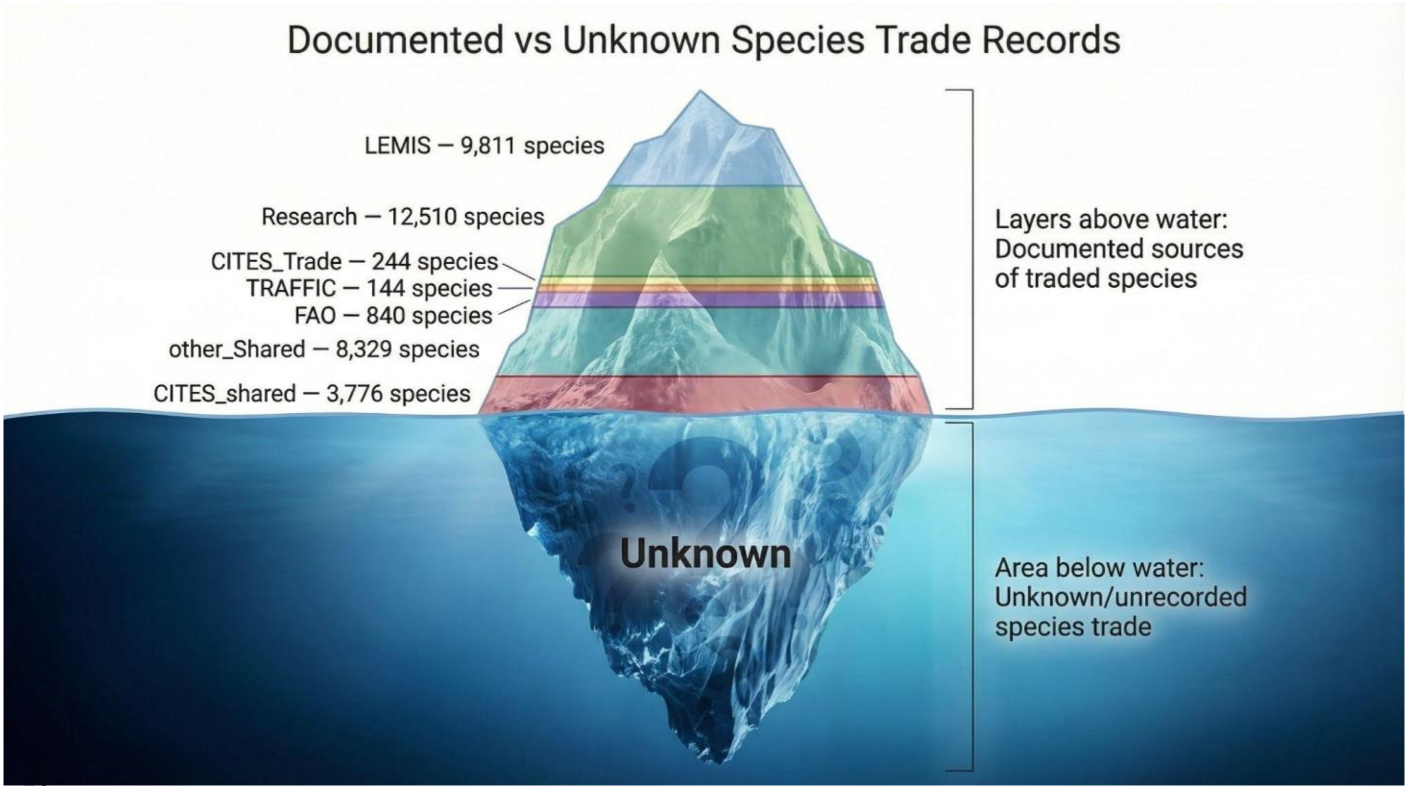
Keywords: Threatened species; Global Biodiversity Framework; Conservation targets; Sustainable use; Conservation gaps

This PDF file includes:

Main Text
Figures 1 to 2
Tables 1

Abstract: Overexploitation of wildlife is a major driver of biodiversity loss. International wildlife trade is regulated and monitored at local, national, regional and global scales through a variety of mechanisms, including the UN, Multilateral Environment Agreements (MEAs), with CITES playing a key role. Whilst databases and systems are available to measure, monitor, and manage legal trade, the data for species that fall outside the scope of existing MEAs are both limited and highly fragmented. Illegal trade further complicates efforts to monitor and manage wildlife trade, and under-regulation creates 'grey-areas' of purportedly legal trade. Here, we review available wildlife trade monitoring programs to assess how complete is our understanding of international wildlife trade. We find that far more species are in international legal trade than are regulated through international agreements. We found that 24,331- 42,385 animal species, including at least 22.3-42% of described vertebrate species, are in international trade. When including plants, this number increases to at least 102,056 species in use and trade. However, the US-specific LEMIS dataset, despite being only national in scope, frequently had higher diversity of species in trade than global databases. This highlights the current fragmentation and incompleteness of global wildlife trade data. Yet, whilst the US is the only country to make national level data available publicly, most countries have programs to control wildlife collection and import, which could be modified to monitor trade. Standardised collation of wildlife trade data would enable more sustainable trade of wildlife globally.

Significance Statement: Wildlife trade is a global driver of biodiversity loss, but, at most, 3% of species in trade are reflected in the monitoring indicators for global conservation targets. We estimate that the number of species in use and trade is around double previous estimates at 102,056 species. Standardising the monitoring and collation of trade data is essential for sustainable management.



Graphical abstract: Animal species in international trade, with data either sourced exclusively from a single source (as labelled) or shared between databases. For the sources given, only those which include CITES, TRAFFIC or FAO data are truly global, whereas the others represent the work of researchers, or data from a single country; highlighting just how incomplete our knowledge of species in trade is. Graphic designed with the help of FigureLab. Plants are not shown as separating international trade from local trade and use is particularly challenging

Main Text

1 Introduction

Unsustainable wildlife 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, 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 harvest on these populations. Well managed, sustainable use and trade can deliver critical benefits for people and species, including funding and motivating conservation efforts, income diversification and increasing food security (Corey et al., 2017, Sahley et al., 2007), while also incentivising long-term stewardship for wild populations (Abensperg-Traun, 2009). 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; yet the lack of systematic data collection means we may not learn what works in order to implement more widely, or identify declines whilst effective interventions could be made. In addition, wildlife trade is estimated to have contributed, directly or indirectly, to the global extinction of 294 species, 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 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). Legal trade is valued at ~10-fold that of illegal trade, or over $100 billion annually (Hughes 2021). 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, is to be halted. 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, whilst 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).

Assessing the most basic dimensions of global wildlife trade has remained a persistent issue. Whilst the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) notes that approximately 50,000 species are in trade (IPBES 2022), 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 take 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 that would help with monitoring 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, relative to 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 data (since data are often not available prior to listing, see Friedman et al., 2020) and risk waiting until species are already trade-threatened to apply measures to reduce threat and facilitate recovery (Challender et al., 2023; Cooney et al., 2021). Yet, despite the recognised threat posed by extraction for trade to thousands of species, whilst there has been some assessment of global initiatives, there has been little assessment of the coverage of regional and national trade databases. Furthermore, whilst the CBD recognises the importance of “sustainable use”, with its current “Global biodiversity framework" (GBF) having two targets on wildlife trade, its only headline indicator is in Target 5, and focuses on sustainably harvested fish for food.

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 internationally traded into and out of the United States, which collates all 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. However, 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., 2025). 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 powerful, country. LEMIS data has allowed the 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., 2025, 2025a), 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, whilst 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 officers etc.) to where they are most needed.

No assessment exists of the systems in place for monitoring the trade of wildlife at a global scale nor their accessibility and coverage. Here, we first assess the systems responsible for monitoring legal and illegal wildlife trade at various scales, and the consistency of the number of species recorded in trade across taxa. Second, we comprehensively document global, regional, and national systems for monitoring legal and illegal wildlife trade and compare and contrast the remit and coverage of the existing monitoring infrastructure. Based on these assessments, we identify key gaps in taxonomic coverage and assess how interoperable the information collected within these systems is. Furthermore, we assess the types of error, and sources of uncertainty, within trade data. In light of these analyses, we determine ways to dramatically improve our knowledge of and ability to sustainably manage international, as well as national and local, wildlife trade.

2 Results

Whilst we report monitoring of wildlife trade at global, regional and national levels, wildlife trade data are almost always made up of reporting via national programs which may then feed into international programs and structures to enable the monitoring of trade. Operations on detection of illegal trade can also include international programs and structures (such as those led by TRAFFIC). We first explore the scope of systems monitoring the global, legal wildlife trade (such as CITES), as well as global commodity trade for timber and fish (through global agencies with a global mandate for resource management, such as the FAO), then we review systems monitoring illegal trade. Finally, we assess the landscape of regional and national trade monitoring.

2.1 Global databases and coverage

<u>*Overall scope and coverage of global databases*</u>

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). However, whilst 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). However, there are some instances where these databases have had sufficient resolution to track trade (e.g., European eel *Anguilla anguilla*; Kaifu et al., 2019). Additionally, 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, pg 16)).

CITES remains the main source of detailed, species-level information on global-scale international wildlife trade (despite only covering a subset of species in trade). At present (Jan 2026), approximately 40,900 species are included in CITES Appendices (I, II, III), of which 6,610 (16.2%) are animal species and 34,310 species (83.9%) are plants, with orchids making up more than 70% of the total number of CITES-listed species (Table 1). Within the CITES framework, international trade in CITES-listed species is reported by CITES Parties in their annual trade reports, collated and made publicly available via the CITES Trade Database (https://trade.cites.org/, https://tradeview.cites.org/). There are currently over 28 million records of international trade in CITES-listed species dating back to 1975. This database provides details on the species, countries of import and export, source of the specimen, etc. However, CITES data remains prone to reporting errors and time lags

(Okes and Sant, 2022); many records still rely on “paper permits” and the manual compilation of annual trade reports by CITES authorities, with limited standardisation or exchange across digital systems, where implemented (e.g. eCITES) (ESCAP et al., 2025; CITES 2024a; Pavitt 2021). This process makes it harder to cross-reference records and identify errors and discrepancies (Blundell & Mascia 2005). eCITES may overcome some of the challenges here, but how that is translated into practice over time remains to be seen (CITES 2024).

For timber and fish, the FAO plays a major role in global trade monitoring, though with a principle focus on food rather than aquaria fish (Tlusty et al., 2013). However, global conservation targets related to the wildlife trade focus on sustainably harvested stocks of fish rather than species, and species-level data, where available, is most frequently focused on commercially valuable food fish (Sharma et al., 2025). Notably, previous efforts have assessed the taxonomic resolution of this data (UNEP-WCMC 2003; Wabnitz et al., 2003; https://aquariumtradedata.org; CITES 2024), and some lack sufficient species-level data to capture all elements of trade (e.g., FishStatJ: FAO 2025d). The FAO Global Capture Production Database provides critical baseline data for monitoring fishery data, though some analysis has contested interpretations; and more work is clearly needed (Pauly & Zeller 2016). Notably, FAO FISHSTATJ is the longest time series of any known DB 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, Pauly and Zeller 2016). 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). However, while 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.

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 (TRAFFIC

2024). For timber, the lack of species-level data is starting to drive independent assessment (World Forest ID) of the Global Priority Wood Species List (GPWSL) (Richardson et al., 2023).

