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Review

Determining the sustainability of legal wildlife trade

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ABSTRACT

Exploitation of wildlife represents one of the greatest threats to species survival according to the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. Whilst detrimental impacts of illegal trade are well recognised, legal trade is often equated to being sustainable despite the lack of evidence or data in the majority of cases. We review the sustainability of wildlife trade, the adequacy of tools, safeguards, and frameworks to understand and regulate trade, and identify gaps in data that undermine our ability to truly understand the sustainability of trade. We provide 183 examples showing unsustainable trade in a broad range of taxonomic groups. In most cases, neither illegal nor legal trade are supported by rigorous evidence of sustainability, with the lack of data on export levels and population monitoring data precluding true assessments of species or population-level impacts. We propose a more precautionary approach to wildlife trade and monitoring that requires those who profit from trade to provide proof of sustainability. We then identify four core areas that must be strengthened to achieve this goal: (1) rigorous data collection and analyses of populations; (2) linking trade quotas to IUCN and international accords; (3) improved databases and compliance of trade; and (4) enhanced understanding of trade bans, market forces, and species substitutions. Enacting these core areas in regulatory frameworks, including CITES, is essential to the continued survival of many threatened species. There are no winners from unsustainable collection and trade: without sustainable management not only will species or populations become extinct, but communities dependent upon these species will lose livelihoods.

1. Introduction

Unsustainable use of biodiversity and anthropogenic-induced change in biotic communities represent major threats to species globally (e.g., Chapin et al., 2000; Pimm et al., 2014; Boivin, 2016; Ceballos, 2017; Pelletier and Coltman, 2018; Dulvy et al., 2021). While in political and public discussions 'unsustainable trade' is often equated with 'illegal trade', the lack of standards and processes to ensure sustainability is also prevalent for large parts of 'legal' wildlife trade. The sustainability of wildlife trade is entirely dependent on the long-term viability of the harvest of wild-collected individuals, rather than the act of trade itself. However, because demand and trade drive harvest, we will refer to exploitation as trade throughout. The risks of unsustainable legal trade have been recognised and built upon by various United Nations conventions, which aim to reduce global biodiversity loss (United Nations Conference on Environment and Development, 1993). Whilst the mandate of the Convention on Biological Diversity (CBD) is to ensure the sustainable use of wildlife, biodiversity loss has continued or even

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accelerated since its inception in 1992 (cf. Sustainable Development Goals [SDG] report 2021). Similarly, the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) has a mandate to "ensure that international wildlife trade does not threaten the survival of the species". Yet CITES covers only a small fraction of wildlife species in trade, while studies continue to demonstrate that its success in fulfilling this mandate is variable (e.g., Frank and Wilcove, 2019; Altherr and Lameter, 2020; Marshall et al., 2020; Morton et al., 2022).

The pace of biodiversity decline is faster than at any time in human history, being termed the sixth mass extinction (e.g., Leakey and Lewin, 1995; Dirzo et al., 2014; Ceballos and Ehrlich, 2018), with exploitation of wildlife (e.g., unsustainable harvest) highlighted as the second greatest threat to global diversity and its vital contributions to people (IPBES et al., 2019). Globally, monitored population sizes of mammals, fish, birds, reptiles, and amphibians have declined an average of 68% between 1970 and 2016, according to World Wildlife Fund's (WWF) Living Planet Report 2020 (Almond et al., 2020). As an important indicator of planetary health, these drastic trends in species populations signals a fundamentally broken relationship between humans and the natural world, the consequences of which — as demonstrated by the increasing health risk by zoonotic diseases, linked to wildlife trade (e.g., Karesh et al., 2007; Travis et al., 2011; Hoffmann et al., 2015; Schlottau et al., 2017; Borzée et al., 2020; Nijman, 2021a) — can be catastrophic.

Against this backdrop of rapidly declining biodiversity, thousands of species are traded for food, pets, fashion, curios, traditional medicines, and as hunting trophies, spanning hundreds of millions of individuals annually. These species require often very different modes of monitoring. The majority are exploited in the tropics, and at spatial scales from local bushmarkets to national and international vendors of pets, medicines, and international fashion houses (Scheffers et al., 2019; Hughes et al., 2021). International socio-economic inequality drives global patterns in wildlife trade, with the trade network connecting wealthier importing and poor exporting countries (Nijman, 2010; Auliya et al., 2016a; Liew et al., 2021).

