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Short communication

Global wildlife trade permeates the Tree of Life

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ABSTRACT

Legal and illegal wildlife trade is a multibillion dollar industry that is driving several species toward extinction. Even though wildlife trade permeates the Tree of Life, most analyses to date focused on the trade of a small selection of charismatic vertebrate species. Given that vertebrate taxa represent only 3% of described species, this is a significant bias that prevents the development of comprehensive conservation strategies. In this short contribution, we discuss the significance of global wildlife trade considering the full diversity of organisms for which data are available in the IUCN database. We emphasize the importance of being fast and effective in filling the knowledge gaps about non-vertebrate life forms, in order to achieve an in-depth understanding of global trading patterns across the full canopy of the Tree of Life, and not just its most appealing twig.

1. Introduction

Exploiting wildlife by selling it, their parts or products, is one of the most profitable activities in the world (Robinson and Sinovas, 2018; Scheffers et al., 2019). At the same time, the international trade in wildlife is a major threat to biodiversity (Scheffers et al., 2019; Sutherland et al., 2019; Smith et al., 2019). Moreover, wildlife trade periodically causes hundreds of billions of dollars of economic damage around the world because of disease outbreaks (Karesh et al., 2005; Swift et al., 2007). The coronavirus COVID-19 outbreak might be the most recent example, since it is suspected to have its origin in Chinese wild-animal markets (Mallapaty, 2020). Despite this socio-economic importance, no comprehensive analysis of the global patterns of wildlife trade has been made. The only exception is for terrestrial vertebrates, for which phylogenetic signal in trading was detected and global hotspots of trade were mapped based on data mined from the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) and the International Union for Conservation of Nature (IUCN) Red List of Threatened Species (Scheffers et al., 2019). Another recent study attempted to quantify the volume of reported trade globally, revealing that the volume of CITES-listed wildlife items quadrupled from 1975 to 2014 (Harfoot et al., 2018). Yet, despite being global in scale, this analysis was biased toward vertebrates and a small fraction of plant groups, mainly orchids.

Despite representing only 3% of described species (roughly 70,000 species) and a much lower fraction of extant species (probably < 1%) (IUCN, 2019), vertebrates are often used to make considerations and extrapolations to the whole Tree of Life in biodiversity and conservation analyses (Titley et al., 2017). This, in spite of the fact that those emblematic vertebrate species are just a small fraction of what is available in the market. Plants (e.g., Margulies et al., 2019) and invertebrates (e.g., Morell, 2007; Simičević, 2017; Law, 2019) account for a substantial, yet often overlooked and poorly documented, fraction of the wildlife trade, legal or illegal. For example, in recent seizures of protected fauna and flora across 109 countries by the International Criminal Police Organization (Interpol), the so-called "Operation Thunderball" (INTERPOL, 2019), it emerged that the largest fraction of smuggled material was timber (604 t and 2550 m^3, equivalent to 74 truckloads). Regarding the legal trade of species listed on CITES, considering the imports made only by the European Union, plants appear by far as the most traded group when considering the number of species (77.80%, most of which are orchids), weight (48.2%) and volume, in the period of 2007 to 2016 (Musing et al., 2018). In light of these considerations, any analysis of the global wildlife trade across the Tree of Life should take into account diverse taxa. In this short communication, we seek to spotlight the significance of all major taxonomic groups in the global wildlife trade and calling for more research on these neglected taxa.

2. Material & methods

We mined from IUCN database (IUCN, 2019) data from phyla/

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divisions with > 10 species assessed and, for each phylum/division, we quantified the number of species listed under the category *Use and Trade*. Species included in the following Red List categories were used for the analysis: critically endangered (CR), endangered (EN), vulnerable (VU), near threatened (NT), least concern (LC) and data deficient (DD). Note that IUCN red list assessments are often opportunistic, and in many groups species known to be threatened are prioritized for assessment. This way, the percentages of traded species in undersampled taxa, such as invertebrates, could be inflated. To avoid this possible bias we also calculated the percentages of trade among threatened taxa only. We considered species traded under all conditions (legal or illegal, commercial or scientific, in all magnitudes) but is important to differentiate species that are being traded from species that are at risk of extinction due to the trade, in order to prioritize the right groups and take the suitable conservation actions (Challender et al., 2019; Kolby, 2019).