Overall, there are more programs to attempt to detect and quantify illegal trade events (especially for vertebrates) than to monitor legal trade, including global, regional and national initiatives. Analysis of these data is also often more comprehensive (i.e. see Tow et al., 2025) as the standards for what details should be recorded can allow analysis of finer-scale geographic patterns and monitoring of changes over time, which is not possible for the majority of legal wildlife trade. However, even in cases of seizure data from illegal trade, species-level information is often not recorded (especially for smaller bodied groups such as invertebrates, fish, etc), and data based on customs codes can also 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 information (TRAFFIC 2023). Thus, even for more taxa with better monitoring (such as those listed in CITES), trade data may be partial and incomplete. Similarly, seizure data only represents the illegal trade that was uncovered, a potentially highly unrepresentive sample. Successful illegal trade thus cannot be directly monitored.

<u>Fragmentation and completeness of wildlife trade data</u>

Managing wildlife trade sustainably is contingent on the data to assess what is in trade and the impacts on source populations. Comparison between the databases discussed above demonstrate how fragmented and incomplete is the monitoring of trade. Global and national databases show different numbers of species in trade for various taxa (Table 1), although focused research papers often show that the numbers captured in global databases on trade are major underestimates, particularly for taxa where a smaller proportion of internationally traded species are represented in conventions such as CITES (e.g., reptiles, amphibians, and invertebrates; Figure 1, CITES 2022). Overall, we detected 42,385 animal species in trade across these databases. This count includes up to 31,703 vertebrate species, equating to 42% of all described vertebrates. An additional 602 animal species were listed in CITES Appendices but not recorded in trade which means they are not legally traded internationally. Most notably, whilst LEMIS only covers wildlife trade involving the US, it still records more species in trade for all vertebrate taxa than other databases that aim to reflect global trade (note that US-reported data in the CITES Trade Database also derives from LEMIS, though inconsistencies do exist). LEMIS alone records 27.4% of all traded species and covers between 29% and 88% of traded species in each taxon we considered (based on databases of recorded trade-Figure 2). Invertebrates had the lowest coverage in LEMIS, as until recently LEMIS has often overlooked their trade (Marshall et al., 2022).

Different collations of data can provide very different estimates on the number of species in trade (Table 1; Figure 2). Here we note recorded trade in species based on accounts which database direct evidence of legal (LEMIS, CITES etc) and illegal (TRAFFIC) trade, then compare it to a potential estimate where suspected trade is also included based on IUCN 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, 28% only in LEMIS), which increases to 10,682 when IUCN assessments are added. The next most traded group (by number of species) was birds (7202 species, 59.4% of all described extant bird species), yet 24% of these species were only recorded in LEMIS (and 72% of traded species in LEMIS), Thus, given a lack of comparably comprehensive data for other world regions, many more bird species may be in trade than we estimate (CITES 2024). Including IUCN data increases the count of bird species in trade to 7691 species. This disparity is similar for fish where 5454 species are in trade, representing 15% of described species, of which 39% are only recorded in LEMIS, whilst LEMIS includes 55% of all traded fish species, though most of these are not accounted for with their harmonised codes) (reaching up to 13997 species when IUCN data is included). Reptiles had the next highest count of species in trade at 4619, which represents 37% of all described species, yet 13% were only recorded in LEMIS (and 66% recorded in LEMIS overall). The number of traded reptile species also increases when IUCN data are added, reaching 5021 species. For mammals, 2266 species were recorded in trade (33% of described species, 51% only in LEMIS, 88% in LEMIS in total), which increased to 2812 species when IUCN assessment data were included. 4124 butterfly species were in trade (11% only in LEMIS, 29% LEMIS overall) as well as 1604 arachnid species (no species were only listed in LEMIS, but 51% were in LEMIS overall). For amphibians, 1793 species were in trade, with 29% only in LEMIS (77% overall in LEMIS) representing 20% of all described species. This increases further to 2182 species when IUCN data are added. Notably, for most taxa the US LEMIS dataset included a high percentage of species in trade, despite only representing trade with a single country; and 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). 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, 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.

Current estimates indicate that at least 40,283 plant species are documented as being used by humans, with the majority of recorded uses relating to medicinal applications (26,842 species), followed by use for materials (13,418 species) (Díazgranados et al., 2020; Pironon et al., 2024). However, documentation of plant use remains highly incomplete and uneven across regions and use categories, with many uses never formally catalogued (Bacchetta et al., 2016). Nevertheless, combining IUCN, CITES and TRAFFIC data with data on useful plants, places the total number of species still higher, reaching 59,671 plant species in use and trade. 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. Nevertheless, 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) in use were assumed to be traded, this would imply that over 102,056 wild species are in use or trade, and of these at least 74,054 are likely traded commercially internationally.

Only 9% of plant species documented as being used by humans are currently listed under CITES. Among angiosperms, the vast majority of species in use remain unlisted: 95% of used eudicots and 81% of used monocots fall outside CITES. The comparatively higher representation of monocots reflects the precautionary, group-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 53% of utilized species being included. These patterns highlight a fundamental mismatch between species in use and the availability of trade data: many plant species listed under CITES show little or no evidence of use, whilst limited alternative mechanisms for monitoring international trade means that most species in demonstrable use are not formally monitored (Table 1). 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 vs use highlight the complexities of trade, especially in assessing what is sustainable, given the different scales and volumes of use.

2.2 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). Other platforms and organisations providing regulation and monitoring of timber trade at a regional-scale 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; FSC, 2023, https://www.pefc.org/).

Many regional systems have been developed to collate seizure information for illegal trade. This includes 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). 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). In addition to these there are some taxa specific initiatives such as ETIS (Elephant Trade Information System) and MIKE (Monitoring the Illegal Killing of Elelphants) for elephants; however, comparable examples do not exist for most taxa (TRAFFIC 2025; ETIS 2025).

Patchy efforts have been made to collate data on wild meat use (https://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, generally under Comtrade harmonised codes (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 like FairWILD standards and WildCheck (Mosig Reidl et al., 2023) counteract these overarching trends, but they are focused on a smaller subset of species and regions. These programs now have almost global coverage (TRAFFIC 2025).

2.3 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 a national level (Figure S1), LEMIS represents one of 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 Supplement 3). 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. Whilst many of these are higher income economies (e.g., US, Canada), CITES-associated regulations also relate to permitting in various African countries, given the high number of species traded for purposes such as trophy hunting (many species may be subject to annual national quotas, though information on how the 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 reflected 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.

3 Discussion

3.1 Assessing the adequacy of data on species trade

The IPBES Sustainable Use of Wild Species assessment (2022) estimated that around 50,000 species were in trade (though provided little evidence on what they were), yet here we find data to show that potentially over double that number, up to 102,056 species are now in use or trade, though only 74,054 of these are confirmed to be in trade for potentially commercial uses. Whilst some of up to 59,671 plant species noted may be traded, or used for subsistence (as this figure relies on the "useful plants" analysis, which includes multiple uses), up to 42,385 animal species were found in international trade (and conservatively at least 24,331 for commercial uses). This highlights major gaps in our knowledge of global trade. Currently, no 'global' database provides an accurate reflection of trade in most taxa, except commercially traded food fish and timber. 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 is likely easier than it has ever been. In addition to new programs (e.g., regional TWIX programs, Aleris and ASEAN-WEN), new tools to detect and curb 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 eCITES permits may effectively prevent laundering and improve accuracy of trade records (Outhwaite 2020). However, seizure data not only reflect illegal trade volumes but also enforcement and reporting effort (e.g., a country with high numbers of seizures 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). Similarly, for other taxa and for national-level data, major gaps exist. As a consequence, even understanding how many species are in trade remains impossible.

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). 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 to how to manage these issues (Supplemental Text). In this context, social media influence extends beyond promotion to include platform features that facilitate access to wildlife trade, and simplify access for users (Fedemma, et al., 2021). National databases for trade in non-CITES species are not publicly available for any country outside the US. 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; Supplement 3). 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.

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). However, 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 away form critical trade issues, especially when widely traded and non-threatened species are adopted onto CITES Appendix II (e.g., the blue shark, *Prionace glauca*).

However, while Article II of 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 l., 2020).

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). Whilst 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).

3.2 Addressing the gaps

Most wildlife trade is not recorded in either domestic or international databases. From a global conservation science and management perspective, addressing these data gaps would ideally involve data on all internationally traded species. However, as developing Non-Detriment findings does require a knowledge of all offtake, systems for gauging this (or local permits) may be needed for accurate quota setting, or other forms of management. Data would be collected nationally and collated globally, with universal reporting standards in place. While CITES and LEMIS offer models to build upon for collecting such data, lessons can also be learned from the timber and fish commodity trade, as they face similar challenges like monitoring supply chains and assessing sustainability, which are common issues across all forms of wildlife trade (Marshall et al., 2025a).

Increased collection of species-level trade data through technological approaches (e.g., optical character recognition applied to trade invoices, machine learning, 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). It has also shown routes for illegal trade (Tlusty et al, 2023) and offers a way for trade to achieve nine of the 23 Kunming–Montreal Global Biodiversity Framework targets (Tlusty et al. 2024). However, 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), and the lack of a requirement for CITES Parties to report on Appendix II imports. 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 country is listed, and discrepancies in such information are common (Marshall et al., 2025a). Likewise, whilst the Lacey Act means that species traded into the US should be in alignment (legal) with national export regulations at the point of origin, the use of third countries, failure to disclose trade origin, and/or unclear origins make the detection of laundering impossible in many instances. Furthermore, whilst the Lacey Act requires species to be legally exported, assessing legality may be challenging as, even if the origin is known, knowledge of national laws and regulations may be limited. 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) 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).

Improvements in the quality of data collected, the 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). Whilst improved tracking has helped reduce illegal trade (NOAA 2025; Barendse et al., 2019; MSC 2025), illegal trade 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). Furthermore, even for fish species listed in CITES, illegal trade remains an issue. For example, around 37 million seahorses (*Hippocampus*) 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 delivering CITES provisions often results in species trade bans, a regulatory mechanism difficult to enforce, and that can result in trade moving to more informal channels (Friedman et al., 2018). Likewise, whilst trade in European eels (*Anguilla anguilla*) outside EU borders is largely illegal, the high value of global trade in eels is estimated $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 global seahorse seizures; Atlas of economic complexity; Kaifu et al., 2025; Foster et al., 2025), but effective enforcement remains challenging due to laundering and mislabelling 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 beginning to be 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 perspective and often lack key information (e.g., species names, quantity, harvest locality, user identity). 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). Furthermore, lessons from timber and fisheries trade have demonstrated the critical importance of understanding geographic patterns of trade to ensure legality (Roberson et al., 2025); yet this information is lacking for most taxa in trade (Marshall et al., 2025a).

3.3 The challenge of assessing sustainability

To assess sustainability of trade and harvest, non-detriment findings (NDFs) can be used (and must be used within CITES) and are commonly conducted as part of quota setting within CITES. Although there is no standardized template or content requirements for NDFs, a positive assessment is meant to confirm that trade will not be 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. That said, some countries have harvest quota systems in place for nationally protected species (see section 2.3 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. In practice, 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 we detect in trade.