At its best, well-managed wildlife trade can help protect biodiversity, maintain ecosystem function, and sustainably support local livelihoods so that future generations can continue to secure an income by not driving declines in wild populations (James and James, 1994; Cooney et al., 2017). Understanding the ecological roles that species play is critical to ensuring offtake does not cause major changes in ecosystem function (Hughes et al., 2022), and such data are critical to setting quotas that ensure wildlife offtakes and trade are sustainable (Purcell et al. 2018, 2018i; Çiçek et al., 2020). At its worst, species in trade can quickly transition from being of little conservation concern to at critical risk of extinction, also undermining the livelihoods they support (Lachs and Oñate-Casado, 2019). For instance, 506 traded populations of a diverse range of taxa suffered on average a 62% decline in abundance between 2005 and 2015, with local extirpations observed in 83 traded populations (Morton et al., 2021), 21 amphibian species had their populations traded to possible extinction in the wild (Auliya et al., 2016b), and populations of red coral (*Corallium rubrum*) in the Mediterranean have collapsed throughout most of their range (Garrabou et al., 2017, see Table S1). In many of these species, a lack of understanding of their basic biology, as well as the level of trade, mean that the impacts of trade can only be detected when it is already too late to preserve the exploited population.

1.1. Data needs

In acknowledgement of these risks, SDG15 "Life on Land" makes explicit provision to "take urgent action to end poaching and trafficking of protected species of flora and fauna and address both demand and supply of illegal wildlife products (https://www.undp.org/sustainable-development-goals#life-on-land)". Furthermore, within the Kunming-Montreal Global Biodiversity Framework, Targets 5 and 9 both focus on the sustainability of wildlife trade. The majority of CITES-listed species are orchids (70%), making legal trade of orchids a major focus of the convention (Hinsley et al., 2018). Yet, for animals, whilst combating illegal trade is often a focus of conservation management and policy, this overlooks insidious risks that legal international wildlife trade pose for species that lack adequate regulation, which represent the majority of species in trade (Janssen and Leupen, 2019; Leupen et al., 2020; Harris et al., 2015). For most species and populations, we neither have accurate data to estimate wild population sizes or population abundance (Rosser and Mainka, 2002; Ribeiro et al., 2019; Indraswari et al., 2020), nor volumes collected or traded (e.g., Rowley et al., 2016; Janssen and Shepherd, 2018; Fukushima et al., 2020; Biondo and Calado, 2021). A basic data standard that should be a prerequisite for sustainable trade is often not available. When combined with a lack of political will, this often results in scientific and economic uncertainties being propagated through most national to international trade. Consequently, there is little to no information to answer the most basic and fundamental question in collecting a species: what is a sustainable offtake?

Because of this apparent limitation in knowledge, policymakers should seek to exercise the precautionary principle, for instance, as a founding tenet of CITES (Wiersema, 2015). Whilst there are various interpretations of the precautionary principle, especially within CITES, it should be undebatable that harvest and trade should not pose a threat to the ongoing survival of species and, where there is doubt on the potential impact of trade, caution should be applied. The precautionary principle asserts caution when collecting species without baseline data on their distribution or population, and those species susceptible to population decline or showing poor recovery from population losses. Importantly, the precautionary principle states that inaction to regulate trade in wildlife should not be justified in the absence of data. The contradiction between a lack of data to assess threat and meet listing criteria, versus potential threat noted by range states was notable for several large groups at the most recent CITES meeting in 2022. For instance, listing of glassfrogs (Centrolenidae spp.) was initially opposed by the EU due to a lack of data virtually impossible to collect for non-CITES listed species (A. Hughes, *pers obs*).

Another option is a regional ban on international wildlife trade applied at broad taxonomic scales. For instance, in 2005, the EU banned importing of wild-caught birds, and the US Wild Bird Conservation Act has served a similar function since 1992. While both only targeted specific regions and taxa, they dramatically reduced the global flow of wild-caught birds through largely sealing major markets, enabling markets to primarily transition to captive stock (Reino et al., 2017) and effectively reduce the risk of unsustainable exploitation and invasion by non-native species (Carrete and Tella, 2008; Cardador et al., 2019). However, substantial illegal trade remains, with birds laundered into the Eus 'captive-bred' market (e.g., Hitchens and Blakeslee, 2020), and regional bans have limited impact on trade elsewhere, such as in Asia, where the 'Asian songbird crisis' represents a threat to hundreds of once-common species (e.g., Eaton et al., 2015, 2017; Eaton et al., 2017a; Leupen et al., 2020; Chng et al., 2021, see also bird section in Table S1, methods for example collation also provided in supplements).