3. Results & discussion

If looking exclusively at absolute species numbers, vertebrates (Chordata) would emerge as the most traded organisms, with 15,374 species listed under the category *Use and Trade* — more than half of which are fish (IUCN, 2019). Amphibians and reptiles are most commonly traded as pets, birds are traded both as pets and products, mammals are predominantly traded as products (Scheffers et al., 2019), while fishes are traded as human food (IUCN, 2019). The second taxon in absolute number of species traded is Tracheophyta, with 7621 species. The group with less species in the trade is Basidiomycota, with only 12 species (Fig. 1). Yet, given the predominance of vertebrates in the IUCN database (Fig. 2A), these results can be misleading. For example, several Divisions of Fungi are simply absent in IUCN and CITES (2019), preventing us to draw any inference about their significance in the global wildlife trade. In addition, it is acknowledged that IUCN assessments are substantially biased toward vertebrate species (Cardoso et al., 2011a), meaning that absolute numbers that can be extracted from IUCN do not express a real picture about the fraction of traded species across the Tree of Life (Fig. 2A).

When considering the identity and ratio of the traded/non-traded species based on IUCN assessments, eliminating such bias, it emerges that wildlife trading affects a large number of Phyla and Divisions, including plants (Tracheophyta), fungi (Basidiomycota), most major invertebrate groups (Arthopoda, Cnidaria, Mollusca, and Echinodermata), and both terrestrial and aquatic vertebrates (Chordata) (Fig. 1). In Basidiomycota, Tracheophyta, and Cnidaria, the ratio of threatened species among the traded groups is > 25%, and higher than that of vertebrates (Fig. 1). On the other hand, Echinodermata and Cnidaria have > 70% of their critically endangered, endangered or vulnerable species threatened by trade, more than twice the number of vertebrates (30%) (Fig. 1). The results were very similar to the full data, except for Echinodermata (Fig. 2B).

According to IUCN (2019), 45% of the Tracheophyta traded are for horticulture purposes and about 27% for medicinal use. In terms of number of species, only 230 species are listed under the *Fibre* category and 51 under *Specimen Collecting*. In this last category are included species traded due to their value in the collector market, especially orchids (Ticktin et al., 2020). They are harvested due to their edible, medicinal, ritual, and ornamental values and are sold in local and regional markets across the globe, often in massive quantities (Hinsley et al., 2018). Orchids make up approximately 70% of the species listed under CITES, with most families listed under Appendix II (Ticktin et al., 2020). Considering timber, the European Union in particular plays a significant role in the demand for tropical timber for the furniture market and imports and re-exports products derived from tree species listed in CITES appendices such as Big-leaf Mahogany *Swietenia macrophylla* King, Ramin *Gonystylus* spp., and African Teak *Pericopsis elata* (Harms) van Meeuwen (Engler and Parry-Jones, 2007). The European Union also imports tropical tree species that are not listed in CITES Appendices but nonetheless are threatened by trade, such as Merbau *Intsia* spp. (Engler and Parry-Jones, 2007).

The contribution of plants to the trade can be further evaluated using data from sources other than IUCN, and be examined from different angles: for example, the abundance in the trade as well as the monetary value generated by the species' commerce. When considering the value of legal wildlife commerce at global scale, timber trade is the most relevant, with an estimated value of US$190 billion in 2005, followed by fisheries (US$81.5 billion) (Roe, 2008). Plants emerge as