Recent efforts to reduce the impacts of 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, decades of trade data have been collected by the FAO (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. Despite this apparent wealth of data, overestimation of stocks remains common, and consequently 85% more stocks than officially recognized by regulatory bodies (such as the FAO) have collapsed to below 10% of their maximum historical biomass (Edgar et al., 2024), with parallel issues also found in timber markets (Richardson & Peres 2016). To prevent further declines, improved models and better analyses are necessary to prevent over-fishing and population collapses, though applying such models accurately remains challenging (Perryman et al., 2023; McGregor et al., 2024).

Despite extensive data on populations and harvest for some taxa (such as fisheries), assessing sustainability is challenging; this reality highlights the even greater hurdles for accurate assessment of most taxa, which suffer from lack of relevant data (Richie & Roser 2021). Furthermore, obtaining accurate estimates of bycatch (e.g., Gilman et al 2022; Dasnon et al., 2022) and understanding the ecosystem-wide impacts of harvest 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 include information on species ecology (Edgar et al., 2024; Booth et al., 2020; Richardson & Peres 2016). For instance, in fisheries, adhering to Maximum Sustainable Yields (MSY) for a target species (e.g., forage fish such as anchovy), may fail to 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.

3.4 Persistent challenges and solutions

While wildlife trade poses a significant threat to the survival of many species, gaps in data create a major obstacle to understanding and managing trade. These gaps arise from the fragmentary nature of global monitoring systems, which fail to record many species in trade and often lack detailed, species-level information (Text S2). For some taxa, such as fish and insects, particularly high levels of uncertainty remain as little effort exists to accurately record traded species, which are harder to detect during trade (CITES Secretariat & UNEP-WCMC, 2024).

Developing more accurate wildlife trade systems is possible given that most countries already have mechanisms to check zoosanitary and phytosanitary data, as well as to compile relevant data on exports (and often imports) of CITES-listed species. New technologies are needed for monitoring and management for all forms of trade to increase the accuracy of reporting (Brown et al., 2025). Systems that require less work from importers could help overcome issues in species identification and accurate quantification and could increase our ability to identify inconsistencies in trade data (Text S2). Such systems should automate parts of the process, such as automating invoice digitisation (Tlusty et al., 2023), flagging potential mislabelling based on inconsistencies such as price (Nijman & Stein 2022; Stein et al., 2021), or verifying identities using AI. For example, new platforms have already been developed to enable the more sustainable use of trees (e.g https://woodid.info/). Furthermore, the burden of managing such data may represent a major concern, especially if done globally. However, if we compare it to the monitoring of other animals, it is clear that 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 the tracking of millions of animals (AHDB 2024). These tags are also interoperable even at global levels. Therefore, such data volumes clearly can be managed, and systems that can track individual provenance and history highlight that monitoring species-level trade is feasible. Yet the trade of wildlife outside CITES remains a persistent blindspot for governments globally, with virtually none outside the US providing available comprehensive databases of wildlife in trade.

3.5 Synergy

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 taxa, remains one of the most neglected components of the global biodiversity crisis. Our analysis provides a new, much higher total for the total number of species in trade: of up to 102,056 species once plants and fungi are considered, almost double the IPBES (2022) estimate of 50,000 species. Even though this is likely to be a considerable underestimate due to a lack of systematic data collection, this estimate already represents 22-42% of all recognized vertebrate species.

Whilst not free from issues, the US currently has a publicly accessible, taxonomically comprehensive assessment of their internationally traded animal species (with at least 27.4% of traded animal species only recorded in LEMIS). Comparable data for other countries are sorely needed. Whilst wildlife trade is acknowledged as a major threat to species survival (IPBES 2022), even indicators for trade included within global frameworks such as the Kunming-Montreal Global Biodiversity Framework fail to include data for the majority of taxa in trade, with at most 7% of internationally traded vertebrate species and 3% 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 entirely on sustainably harvested fish, and whilst currently including 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 systems of permits for the collection or international trade of some wildlife, but there are no standards to collate the information from these in terms of what species can be harvested and traded at different levels. Furthermore, even 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). Furthermore there are many CITES listed taxa that do not appear in trade, highlighting the nuances of understanding the landscape of trade. 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, yet 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 (Comtrade HS codes provide high detail for most exports and livestock trade is increasingly traceable at the level of individual animals). 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, real-time wildlife trade monitoring. However, current monitoring systems do not yet integrate these advancements at regional or global scales. Thus the lack of comparable progress in wildlife trade monitoring reflects a time where wildlife trade was less diverse than at present, and highlights an urgent need to bring wildlife trade monitoring in line with other elements of commodity trade.

Whilst developing new systems to collate wildlife trade data may seem intimidating, CITES and LEMIS already provide case-studies on how data could be collated across taxa, whilst international timber and fish trade provide examples on how certification and tracing may be used to assess the legality of trade, and new tools may strengthen our ability to better monitor trade. Thus, whilst creating entirely new systems for trade monitoring may seem daunting, the international nature of much trade and existing structures mean that systems could be modified to enhance the value of data that is already collected in some form to ensure it is interoperable and enables monitoring. We highlight the urgent need to shift to collate more representative data across taxa at a national and international level, and to share these data to finally enable the accurate monitoring of wildlife trade across taxa and scales. Whilst efforts to better understand illegal trade will require continued innovations to detect and disrupt illegal supply chains, we do have an opportunity to greatly enhance our understanding of legal trade. The legal trade is where our greatest knowledge gaps (particularly in species identity) exist, which precludes a complete understanding of the sustainability of trade.

Modifying existing national customs requirements to record the same fields as those already used within CITES and LEMIS databases would enhance the interoperability of data and provide a model to build from, as well as the motivation to develop tools which could work with such standardised data and the ability to develop consistent pipelines for data analysis. 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 and engagement. Starting at a regional level (such as Europe) to provide a model may provide a scalable means to collate data at the scale, and with the granularity needed for monitoring at all scales.

Ultimately, whilst the threat posed by 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 in trade is traded sustainably.

4. Materials and Methods

4.1 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, Macaques; Hansen et al., 2022, European eel; Nijman 2017; de Frutos, 2020).

4.2) 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) and one Basidiomycete (Lacquered bracket fungus) are recorded in TRAFFIC seizures, whilst 260 species are listed in use by the IUCN. While CITES Parties agreed that fungi are covered by the Convention at CoP12 in 2002 (CITES Res. Conf. 12.11) 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 is highly variable. 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 publically 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 under-estimates; however, 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.

4.3) 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. We applied these conformed names to the original dataset and combined the datasets by taxa. Following this, 1-1 matches with the taxonomic backbone are automatically accepted, and for remaining names taxize's gna_verifier's solution that does use some fuzzy/similar matching.

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), 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.

4.4) 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 (Supplement 1).

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 licences 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 (Supplement 2).

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 (Supplement 3) 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.

Acknowledgements

Neil Burgess was supported by the European Union's Horizon Europe Research and Innovation Programme under Grant Agreement No. 101133983, project more4nature.

References

Abensperg-Traun, M. (2009). CITES, sustainable use of wild species and incentive-driven conservation in developing countries, with an emphasis on southern Africa. Biological Conservation, 142(5), 948-963.

AHDB (2024) Sheep population: Defra's June census shows continued shrinking of the UK sheep flock. https://ahdb.org.uk/news/sheep-population-defra-s-june-census-shows-continued-shrinking-of-the-uk-sheep-flock

Ahlers, N., Creecy, J., Frankham, G., Johnson, R. N., Kotze, A., Linacre, A., ... & Webster, L. M. I. (2017). 'ForCyt'DNA database of wildlife species. Forensic Science International: Genetics Supplement Series, 6, e466-e468.

Alonso, A. I., & van Uhm, D. P. (2023). The illegal trade in European eels: outsourcing, funding, and complex symbiotic-antithetical relationships. Trends in Organized Crime, 26(3), 293-307.

Armstrong, O. H., Wong, R., Lorenzo, A., Sidik, A., Sant, G., & Chng, S. C. L. (2023). Illegal Wildlife Trade: Baseline for monitoring and law enforcement in the Sulu-Celebes Seas. TRAFFIC, Petaling Jaya, Malaysia.

Atlas Economic Complexity (2025) Who imported Live eels in 2023? https://atlas.hks.harvard.edu/explore/geomap?year=2023&exporter=group-1&tradeDirection=imports&startYear=1995&endYear=2023&product=product-HS92-5067

Bacchetta, L., Visioli, F., Cappelli, G., Caruso, E., Martin, G., Nemeth, E., ... & Eatwild Consortium. (2016). A manifesto for the valorization of wild edible plants. Journal of Ethnopharmacology, 191, 180-187.

Basel Institute on Governance (2021). Wildlife crime – understanding risks, avenues for action Part 4: Corruption in marine wildlife trafficking. Basel: Basel Institute on Governance, https://baselgovernance.org/publications/wildlife-crime-series

Bellmann, C., Tipping, A., & Sumaila, U. R. (2016). Global trade in fish and fishery products: An overview. Marine Policy, 69, 181-188.

Biondo, M. V., Burki, R. P., Aguayo, F., & Calado, R. (2024). An updated review of the marine ornamental fish trade in the European Union. Animals, 14(12), 1761.

Blundell, A. G., & Mascia, M. B. (2005). Discrepancies in reported levels of international wildlife trade. Conservation Biology, 19(6), 2020-2025.

Booth, H., Pooley, S., Clements, T., Putra, M. I. H., Lestari, W. P., Lewis, S., ... & Milner-Gulland, E. J. (2020). Assessing the impact of regulations on the use and trade of wildlife: An operational framework, with a case study on manta rays. Global Ecology and Conservation, 22, e00953.

Brown, M. R., Wells, V. K., & Beale, C. M. (2025). Assessing the integration of social marketing principles in ivory demand management interventions in China and Southeast Asia. Conservation Biology, e70191.

Brownell, B. (2024) Remember When A Dutch Airline Put 440 Squirrels Into A Giant Shredder? When you have too many squirrels around, just feed them by hand into a wood chipper. https://www.jalopnik.com/remember-when-a-dutch-airline-put-440-squirrels-into-a-1851573516/

Brusland S., Jurgens, J. (2024) Supporting CITES for conservation outcomes with the Songbird Species Knowledge Index. https://cites.org/sites/default/files/common/docs/meeting_info/songbirds/1%20SONGBIRD%20SKI.pdf

Bruslund, S., Leupen, B.T.C., Juergens, J., Shepherd, C.R. & Nelson, S.S. (2025). Songbirds in Trade Database (version 1.0). Monitor Conservation Research Society. Accessed on [date] at https://www.sitdb.org/.