The scale of these issues, lack of access to funds for species monitoring and population assessment, and absence of political will for protection of certain groups mean that even for groups where unsustainable trade is known, the need for species-level assessments prior to listing species within CITES presents a major barrier to providing appropriate listing or adequate protection. This may mean species potentially under threat do not get listed due to inadequate data needed for assessment. In turn, these issues provide further barriers to the listing of species at risk of unsustainable trade by increasing the requirements for data before a species potentially at risk can be listed. Understanding the intersections between legality, threat, and sustainability are critical to quantifying species vulnerability to overharvest and effectively regulate trade (Fig. 1), requiring assessment of the dimensions of trade

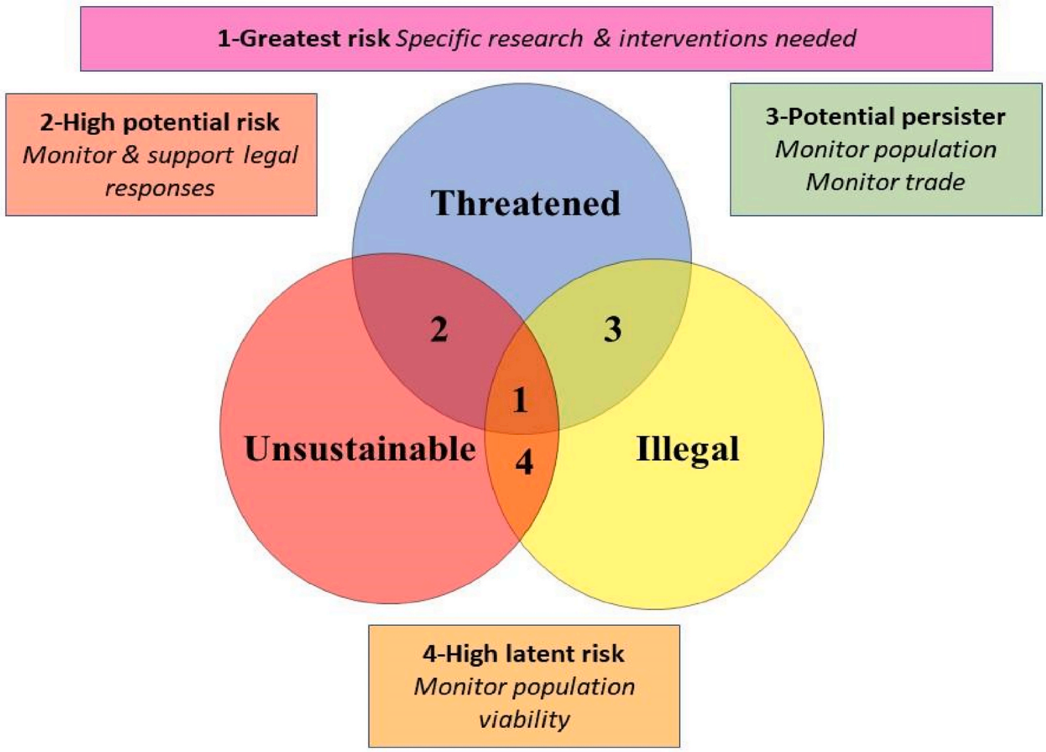

Fig. 1. Framework to assess the impacts of trade on species, examples of species within each category are noted in Table S1. Three dimensions of wildlife trade exist in assessments of species vulnerability: threat status, sustainability of trade, and legality. Combinations of these three dimensions describe four distinct classes of vulnerability to trade, each with specific implications for conservation. (1) 'At greatest risk', species considered at high risk of trade are threatened and currently illegally traded at unsustainable levels. These species are of high priority for monitoring, identification of research needs, and require immediate intervention to halt possible extinction. (2) 'High potential risk' are species that are currently threatened (either by trade or a suite of disturbances) and traded at unsustainable levels. Although the trade is legal, immediate population monitoring combined with support of legal responses is required. (3) 'Potential persisters' are those species currently threatened by human disturbance and are traded illegally; yet, their current trade is expected to be at sustainable levels. Monitoring of populations and enhanced enforcement is essential to ensure this group of species do not transition to 'at greatest risk' owing to transitions to unsustainable offtake. (4) 'High latent risk' are species with high levels of unsustainable and illegal trade. Although these species are not threatened owing to large population and range sizes, unsustainable illegal offtake may quickly threaten species. Thus, although not of immediate concern, continued monitoring of population sizes as well as offtake and reassessments of threat status are imperative, in addition to the implementation of regulations established at national level to detect and prevent illegal trade.

(including a lack of transparency and changing temporal dynamics) and in-depth understanding of all threats to species and their vulnerability.

Unsustainable trade both degrades biotic communities and eventually undermines livelihoods. This contradicts the notion that 'local livelihoods from wildlife trade' as part of access and benefit sharing do not need regulation (Cardoso et al., 2021), especially for external markets. The long-term future of traded species and trade-based local economies are thus inextricably linked (cf. Nasi et al., 2008; Ramírez-González et al., 2020; Cardoso et al., 2021). In addition, unsustainable trade often corrodes the objectives and implementation of both national and international wildlife-trade regulations. It is thus critical to identify a combination of appropriate, pragmatic, and easily enforceable mechanisms (Di Minin et al., 2019) to facilitate legal trade that does not detrimentally impact species/populations (see section IV).