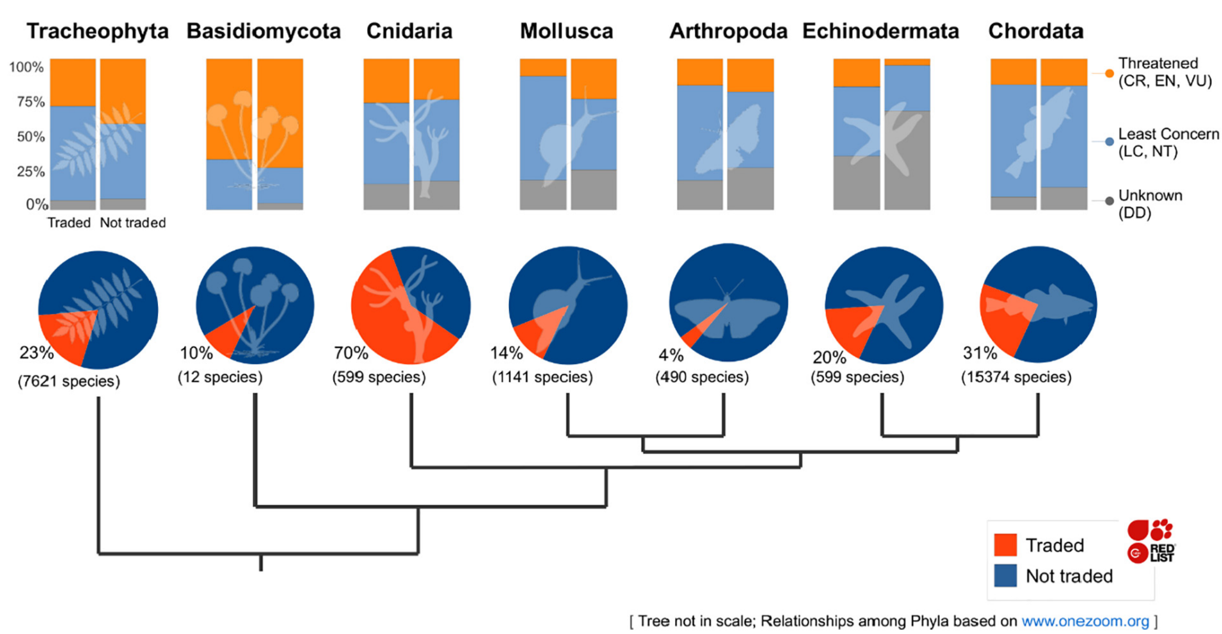

Fig. 1. Wildlife trade across the Tree of Life. Tree not in scale; relationships among branches based on Open Tree of Life project (https://tree.opentreeoflife.org; Accessed on 18 Oct, 2019). Tree is pruned to all Phyla or Divisions with > 10 traded species based on IUCN. Numbers in brackets are the total number of traded species, according to the IUCN subcategory *Use and Trade*. IUCN threat status codes: data deficient, DD; least concern, LC; near threatened, NT; vulnerable, VU; endangered, EN; and critically endangered, CR.

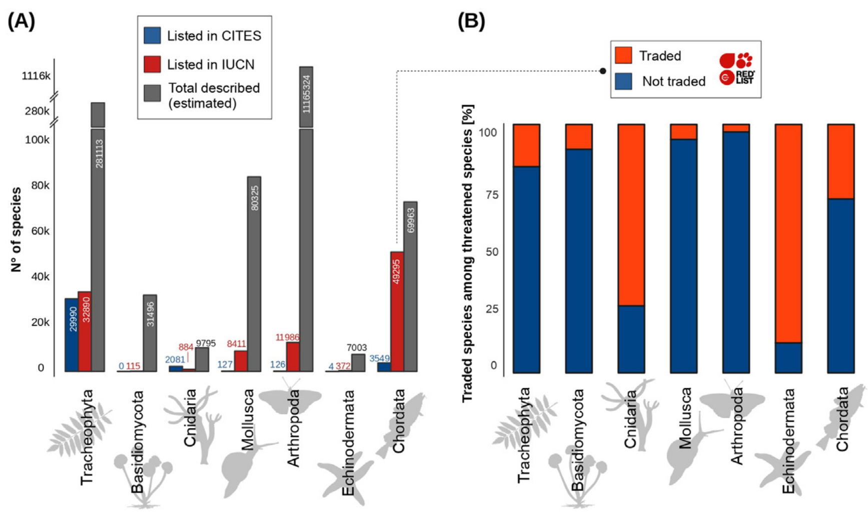

Fig. 2. Number of species listed in IUCN and CITES relative to the estimated total number of extant described species and percentage of traded species among the threatened species. A) Total number of species listed in CITES (2019) and IUCN (version 2019-2; IUCN, 2019), and total estimated number of described species based on IUCN (IUCN 2019-2). Numbers of CITES-listed invertebrates account for species that are listed in the current but also in previous versions of CITES appendices and/or in EU Wildlife Trade Regulations and were extracted from Species+ database (https://speciesplus.net/). B) For each taxonomic group, bars represent percentages of trade among taxa included in IUCN's threatened categories only. Trade is defined according to the IUCN subcategory *Use and Trade*.