CITES (2022) Disposal of illegally traded and confiscated specimens of CITES listed species in CITES CoP19 (Resolution conf. 17.8 (Rev. CoP19)). Accessed on November 2025 at https://cites.org/eng/imp/Disposal_of_confiscated_specimen

CITES (2025) Monitoring the Illegal Killing of Elephants (MIKE) https://cites.org/eng/prog/mike/index.php/portal

CITES (2025a) Twentieth meeting of the Conference of the Parties Samarkand (Uzbekistan), 24 November – 5 December 2025 Committee I Draft decisions on resolving the implementation of the CoP12 decision that the Convention applies to fungi https://cites.org/sites/default/files/documents/E-CoP20-Com-I-01.pdf

CITES (2025b) Consideration of proposals for amendment of appendices I and II. CoP20 Prop. 35. https://cites.org/sites/default/files/documents/E-CoP20-Prop-35_1.pdf

CITES (2022) Representation of songbirds (Passeriformes) in the Cites appendices and their prevalence in trade. Nineteenth meeting of the Conference of the Parties Panama City (Republic of Panama), 14 - 25 November 2022. https://www.birdlife.org/wp-content/uploads/2022/11/CITES-InfDoc-REPRESENTATION-OF-SONGBIRDS-PASSERIFORMES-IN-THE-CITES-APPENDICES-submitted-to-CITES-1.pdf

CITES (2022a) Conf. 17.8 (Rev. CoP19)* Disposal of illegally traded and confiscated specimens of CITES-listed species. Resolution Conf. 17.8 (Rev. CoP19) – 1. https://cites.org/sites/default/files/documents/COP/19/resolution/E-Res-17-08-R19.pdf

CITES (2025) Conf. 11.17 (Rev. CoP19) National reports. Resolution Conf. 11.17 (Rev. CoP19) – 1. https://cites.org/sites/default/files/documents/COP/19/resolution/E-Res-11-17-R19.pdf

CITES (2016) Conf. 16.7 (Rev. CoP17)* Non-detriment findings. https://cites.org/sites/default/files/documents/COP/19/resolution/E-Res-16-07-R

CITES (2024) AC33 Doc. 44 (Rev. 2) Annex 4 (https://cites.org/sites/default/files/documents/E-AC33-44-R2.pdf, https://cites.org/sites/default/files/documents/E-AC33-44-A4_2.xlsx

CITES (2024a) eCITES https://cites.org/eng/prog/eCITES

CITES Secretariat and UNEP-WCMC. (2024). International trade in non-CITES listed marine ornamental fish: International trade, conservation status, management and legislation for non-CITES marine ornamental fish in support of the implementation of Decision 18.296 [Updated]. UNEP-WCMC, Cambridge.

CITES-TRAFFIC (2025) CITES briefing document for the 20th meeting of the conference of the parties to cites Samarkand, Uzbekistan 24 November - 05 December 2025. https://www.traffic.org/site/assets/files/28130/traffic-_cites_cop20_briefing_paper_s.pdf

CITES (2025c) Consideration of proposals for amendment of appendices I and II. CoP20 Prop. 35. https://cites.org/sites/default/files/documents/E-CoP20-Prop-35_1.pdf

CITES (2022) Seventy-fourth meeting of the Standing Committee Lyon (France), 7 - 11 March 2022. Missing sharks: a country review of catch, trade and management recommendations for cites-listed shark species. /https://cites.org/sites/default/files/eng/com/sc/74/Inf/E-SC74-Inf-024.pdf

Challender, D. W., Cremona, P. J., Malsch, K., Robinson, J. E., Pavitt, A. T., Scott, J., ... & Hoffmann, M. (2023). Identifying species likely threatened by international trade on the IUCN Red List can inform CITES trade measures. Nature Ecology & Evolution, 7(8), 1211-1220.

Chamberlain, S and Szocs, E. (2013). taxize - taxonomic search and retrieval in R. F1000Research, 2:191. URL: https://f1000research.com/articles/2-191/v2

Chamberlain S, Szoecs E, Foster Z, Arendsee Z, Boettiger C, Ram K, Bartomeus I, Baumgartner J, O'Donnell J, Oksanen J, Tzovaras BG, Marchand P, Tran V, Salmon M, Li G, and Grenié M. (2020) taxize: Taxonomic information from around the web. R package version 0.9.98. https://github.com/ropensci/taxize

Corey, B., Webb, G. J. W., Manolis, S. C., Fordham, A., Austin, B. J., Fukuda, Y., ... & Saalfeld, K. (2018). Commercial harvests of saltwater crocodile Crocodylus porosus eggs by Indigenous people in northern Australia: lessons for long-term viability and management. Oryx, 52(4), 697-708.

CMS (1979) Convention on the Conservation of Migratory Species of Wild Animals. Bonn, 23 June 1979. https://www.cms.int/

Cooney R, Challender DWS, Broad S, Roe D and Natusch DJD (2021) Think Before You Act: Improving the Conservation Outcomes of CITES Listing Decisions. Front. Ecol. Evol. 9:631556. doi: 10.3389/fevo.2021.631556.

Dasnon, A., Delord, K., Chaigne, A., & Barbraud, C. (2022). Fisheries bycatch mitigation measures as an efficient tool for the conservation of seabird populations. Journal of Applied Ecology, 59(7), 1674-1685.

Datta, D., Self, N., Simeone, J., Meadows, A., Outhwaite, W., Walker, L., ... & Ramakrishnan, N. (2023). TimberSleuth: Visual anomaly detection with human feedback for mitigating the illegal timber trade. Information Visualization, 22(3), 223-245.

Datta, D., Simeone, J. C., Meadows, A., Outhwaite, W., Keong Chen, H., Self, N., ... & Ramakrishnan, N. (2025). Combating trade in illegal wood and forest products with machine learning. PloS one, 20(1), e0311982.

DEFRA (2009) Electronic identification (EID) in sheep Your technical guide. https://assets.publishing.service.gov.uk/media/5a79e592e5274a684690ce13/pb13616-sheep-eid-technical-guide-091127.pdf

de Frutos, P. (2020). Changes in world patterns of wild edible mush- rooms use measured through international trade flows. Forest Pol- icy and Economics, 112(January), 102093. https://doi.org/10.1016/j. Forpol.2020.102093

De Smedt, P., Jones, N. T., Kästle, B., Robla, J., Soares Campos Filho, I., Sfenthourakis, S., ... & Szlavecz, K. (2025). Rise of terrestrial isopods in the pet trade and the need for their inclusion in trade regulation. Conservation Biology, e70166.

Diazgranados, M., Allkin, B., Black, N., Cámara-Leret, R., Canteiro, C., Carretero, J., Eastwood, R., Hargreaves, S., Hudson, A., Milliken, W., Nesbitt, M., Ondo, I., Patmore, K., Pironon, S., Turner, R., & Ulian, T. (2020). World Checklist of Useful Plant Species [Dataset]. KNB Data Repository. https://doi.org/10.5063/F1CV4G34

Dickey, J. W., Liu, C., Briski, E., Wolter, C., Moesch, S., & Jeschke, J. M. (2023). Identifying potential emerging invasive non-native species from the freshwater pet trade. People and Nature, 5(6), 1948-1961.

Digirolamo, R. (2024). Google Trends and Online Q&A site Reveal Surging Demand for Endemic Pet Reptiles in Japan. bioRxiv, 2024-04.

Donald, P. F., Fernando, E., Brown, L., Busana, M., Butchart, S. H., Chng, S., ... & Safford, R. (2024). Assessing the global prevalence of wild birds in trade. Conservation Biology, 38(5), e14350.

Edgar, G. J., Bates, A. E., Krueck, N. C., Baker, S. C., Stuart-Smith, R. D., & Brown, C. J. (2024). Stock assessment models overstate sustainability of the world's fisheries. Science, 385(6711), 860-865.

Ellis, P. W., Gopalakrishna, T., Goodman, R. C., Putz, F. E., Roopsind, A., Umunay, P. M., ... & Griscom, B. W. (2019). Reduced-impact logging for climate change mitigation (RIL-C) can halve selective logging emissions from tropical forests. Forest Ecology and Management, 438, 255-266.

ESCAP, U., ECA, U., ECE, U., ECLAC, U., & ESCWA, U. (2025). Digital and sustainable trade facilitation: global report 2025. https://repository.unescap.org/server/api/core/bitstreams/3b5fba63-9007-439e-849c-6c97a8fe938a/content

Eskew, E. A. et al. (2019) United States LEMIS wildlife trade data curated by EcoHealth Alliance. Zenodo Dataset. https://doi.org/10.5281/zenodo.3565869.

Eskew, E. A., White, A. M., Ross, N., Smith, K. M., Smith, K. F., Rodríguez, J. P., ... & Daszak, P. (2020). United States wildlife and wildlife product imports from 2000–2014. Scientific Data, 7(1), 22.

EU Commission (2023) TRACES 2023 Annual Report. https://euagenda.eu/publications/traces-certification-2023-annual-report

EU Commission (2022) Commission staff working document. Evaluation of the EU action plan against wildlife trafficking. Accompanying the document. Communication from the commission to the European parliament, the council, the European economic and social committee and the committee of the regions. Revision of the EU action plan against wildlife trafficking. {COM(2022) 581 final} - {SWD(2022) 355 final}. https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:52022SC0354

European Commission (2025) DG Environment Study on the need for, added value, and feasibility of (Lot 2) criminalising all trade in illegal wildlife across the EU. Reference Number: ENV/2023/OP/0017. https://circabc.europa.eu/ui/group/3f466d71-92a7-49eb-9c63-6cb0fadf29dc/library/13062c04-a41e-434a-837b-65e5ed2bda9f/details

EU-LEX (2016) Consolidated version of the Treaty on the Functioning of the European Union. Part three - union policies and internal actions. title ii - free movement of goods. chapter 3 - prohibition of quantitative restrictions between member states. Article 37 (ex Article 31 TEC). Document 12016E037. https://eur-lex.europa.eu/eli/treaty/tfeu_2016/art_37/oj/eng

Evans, L. J., Baecher, J. A., & Scheffers, B. R. (2025). Invasion risk posed by the pet trade. Frontiers in Ecology and the Environment, 23(3), e2825.

FAO (2025d) FishStatJ - Software for Fishery and Aquaculture Statistical Time Series https://www.fao.org/fishery/en/statistics/software/fishstatj

Feddema, K., Harrigan, P., & Wang, S. (2021). The dark side of social media engagement: an analysis of user-generated content in online wildlife trade communities. Australasian Journal of Information Systems, 25.

Fiennes, S., Hardianto, N., Ansari, S. D., Dwiyahreni, A. A., Jackson, T., Holmes, G., ... & Hassall, C. (2024). Rethinking extinction “crises”: The case of Asian songbird trade. Cambridge Prisms: Extinction, 2, e15.

Fisheries FAO. (2024). The state of world fisheries and aquaculture 2024 blue transformation in action. https://www.fao.org/publications/fao-flagship-publications/the-state-of-world-fisheries-and-aquaculture/en

Foster, S. J., Ascione, S. J., Santaniello, F., & Phelps Bondaroff, T. N. (2025). Using online reports of seahorse seizures to track their illegal trade. Conservation Biology, e70047.

Fox, N., Di Minin, E., Carter, N., Tomkins, S., Van Berkel, D., 2025. Balancing accessibility and security: Safeguarding citizen-sourced biodiversity data in the age of AI and open-sourced software. Ecological Informatics 92, 103443. https://doi.org/10.1016/j.ecoinf.2025.103443

Friedman, K., Braccini, M., Bjerregaard-Walsh, M., Bonfil, R., Bradshaw, C. J., Brouwer, S., ... & Yokawa, K. (2020). Informing CITES Parties: Strengthening science-based decision-making when listing marine species. Fish and Fisheries, 21(1), 13-31.