the most traded group also when considering the abundance of groups in the wildlife trade. For example, 370 million orchids, 244 million of snowdrop flowers of the genus *Galanthus*, and 88 million cacti were traded internationally during 2000–2005 (Roe, 2008). Although making comparisons between distantly related groups is not a trivial exercise, it is interesting to note that these numbers are two to three orders of magnitude higher than the 1.7 million snakes, 5.6 million lizards, 600,000 turtles, and 236,000 amphibians included in CITES traded live during the same period (Roe, 2008).

The phylum Mollusca has 1141 species traded, 695 of which are classified under the *Sport hunting / specimen collecting* category of *Trade and Use* (IUCN, 2019). The vast majority of these species belong to the genus *Conus* Linnaeus, and are traded by specimen shell dealers for the collector market and for tourists as souvenirs (IUCN, 2019). Other mollusc species are also traded because of their value in medicine, as tools or religious symbols, as a source of protein, and as ornaments (Nijman et al., 2015).

Among cnidarians, corals are the most traded group (Morell, 2007). Corals are traded as live specimens, skeletons, or "live rock". They are used locally for building materials, road construction, and the production of lime and traded internationally for sale as souvenirs, jewelry, and aquarium organisms (Bruckner, 2000; IUCN, 2019). The flowerpot coral (*Goniopora* Blainville) and the anchor coral (*Euphyllia* Dana) are pointed as the most abundant corals in trade, partly because of their poor survival in captivity (Bruckner, 2000).

Sea urchins and sea cucumbers (Echinoidea) are under high commercial fishing pressure (Micael et al., 2009). In addition to overfishing, the emerging global trade in the collection of echinoderms for home aquaria, souvenirs, and biomedical products is at a critical stage and certain species of echinoderms are now listed as threatened (Micael et al., 2009). The most commonly collected seastar in the aquarium trade seems to be *Linckia laevigata* (Linnaeus), which is taken mainly from the shallow waters of the tropical Indo-Pacific (Micael et al., 2009). According to the Global Marine Aquarium Database (GMAD), this species accounts for 3% of the total global trade in marine invertebrates (Micael et al., 2009). Forty-two species of sea cucumbers are also fished commercially (Bruckner, 2000).

The majority of arthropods are traded under the category *Food — Human* and 99% are crustaceans of the class Malacostraca (IUCN, 2019). Species collecting for the pet trade also appears very relevant for arthropods, especially in insects, malascostracs, and arachnids (IUCN, 2019). In CITES, there are only 3 species and 2 subspecies of arthropods, all butterflies threatened by poaching, listed in Appendix I (CITES, 2019). In the less strict Appendix II, instead, there are 36 species of tarantulas, 5 species of *Pandinus* scorpions, 1 species of stag beetle, and several species of butterfly belonging to 8 genera, all related to species collecting for the pet trade (CITES, 2019; Fukushima et al., 2019). As bug smuggling represents a significant business (Actman, 2019), illegal trade is considered to be a serious but many times overlooked threat to arthropod populations (Tournant et al., 2012; Lehnert et al., 2017; Fukushima et al., 2019; Cardoso et al., 2020). However, it should be noted that invertebrates currently listed in CITES and IUCN are just the tip of the iceberg: the numbers of traded taxa in such databases are a gross underestimation of what is really traded. Moreover, as CITES is a database related to legal trade, this data does not account for seizures and illegal commerce. Thus, the picture of wildlife international trade for invertebrates and other poorly-studied taxonomic groups remains crude.

For Basidiomycota, the species traded are commercialized due to their value as human food, such as some species of boletes (*Boletus* spp.). Species of truffles (*Tuber* spp.), matsutake [*Tricholoma matsutake* (S. Ito et S. Imai) Singer], chanterelles (*Cantharellus* spp.), and morels (*Morchella* spp.) are also traded in the wild edible fungi market (Boa, 2004).

4. Concluding remarks

IUCN and CITES lists are by far the most commonly used data sources regarding wildlife trade analyses (Harfoot et al., 2018; Scheffers, 2019). However, it is fundamental to approach these data carefully, to avoid misinterpreting patterns and processes in wildlife trade due to the many biases inherent to these databases (e.g., Robinson and Sinovas, 2018). This is especially true for the CITES list, since often genus is the lowest taxonomic level used for precautionary purposes (the "look-alike" reason: the species is not traded but resembles one that is) (Challender et al., 2019; Kolby, 2019) This might lead to the incorrect idea that all species of the genus can be found on the trade. Also, we should always keep in mind that wildlife trade information is available in other databases such as LEMIS from the U.S. Fish and Wildlife Services, NGO reports and other grey literature, representing an additional rich source of data about non-CITES-listed species (e.g., Janssen and Leupen, 2019) and about illegal trade (e.g., 't Sas-Rolfes et al., 2019). Such data sources could be particularly relevant for many non-vertebrate groups.

To the extent that we have looked at global trading patterns using a limited share of species, we are still far from drawing a comprehensive picture about the legal and illegal trade of wildlife and its consequences in terms of biological conservation. The question still remains as to what inferences can be drawn from these scattered sources of information. To us, it is evident that the phenomenon of global wildlife trade is much more complex and pervasive across the branches of the Tree of Life than previously acknowledged, as it encompasses species from almost all marine and terrestrial realms and habitats. A small share of animals continuously receives attention from the general public and conservation scientists (Lawler et al., 2006), leading some conservation biologists to coin expressions such as "plant blindness" (Margulies et al., 2019) to refer to the privilege of vertebrate animals over plants, and "vertebratism" (Leather, 2013), to the preference of vertebrates over invertebrates in policy, law, and society. Yet, on a positive note, Scheffers et al. (2019) recently showed us a valuable research track to follow: they provided a thorough analysis focused on vertebrate trading at the global scale. They not only looked at absolute numbers of traded species in the market, but also mapped global hotspots of wildlife trade and explored whether certain groups are traded more than others by looking at the phylogenetic signal in trading (Scheffers et al., 2019).

Arguably, an extensive analysis of all the spatial, phylogenetic, or functional patterns in global trade taking into account the full diversity of species – the real Tree of Life – is currently impossible. For most non-vertebrate Phyla and Divisions, we simply lack high-resolution distribution maps, phylogenies, or functional trait data, as well as a reliable coverage in terms of number of IUCN assessments or in representativity on CITES Annexes. Future work including all organisms would help to unveil the interconnections among the different actors involved in the wildlife trade, and ultimately to incorporate biodiversity in policy strategic plans curbing trafficking. To pursue such an ambitious goal, a number of key steps need to be made. First, we need to obtain a less biased representation of the species involved in the global trading, in both IUCN and CITES lists. The knowledge about terrestrial vertebrates seems to be already fairly good (Scheffers et al., 2019), thus a special effort on assessing fungi, plants, and invertebrates against the IUCN criteria would be needed (Cardoso et al., 2011b). Second, we would need to assemble robust phylogenies for non-vertebrate Phyla and Divisions (Fig. 1) or eventually use the Linnean distance between species as a surrogate to detect phylogenetic signal in wildlife trading across taxa. Third, it would be fundamental to assemble databases of traits that can be compared across the breadth of taxa that are traded in the global market (Schneider et al., 2019), in order to unravel if species-specific attributes correlate with a higher probability of being traded. Ultimately, this knowledge would generalize and inform about the potential probability of a species to become part of the global trade. In other words, what we have to do is to be effective and fast in filling current knowledge gaps about all life forms, in order to achieve an in-depth understanding of global trading patterns across the full canopy of the Tree of Life, and not just its most appealing twig.

Data availability

All numbers used to generate Figs. 1 and 2 were extracted from the International Union for Conservation of Nature Red List of Threatened Species (IUCN Red List) (Accessed on 18 Oct 2019) and the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) databases (Accessed on 27 February 2019).

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Credit authorship contribution statement

Caroline Sayuri Fukushima: Conceptualization, Data curation, Funding acquisition, Writing - original draft. **Stefano Mammola:** Conceptualization, Data curation, Visualization, Writing - original draft. **Pedro Cardoso:** Conceptualization, Funding acquisition, Supervision, Writing - original draft.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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