Friedman, K., Gabriel, S., Abe, O., Adnan Nuruddin, A., Ali, A., Bidin Raja Hassan, R., ... & Ye, Y. (2018). Examining the impact of CITES listing of sharks and rays in Southeast Asian fisheries. Fish and Fisheries, 19(4), 662-676.

Gangi, J., Petrossian, G. A., & Sosnowski, M. (2025). The role of transit countries in global wildlife trafficking. Trends in Organized Crime, 1-27.

García-Moreno, J. (2023). Zoonoses in a changing world. BioScience, 73(10), 711-720.

GBIF Secretariat (2023). GBIF Backbone Taxonomy. Checklist dataset https://doi.org/10.15468/39omei accessed via GBIF.org on 2025-11-30.

Gerson, H., Cudmore, B., Mandrak, N. E., Coote, L. D., Farr, K., & Baillargeon, G. (2008). Monitoring international wildlife trade with coded species data. Conservation Biology, 22(1), 4-7.

Gilman, E., Hall, M., Booth, H., Gupta, T., Chaloupka, M., Fennell, H., ... & Milner-Gulland, E. J. (2022). A decision support tool for integrated fisheries bycatch management. Reviews in Fish Biology and Fisheries, 32(2), 441-472.

Gippet, J. M., & Bertelsmeier, C. (2021). Invasiveness is linked to greater commercial success in the global pet trade. Proceedings of the National Academy of Sciences, 118(14), e2016337118.

Gippet, J. M., Sherpa, Z., & Bertelsmeier, C. (2023). Reliability of social media data in monitoring the global pet trade in ants. Conservation Biology, 37(3), e13994.

Gray, T. N. E., Marx, N., Khem, V., Lague, D., Nijman, V., & Gauntlett, S. (2017). Holistic management of live animals confiscated from illegal wildlife trade. Journal of Applied Ecology, 54, 726–730. doi: 10.1111/1365-2664.12916

Gomes Destro, G. F., de Fernandes, V., Alves de Andrade, A. F., de Marco, P., & Terribile, L.C. (2019) Back home? Uncertainties for returning seized animals to the source areas under climate change. Global Change Biology, 25, 3242–3253. doi: 10.1111/gcb.14760

Gov.UK (2024). Keeping sheep and goats in England. https://www.gov.uk/government/collections/keeping-sheep-and-goats-in-england

Government of Canada (2025) Legality and sustainability. https://natural-resources.canada.ca/forest-forestry/sustainable-forest-management/legality-sustainability

Hansen, M.F., Gill, M., Briefer, E.F., Nielsen, D.R. and Nijman, V., 2022. Monetary value of live trade in a commonly traded primate, the long-tailed macaque, based on global trade statistics. Frontiers in Conservation Science, 3, p.839131.

Harfoot, M., Glaser, S. A., Tittensor, D. P., Britten, G. L., McLardy, C., Malsch, K., & Burgess, N. D. (2018). Unveiling the patterns and trends in 40 years of global trade in CITES-listed wildlife. Biological Conservation, 223, 47-57.

Haukka, A., Jürgens, J., Staerk, J., Lehikoinen, A., Bruslund, S., & Santangeli, A. (2026). Aesthetic values predict bird trade, but the association varies across product types and trade regions. Biological Conservation, 313, 111572.

Hinsley, A., Willis, J., Dent, A. R., Oyanedel, R., Kubo, T., & Challender, D. W. (2023). Trading species to extinction: evidence of extinction linked to the wildlife trade. Cambridge Prisms: Extinction, 1, e10.

Hinsley, A., De Boer, H. J., Fay, M. F., Gale, S. W., Gardiner, L. M., Gunasekara, R. S., ... & Phelps, J. (2018). A review of the trade in orchids and its implications for conservation. Botanical Journal of the Linnean Society, 186(4), 435-455.

Hočevar, S., & Kuparinen, A. (2021). Marine food web perspective to fisheries-induced evolution. Evolutionary Applications, 14(10), 2378-2391.

Hsu, C. H., Kang, J., Zhao, X., Uryu, S., Imagawa, H., Endo, T., & Kubo, T. (2025). Conservation Implications from a Decade of Online Wildlife Trade for Land Hermit Crabs. Global Ecology and Conservation, e03722.

Hughes, A. C. (2021). Wildlife trade. Current Biology, 31(19), R1218-R1224.

Hughes, A. C., Morton, O., & Edwards, D. P. (2025). Urgent policy change is needed to understand the dimensions of legal international wildlife trade to enable targeted management. Conservation Letters, 18(2), e13097.

Hughes, A., Auliya, M., Altherr, S., Scheffers, B., Janssen, J., Nijman, V., ... & Edwards, D. P. (2023). Determining the sustainability of legal wildlife trade. Journal of Environmental Management, 341, 117987.

Hughes, A. C., & Grumbine, R. E. (2023). The Kunming-Montreal Global Biodiversity Framework: what it does and does not do, and how to improve it. Frontiers in Environmental Science, 11, 1281536.

Hughes, A. C., Marshall, B. M., & Strine, C. T. (2021). Gaps in global wildlife trade monitoring leave amphibians vulnerable. Elife, 10, e70086.

Ingram, D. J., Coad, L., Milner-Gulland, E. J., Parry, L., Wilkie, D., Bakarr, M. I., ... & Abernethy, K. (2021). Wild meat is still on the menu: Progress in wild meat research, policy, and practice from 2002 to 2020. Annual Review of Environment and Resources, 46(1), 221-254.

IPBES (2022). Summary for Policymakers of the Thematic Assessment Report on the Sustainable Use of Wild Species of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. Fromentin, J. M., Emery, M. R., Donaldson, J., Danner, M. C., Hallosserie, A., Kieling, D., Balachander, G., Barron, E. S., Chaudhary, R. P., Gasalla, M., Halmy, M., Hicks, C., Park, M. S., Parlee, B., Rice, J., Ticktin, T., and Tittensor, D. (eds.). IPBES secretariat, Bonn, Germany. DOI: https://doi.org/10.5281/zenodo.6425599

IPBES (2019), Global assessment report of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, Brondízio, E. S.,

IUCN (2019). Guidelines for the management of confiscated, live organisms. Gland, Switzerland: IUCN. iv + 38 pp. Accessed on November 2025 at https://iucn.org/resources/publication/guidelines-management-confiscated-live-organisms

IWT Project (2025) IWT Project Map & Database https://illegalwildlifetradeprojects.org/project-map-and-database/

Jackson, A., Edwards, D. P., & Morton, O. (2023). National spatial and temporal patterns of the global wildlife trade. Global Ecology and Conservation, 48, e02742.

Jenkins M., Timoshyna A., Cornthwaite M. (2018). Wild at Home: Exploring the global harvest, trade and use of wild plant ingredients. Wild at Home: Exploring the global harvest, trade and use of wild plant ingredients. https://www.traffic.org/site/assets/files/7339/wild-at-home.pdf

Jimoh, M. A., Jimoh, M. O., Saheed, S. A., Bamigboye, S. O., Laubscher, C. P., & Kambizi, L. (2023). Commercialization of Medicinal Plants: Opportunities for Trade and Concerns for Biodiversity Conservation. Sustainable Uses and Prospects of Medicinal Plants, 309-332.

Juergens, J., Bruslund, S., Staerk, J., Nielsen, R. O., Shepherd, C. R., Leupen, B., ... & Conde, D. A. (2021). A standardized dataset for conservation prioritization of songbirds to support CITES. Data in Brief, 36, 107093.

Jürgens, J., Staerk, J., Bruslund, S., Nielsen, R. O., & Conde, D. A. (2025). CITES Appendix III matters: Hidden impacts of CITES deletions on global bird trade. Biological Conservation, 310, 111365.

Krassowski M. (2020). krassowski/complex-upset. Zenodo. http://doi.org/10.5281/zenodo.3700590

Kaifu, K., Stein, F., Dekker, W., Walker, N., Dolloff, C.A., Steele, K., Aguirre, A.A., Nijman, V., Siriwat, P. and Sasal, P., 2019. Global exploitation of freshwater eels (genus *Anguilla*): fisheries, stock status and illegal trade. In Eels biology, monitoring, management, culture and exploitation: Proceedings of the first international eel science symposium (pp. 377-422). GB: CABI.

Kaifu, K., Han, Y. S., & Shiraishi, H. (2025). Global consumption of threatened freshwater eels revealed by integrating DNA barcoding, production data, and trade statistics. Scientific Reports, 15(1), 29968.

Kubo, T., Mieno, T., Uryu, S., Terada, S., & Veríssimo, D. (2025). Banning wildlife trade can boost the unregulated trade of threatened species. Conservation Letters, 18(1), e13077.

Lassaline, C. R., Toomes, A., Fagan-Jeffries, E., & Cassey, P. (2025). From forest floor to market door: The global terrestrial invertebrate trade. Biological Conservation, 308, 111266.

Lees, A. C., & Yuda, P. (2022). The Asian songbird crisis. Current Biology, 32(20), R1063-R1064.

Leupen, B.T. C. (2018). Black Spotted Turtle in Asia II: A Seizure Analysis. TRAFFIC, Petaling Jaya, Selangor, Malaysia.

Lex A, Gehlenborg N, Strobelt H, Vuillemot R, Pfister H, UpSet: Visualization of Intersecting Sets, IEEE Transactions on Visualization and Computer Graphics (InfoVis '14), vol. 20, no. 12, pp. 1983–1992, 2014.

Lockwood, J. L., Welbourne, D. J., Romagosa, C. M., Cassey, P., Mandrak, N. E., Strecker, A., ... & Keller, R. (2019). When pets become pests: the role of the exotic pet trade in producing invasive vertebrate animals. Frontiers in Ecology and the Environment, 17(6), 323-330.

Liang, D., Giam, X., Hu, S., Ma, L., & Wilcove, D. S. (2023). Assessing the illegal hunting of native wildlife in China. Nature, 623(7985), 100-105.

Lynam, A. J., Cronin, D. T., Wich, S. A., Steward, J., Howe, A., Kolla, N., ... & Cox, H. (2025). The rising tide of conservation technology: empowering the fight against poaching and unsustainable wildlife harvest. Frontiers in Ecology and Evolution, 13, 1527976.

Marshall, B. M., Strine, C. T., Fukushima, C. S., Cardoso, P., Orr, M. C., & Hughes, A. C. (2022). Searching the web builds fuller picture of arachnid trade. Communications Biology, 5(1), 448.

Marshall, B. M., Strine, C. T., Gore, M. L., Eskew, E. A., Stringham, O. C., Cardoso, P., ... & Hughes, A. C. (2025a). Mapping the global dimensions of US wildlife imports. Current Biology, 35(16), 3959-3972.

Marshall, B. M., Strine, C., & Hughes, A. C. (2020). Thousands of reptile species threatened by under-regulated global trade. Nature communications, 11(1), 4738.

Marshall, B., Alamshah, A. L., Cardoso, P., Cassey, P., Chekunov, S., Eskew, E. A., ... & Hughes, A. C. (2025b). The magnitude of legal wildlife trade and implications for species survival. Proceedings of the National Academy of Sciences, 122(2), e2410774121.

McRae, L., Freeman, R., Geldmann, J., Moss, G. B., Kjær-Hansen, L., & Burgess, N. D. (2022). A global indicator of utilized wildlife populations: Regional trends and the impact of management. One Earth, 5(4), 422-433. https://www.livingplanetindex.org/utilised_index

Memarzadeh, M., Britten, G. L., Worm, B., & Boettiger, C. (2019). Rebuilding global fisheries under uncertainty. Proceedings of the National Academy of Sciences, 116(32), 15985-15990.

Mohanty, N.P., Measey, J. The global pet trade in amphibians: species traits, taxonomic bias, and future directions. Biodivers Conserv 28, 3915–3923 (2019). https://doi.org/10.1007/s10531-019-01857-x

Morton, O., Scheffers, B. R., Haugaasen, T., & Edwards, D. P. (2021). Impacts of wildlife trade on terrestrial biodiversity. Nature Ecology & Evolution, 5(4), 540-548.

Morton, O., Nijman, V., & Edwards, D. P. (2024). International wildlife trade quotas are characterized by high compliance and coverage but insufficient adaptive management. Nature Ecology & Evolution, 8(11), 2048-2057.

Mosig Reidl, P. et al. (2023). Legal and sustainable wild species trade: Learnings and implications for nature market governance. Taskforce on Nature Markets and TRAFFIC. Retrieved from https://www.naturemarkets.net/publications/legal-and-sustainable-wild-species-trade

MSC (2025) Find a supplier. https://cert.msc.org/supplierdirectory/VController.aspx?Path=02d03d11-054d-44f5-9076-b1bd00a2ebdf

Müller K (2020). _here: A Simpler Way to Find Your Files_. R package version 1.0.1, <https://CRAN.R-project.org/package=here>.

Nekaris, K.A.I., Campbell, N., Coggins, T.G., Rode, E.J. & Nijman, V. (2013). Tickled to death: analysing public perceptions of 'cute' videos of threatened species (slow lorises–*Nycticebus* spp.) on Web 2.0 Sites. PloS One, 8(7), 69215.

Nielsen, J. R., Thunberg, E., Holland, D. S., Schmidt, J. O., Fulton, E. A., Bastardie, F., ... & Waldo, S. (2018). Integrated ecological–economic fisheries models—Evaluation, review and challenges for implementation. Fish and Fisheries, 19(1), 1-29.

Nijman, V., 2017. North Africa as a source for European eel following the 2010 EU CITES eel trade ban. Marine Policy, 85, 133-137.

Nijman, V. & Shepherd, C.R. (2010). The role of Asia in the global trade in CITES II-listed poison arrow frogs: hopping from Kazakhstan to Lebanon to Thailand and beyond. Biodiversity and Conservation, 19(7), 1963-1970.

Nijman, V. & Shepherd, C.R. (2011). The role of Thailand in the international trade in CITES-listed live reptiles and amphibians. PloS One, 6(3), 17825.

Nijman, V., Campera, M., Sintya, E., Sukmadewi, D.K.T., Putra, N.G.M., Kuntayuni, Widiaswari, R.A., Shepherd, C.R., Payuse, I.N.A.D. & Chavez, J., 2024. Policies, law enforcement and sustainable use of nautilus shells in Indonesia and the effect of the 2017 CITES Appendix II listing on their trade. Discover Conservation, 1(1), 17.

Nijman, V., & Stein, F. M. (2022). Meta-analyses of molecular seafood studies identify the global distribution of legal and illegal trade in CITES-regulated European eels. Current Research in Food Science, 5, 191-195.

NOAA Fisheries (2025) Harmonized Tariff Codes and Other Resources for the Marine Mammal Protection Act Import Prohibitions. December 04, 2025. https://www.fisheries.noaa.gov/resource/outreach-materials/harmonized-tariff-codes-and-other-resources-marine-mammal-protection

OECD (2019), The Illegal Wildlife Trade in Southeast Asia: Institutional Capacities in Indonesia, Singapore, Thailand and Viet Nam, Illicit Trade, OECD Publishing, Paris, https://doi.org/10.1787/14fe3297-en.

Okes, N., & Sant, G. (2022). Missing sharks: A country review of catch, trade and management recommendations for CITES-listed shark species. Traffic. missing_sharks_a_country_review_of_catch_trade_and_management_recommendations_for_cites-listed_shark_species_final_updated.pdf

Olsen, M. T. B., Geldmann, J., Harfoot, M., Tittensor, D. P., Price, B., Sinovas, P., ... & Burgess, N. D. (2021). Thirty-six years of legal and illegal wildlife trade entering the USA. Oryx, 55(3), 432-441.

Outhwaite, W. (2020) Addressing corruption in CITES documentation processes. https://www.traffic.org/publications/reports/new-study-lifts-the-lid-on-addressing-corruption-in-cites-documentation-processes/#:~:text=They%20range%20from%20permit%20fraud,corruption%20that%20facilitates%20wildlife%20trafficking

Ovando, D. A. C., Stärk, J., Jürgens, J., Nielsen, R. O., & da Silva, R. (2022). Songbird SKI Annex 1: Species Knowledge Initiative to Support CITES Decisions and Recommendations for Passeriformes. https://conservation.species360.org/wp-content/uploads/2022/11/Report.Annex1_.Songbird_SKI_1030-compressed-1.pdf

Oyanedel, R., Levi, M., & Furci, G. (2024). A call to include fungi in wildlife trade research and policy. Conservation Biology, 38(5), e14340.

Pavitt, A., Malsch, K., King, E., Chevalier, A., Kachelriess, D., Vannuccini, S., & Friedman, K. (2021). CITES and the sea: Trade in commercially exploited CITES-listed marine species (Vol. 666). Food & Agriculture Org.

Pedersen T (2025). patchwork: The Composer of Plots. R package version 1.3.2, <https://CRAN.R-project.org/package=patchwork>

Pironon, S., Ondo, I., Diazgranados, M., Allkin, R., Baquero, A. C., Cámara-Leret, R., ... & Willis, K. J. (2024). The global distribution of plants used by humans. Science, 383(6680), 293-297.

Pironon, S., Ondo, I., Diazgranados, M., Allkin, R., Baquero, A. C., Cámara-Leret, R., Canteiro, C., Dennehy-Carr, Z., Govaerts, R., Hargreaves, S., Hudson, A. J., Lemmens, R., Milliken, W., Nesbitt, M., Patmore, K., Schmelzer, G., Turner, R. M., van Andel, T. R., Ulian, T., ... Willis, K. J. (2024). The global distribution of plants used by humans datasets: list of utilised species, occurrence data and model outputs at 10 arc-minutes spatial resolution [Data set]. Zenodo. https://doi.org/10.5281/zenodo.10345634

Pons-Hernandez, M. (2024). Inside the slippery world of glass eel trafficking: Lessons learned from Spain to prevent the illegal trade of European eels. European Journal of Criminology, 21(6), 908-928.

Price, R. (2017). The contribution of wildlife to the economies of Sub-Saharan Africa. Institute of Development Studies: Brighton, UK.

Quinlan, M. M., Mumford, J. D., Messori, S., Enkerlin, W. R., Shimura, J., Smith, L., ... & Torres, G. (2022). Issues and gaps in international guidance and national regulatory systems affecting international live insect trade. Revue Scientifique et Technique (International Office of Epizootics), 41(1), 198-210.

R Core Team (2024). _R: A Language and Environment for Statistical Computing_. R Foundation for Statistical Computing, Vienna, Austria. <https://www.R-project.org/>.

Rhyne, A.L., Tlusty, M.F., Schofield, P.J., Kaufman, L.E.S., Morris Jr, J.A. and Bruckner, A.W., 2012. Revealing the appetite of the marine aquarium fish trade: the volume and biodiversity of fish imported into the United States. *PloS one*, *7*(5), p.e35808.

Rhyne, A. L., Tlusty, M. F., Szczebak, J. T., & Holmberg, R. J. (2017). Expanding our understanding of the trade in marine aquarium animals. PeerJ, 5, e2949.

Richardson, S. B., Simeone, J. C., & Deklerck, V. (2023). The global wood species priority list: a living database of tree species most at risk for illegal logging, unsustainable deforestation, and high rates of trade globally. Wood and Fiber Science, 55(1), 31-42.

Rinne, J., Kulkarni, R., Soriano-Redondo, A., Correia, R., & Di Minin, E. (2025). Using automated content analysis to monitor global online trade in endemic reptile species. Diversity and Distributions, 31, e13771. https://doi.org/10.1111/ddi.13771

Rivera, S. N., Knight, A., & McCulloch, S. P. (2021). Surviving the wildlife trade in Southeast Asia: reforming the 'disposal' of confiscated live animals under CITES. Animals, 11(2), 439.

Richardson, V. A., & Peres, C. A. (2016). Temporal decay in timber species composition and value in Amazonian logging concessions. PloS one, 11(7), e0159035.

Roberson, L., Hosch, G., Wilcox, C., Domiguez-Martinez, R. M., Sant, G., & Klein, C. (2025). A New Seafood Import Policy for Nations to Combat Illegal Fishing. Conservation Letters, 18(1), e13091.

Roberts, D. L., & Hinsley, A. (2020). The seven forms of challenges in the wildlife trade. Tropical Conservation Science, 13, 1940082920947023.

Roe, D., Timoshyna, A., Aust, P., Compton, J., Dar, O., Donaldson, J., ... & Wilson-Holt, O. (2025). Fifty shades of sustainability? A new five-dimensional framework for assessing sustainability of wild species use. PLOS Sustainability and Transformation, 4(9), e0000196.

Ritchie, H., Roser, M. (2021) - "Fish and Overfishing" Published online at OurWorldinData.org. Retrieved from: https://ourworldindata.org/fish-and-overfishing

Sahley, C. T., Vargas, J. T., & Valdivia, J. S. (2007). Biological sustainability of live shearing of vicuna in Peru. Conservation Biology, 21(1), 98-105.

Saito, A. (2025) Where the wild things are...stored? The management and return of seized wildlife. Frontiers in Conservation Science, 5:1489314. doi: 10.3389/fcosc.2024.1489314

Sanchirico, J. N., & Essington, T. E. (2021). Direct and ancillary benefits of ecosystem-based fisheries management in forage fish fisheries. Ecological Applications, 31(7), e02421.

Senior, R. A., Oliveira, B. F., Dale, J., & Scheffers, B. R. (2022). Wildlife trade targets colorful birds and threatens the aesthetic value of nature. Current Biology, 32(19), 4299-4305.

Settele, J., Díaz, S., Ngo, H. T. (eds). IPBES secretariat, Bonn, Germany. 1144 pages. ISBN: 978-3-947851-20-1

Sharma, R., Barange, M., Agostini, V., Barros, P., Gutierrez, N. L., Vasconcellos, M., ... & Levontin, P. (2025). Review of the state of world marine fishery resources–2025. Food & Agriculture Org. 721. Rome. FAO.

Si, H., Hausmann, A., & Li, Z. (2025). The exotic pet craze on Chinese social media: Trends, community dynamics, and conservation implications. Biological Conservation, 311, 111420.

Sigaud, M., Kitade, T., & Sarabian, C. (2023). Exotic animal cafés in Japan: A new fashion with potential implications for biodiversity, global health, and animal welfare. Conservation Science and Practice, 5(2), e12867.

Silalahi, M., Purba, E. C., Sawitri, I. G. A. R., Wakhidah, A. Z., & Yuniati, E. (2023). International trade of medicinal and aromatic plants (MAPs). In Medicinal Plants: Biodiversity, Biotechnology and Conservation (pp. 289-306). Singapore: Springer Nature Singapore.

SiTDB (2025) Songbirds in Trade Database v1.0. https://www.sitdb.org/frm_display/search/?common=&scientific=&redlist=&EiT=Yes&PWC=&CCDT=&CCIT=&RPDTT=&LDCB=&CBE=&SBAP=&KAS= Retrieval date: October 30, 2025

Spee, L. B., Hazel, S. J., Dal Grande, E., Boardman, W. S., & Chaber, A. L. (2019). Endangered exotic pets on social media in the Middle East: Presence and impact. Animals, 9(8), 480.

Stein, F. M., Frankowski, J., Nijman, V., Absil, C., Kranendonk, I., & Dekker, W. (2021). Chinese eel products in EU markets imply the effectiveness of trade regulations but expose fraudulent labelling. Marine Policy, 132, 104651.

Stein, F. M., Nijman, V., Lau, M. C. W., & Dekker, W. (2025). Inclusion of all Anguilla Eel Species in CITES Appendix II Will Support Their Sustainable Management Across the Globe. Aquatic Conservation: Marine and Freshwater Ecosystems, 35(11), e70238.

Pildain, M. B., Visnovsky, S. B., & Barroetaveña, C. (2014). Phyloge- netic diversity of true morels (Morchella), the main edible non- timber product from native Patagonian forests of Argentina. Fun- gal Biology, 118(9), 755–763. https://doi.org/10.1016/j.funbio.2014. 03.008

Tittensor, D. P., Harfoot, M., McLardy, C., Britten, G. L., Kecse-Nagy, K., Landry, B., ... & Malsch, K. (2020). Evaluating the relationships between the legal and illegal international wildlife trades. Conservation Letters, 13(5), e12724.

Tlusty, M. F., Cassey, P., Rhyne, A. L., Omrow, D. A., & Stoett, P. (2024). Species-level, digitized wildlife trade data are essential for achieving biodiversity targets. Proceedings of the National Academy of Sciences, 121(16), e2306869121.

Tlusty, M. F., Cawthorn, D. M., Goodman, O. L., Rhyne, A. L., & Roberts, D. L. (2023). Real-time automated species level detection of trade document systems to reduce illegal wildlife trade and improve data quality. Biological Conservation, 281, 110022.

Tlusty, M.F., Rhyne, A.L., Kaufman, L., Hutchins, M., Reid, G.M., Andrews, C., Boyle, P., Hemdal, J., McGilvray, F. and Dowd, S., 2013. Opportunities for public aquariums to increase the sustainability of the aquatic animal trade. *Zoo biology*, *32*(1), pp.1-12.

Tow, J. H., Nghiem, T. P. L., Choo, J., Chng, S., Rao, M., & Carrasco, L. R. (2025). Two decades of changes in the global network of illegal wildlife trade. Conservation Biology, Article e70196. https://doi.org/10.1111/cobi.70196

TRAFFIC. (2023). An overview of seizures of CITES-listed wildlife in the European union: January to December 2021. https://www.traffic.org/site/assets/files/27874/2_june_-_last_-_traffic-overview_of_2023_eu_seizures.pdf

TRAFFIC (2024) Introducing TimberStats: a novel tool to root out illegal timber trade. https://www.traffic.org/news/introducing-timberstats-a-novel-tool-to-root-out-illegal-timber-trade/

TRAFFIC (2025) ETIS. the Elephant Trade Information System. https://www.traffic.org/what-we-do/thematic-issues/trade-monitoring/elephant-trade-information-system/

TRAFFIC (2025) FairWild. Promoting sustainable harvesting, use and trade of wild plants https://www.traffic.org/what-we-do/thematic-issues/promoting-sustainable-trade/fairwild/

UNEP-WCMC (2003). Global Marine Aquarium Database. Cambridge (UK): https://resources.unep-wcmc.org/products/WCMC_DT004

UNEP-WCMC (2022), International Trade in Non-CITES Listed Marine Ornamental Fish: International Trade, Conservation Status, Management and Legislation for Non-CITES Marine Ornamental Fish in Support of The Implementation of Decision 18.296 (UNEP-WCMC, Cambridge, 2022).

Upadhaya, S., Poudyal, B., & Tumpach, C. (2025). Integrating divergent stakeholder perspectives for sustainable management of high-altitude ecosystems: insights from cordyceps harvesting in the Himalayas. Sustainability Science, 20(1), 207-217.

Utermohlen, M., Baine, P. (2018). In Plane Sight. Wildlife Crimes in the Air Transport Sector. https://globalinitiative.net/wp-content/uploads/2018/08/In-Plane-Sight-Wildlife-Trafficking-in-the-Air-Transport-Sector-C4ADS-ROUTES-2018.pdf

Vasisht, K., Sharma, N., & Karan, M. (2016). Current perspective in the international trade of medicinal plants material: an update. Current pharmaceutical design, 22(27), 4288-4336.

Wabnitz, C., Taylor, M., Green, E. P., Razak, T. (2003). From Ocean to Aquarium: The global trade in marine ornamental species. UNEP-WCMC: Cambridge (UK).

Wang, Z., Chan, W. P., Pham, N. T., Zeng, J., Pierce, N. E., Lohman, D. J., & Meng, W. (2023). One in five butterfly species sold online across borders. Biological Conservation, 283, 110092.

Watson, G. J., Kohler, S., Collins, J. J., Richir, J., Arduini, D., Calabrese, C., & Schaefer, M. (2023). Can the global marine aquarium trade (MAT) be a model for sustainable coral reef fisheries?. Science Advances, 9(49), eadh4942.

Weissgold, B. J. (2024). US wildlife trade data lack quality control necessary for accurate scientific interpretation and policy application. Conservation Letters, 17(2), e13005.

Wickham H. ggplot2: Elegant Graphics for Data Analysis. Springer-Verlag New York, 2016.

Wickham H, François R, Henry L, Müller K, Vaughan D (2023). _dplyr: A Grammar of Data Manipulation_. R package version 1.1.4, <https://CRAN.R-project.org/package=dplyr>.

Wickham H, Vaughan D, Girlich M (2024). _tidyr: Tidy Messy Data_. R package version 1.3.1, <https://CRAN.R-project.org/package=tidyr>.

Wickham H (2023). _stringr: Simple, Consistent Wrappers for Common String Operations_. R package version 1.5.1, <https://CRAN.R-project.org/package=stringr>.

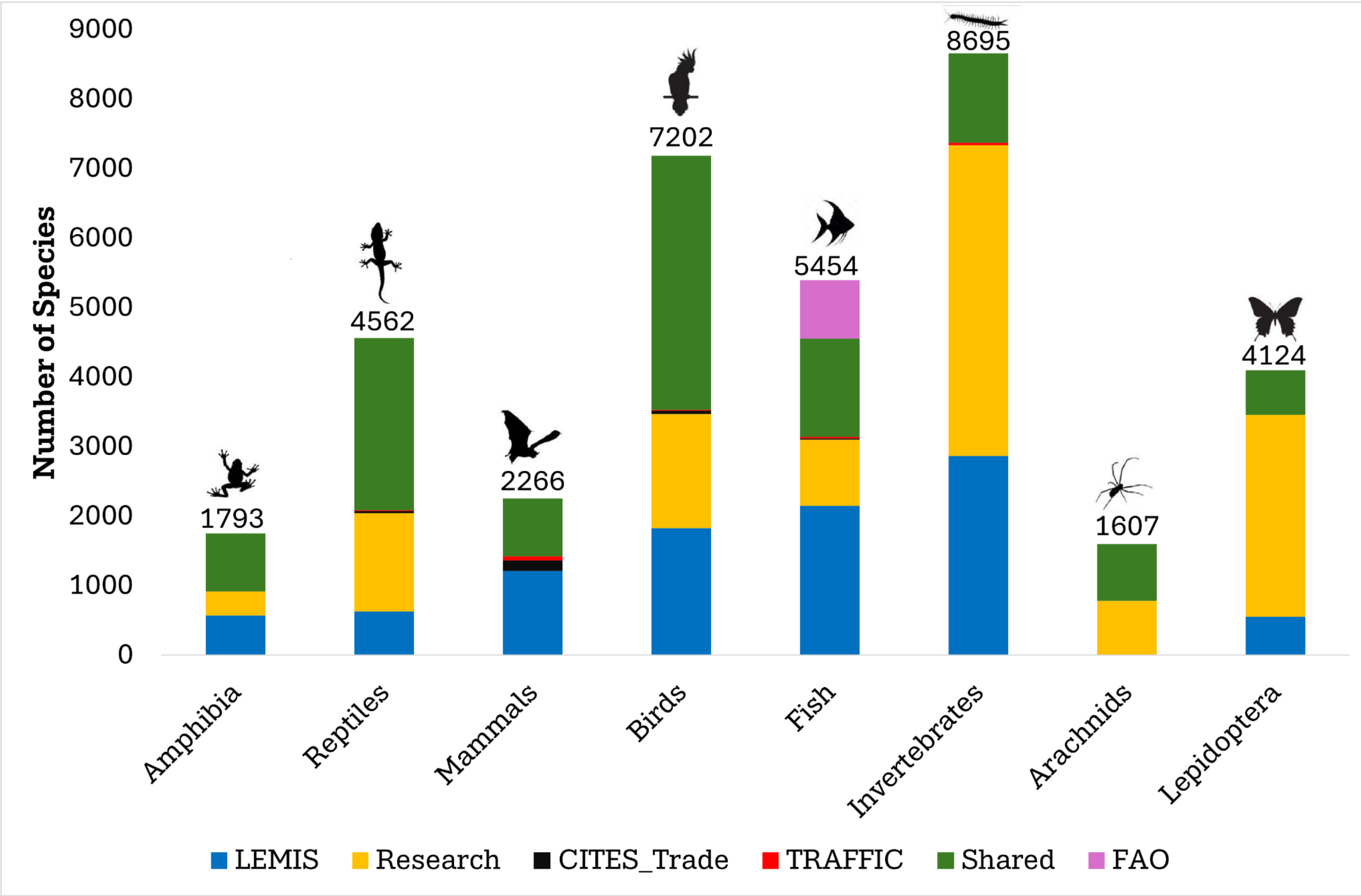
Wijnstekers, W. (2011). The Evolution of CITES - 9th edition. International Council for Game and Wildlife 495 Conservation

Willis, J., Ingram, D. J., Abernethy, K., Kemalasari, D., Muchlish, U., Sampurna, Y., ... & Coad, L. (2022). WILDMEAT interventions database: A new database of interventions addressing unsustainable wild meat hunting, consumption and trade. African Journal of Ecology, 60(2), 205-211.

Xiao, L., Pagani-Núñez, E., Han, X., Zhao, P., Li, X., Hong, Y., ... & Lu, Z. (2024). A mixed black and whitelist approach for wildlife trade regulation in China: Biodiversity conservation is made of shades of gray. Conservation Science and Practice, 6(2), e13062.

Xiang, L., Chen, Z., Wei, S., & Zhou, H. (2022). Global trade pattern of traditional Chinese medicines and China's trade position. Frontiers in Public Health, 10, 865887.

Zamani, S., Fathi, M., Ebadi, M. T., & Máthé, Á. (2025). Global Trade of Medicinal and Aromatic Plants. A Review. Journal of Agriculture and Food Research, 101910.


Number of Species
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
1793
4562
2266
7202
5454
8695
1607
4124
Amphibia
Reptiles
Mammals
Birds
Fish
Invertebrates
Arachnids
Lepidoptera
LEMIS
Research
CITES_Trade
TRAFFIC
Shared
FAO

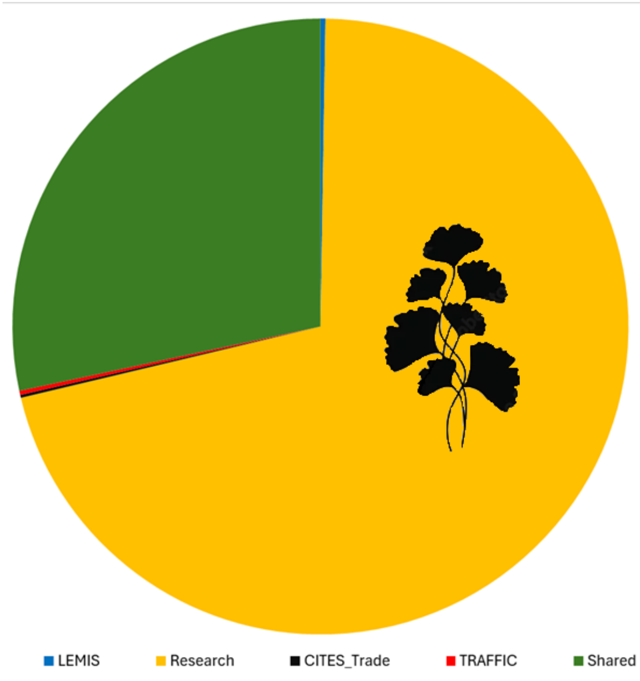


Figure 1. Number of species in trade for each animal taxa following data and name standardisation. Where species are only listed in a single repository, these are shown, whereas any species listed in trade in at least two separate repositories is listed as “Shared”. Interactions and coverage within each database is shown in Figure 2. Invertebrates here includes all invertebrates (including arachnids, lepidopterans and other terrestrial and marine invertebrates). Plants are shown separately due to the large numbers in trade, taxonomic groups are provided in Figure S2. 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.

Figure 2. UpSet plots displaying the overlap between the different sources of trade data. Overlap is calculated using species-level listings after translation of reported species names to the same standard. The top panel shows 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. Trade for different plant groups are provided in Figure S2.

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 listed in CITES, yet only lists 3404 dicotyledons (2732 in use) but 13900 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 equivalent data means it needs to be carefully considered. Notably, as these sources do not share taxonomic backbones, merging data is challenging at present and can only be done once a taxonomic backbone is applied.

Taxa	**Total all**	**Total conservative**	**CITES Trade**	**CITES App**	**LEMIS**	**LEMIS (no scientific purposes)**	**IUCN**	**TRAFFIC**	**Research**
Amphibia	2182	1261	166	376	1413	605	859	38	1203
Arachnida	1607	1607	37	41	818	628	36	65	1604
Aves	7691	5597	1582	1388	5173	2539	4793	966	5227
Fish	13997	4348	163	257	3031	1602	11580	215	2050

Invertebrates	10681	7502	102	159	4163	2860	2159	158	5746
Lepidoptera	4156	3893	52	50	1208	914	142	26	3556
Mammalia	2812	1481	821	900	2010	1054	1513	581	NA
Plants	59671	49723	13747	13640	295	228	18921	697	37212
Reptilia	5020	4143	888	1160	3046	2058	1666	472	3931

Supplements

Supplement 1. Questionnaire responses from 61 countries on the existence of National trade databases. For countries claiming presence of a database verification and relevant links are also provided

Supplement 2. Search terms for National databases in 30 languages. Any potentially relevant websites are listed (though most of these note information on permitting rather than the presence of any database). Relevant sections of text are also provided in "Scope".

Supplement 3. Search results for national databases on trade for each UN region. The overall summary, and cross-validation of all elements of the summary (noted in italics) is also provided.

All Data and code is also provided in supplements and will be made available via Zenodo on acceptance

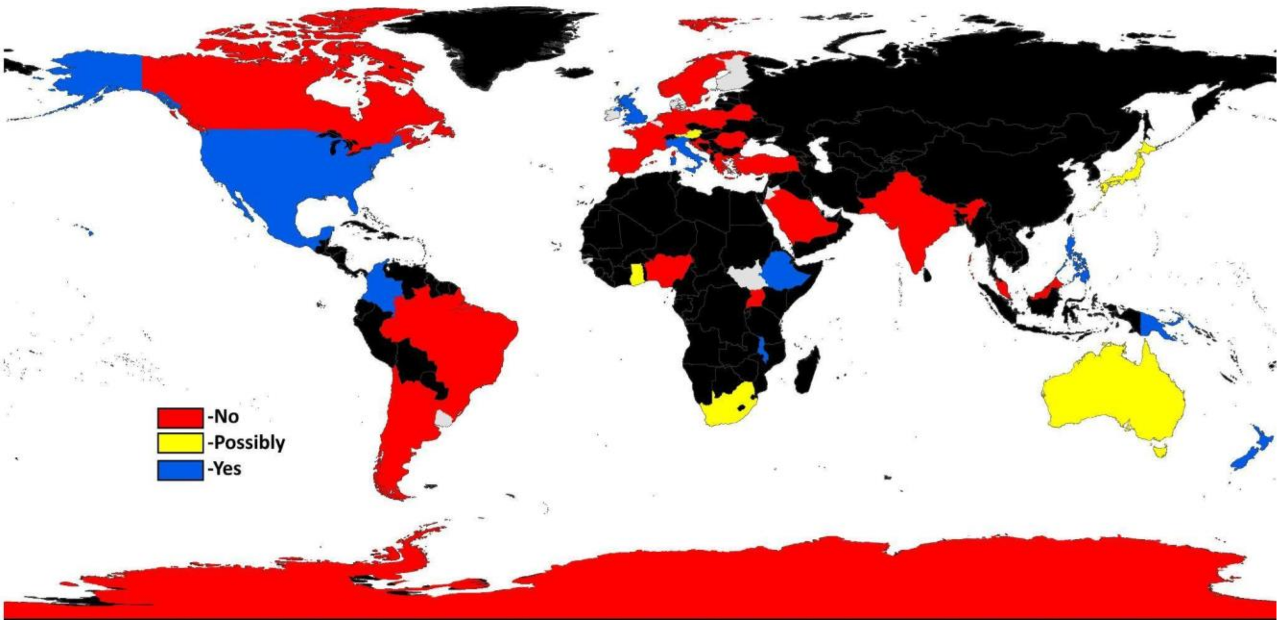


Figure S1. Self-reported legal wildlife trade databasing (outside species recorded by CITES or FAO, or seizures) from the questionnaire, for "yes" - has a system, "possibly"- may have a system (i.e. conflicting responses). "No" does not have a system. Although the level of detail and accessibility of 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.

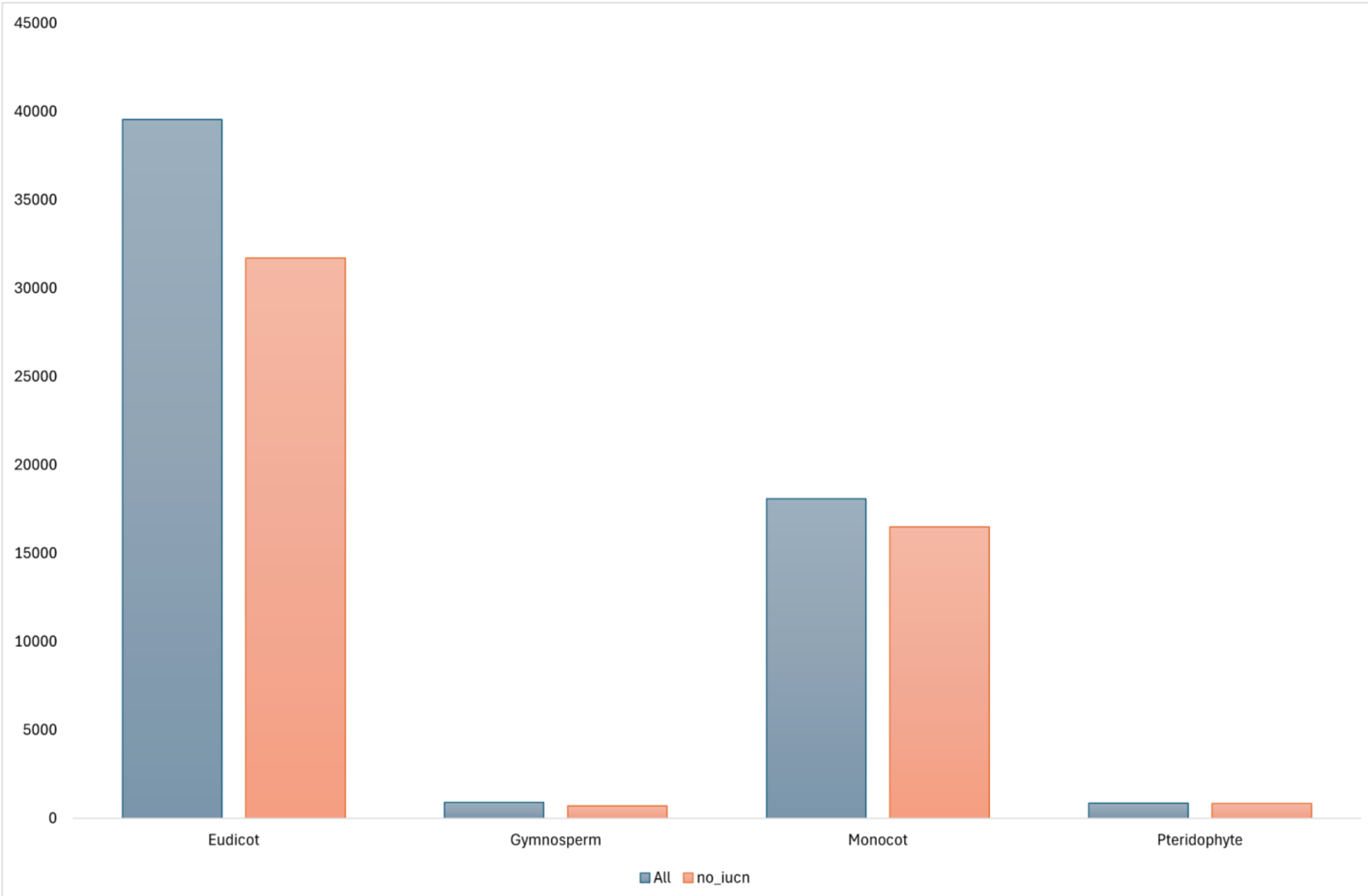


Figure S2. Numbers of plant species recorded in trade for different taxonomic groups.

Table S1. 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	1605
Lepidoptera	230
Fish	1105

Invertebrates	1193
Mammalia	784
Plants	32
Reptilia	474

Supplemental text

Text S1: Other considerations for sustainability

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. 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).