In this synthesis, we distinguish four main focal elements. First, we investigate the relationships between legality and sustainability, discussing what is needed to bridge the gaps that often exist between the two. Second, we broadly review the scale, benefits, and negative impacts of legal trade, spanning both the unregulated and regulated trade in species, and various other facets of governance. Third, we review the successes and difficulties of CITES as the regulated component of international trade. Finally, we develop a research and policy framework for how to achieve and improve sustainability in wildlife trade. This review is supported by a comprehensive dataset of 183 species categorized in IUCN's Red-List threat categories, consisting of CITES and non-CITES species (for details see Table S1). In summary, we caution against assumptions that species can withstand high offtakes in the absence of data, instead underscoring the need for appropriate application of the precautionary principle to prevent population declines and species extinctions, plus enable long-term economically viable wildlife trade.

2. Three dimensions of trade

The extinction-risk, illegality, and unsustainability dimensions of wildlife trade intersect to create four broad categories of risk (Fig. 1), examples of species under each of these risk categories are noted in Table S1. This intersection of threat and rarity, as well as the detectability and recognisability of a species, is also reflected in the seven forms of challenge for managing wildlife trade (Roberts and Hinsley, 2020), which require different mitigation measures.

Category 1 indicates species where trade is illegal (with regards to national legislation) and unsustainable, and species are threatened, for example, Javan hawk-eagle (*Nisaetus bartelsi*), Pethiyagoda's crestless lizard (*Calotes pethiyagodai*), zebra loach (*Botia striata*), and Tiannan crocodile newt (*Tylototriton yangi*) (Table S1). These species were threatened by unsustainable trade and can no longer be legally traded from range states. Category 2 encompasses species threatened by unsustainable trade, but legally traded, for example, Chinese water dragon (*Physignathus cocincinus*; listed at the COP19 in Panama), Chipokae cichlid (*Melanochromis chipokae*), Banggai cardinalfish (*Pterapogon kauderni*), *Corallium rubrum*, and various Siamese fighting fish (*Betta* spp.) (Lees et al., 2020) (Table S1). Like category 1, these species are threatened and traded unsustainably (Fig. 1), yet they can be legally traded either within or outside CITES.

Category 3 species are threatened and cannot be legally traded, but the trade of these species could be sustainable. This may include CITES look-alike species that could be traded sustainably, for example, North Indian rosewood (*Dalbergia sissoo*) which could be sustainably grown for sale, but cannot be currently legally traded under CITES because it is a look-alike to trade-threatened *Dalbergia* spp. (look-alikes listed under CITES are generally demarcated by genus). Category 4 species are not threatened, but trade is unsustainable and illegal. A large number of geographically widespread species are currently not IUCN Red-Listed, although some are protected nationally or internationally but reportedly laundered as captive bred, for example, southern green tree python (*Morelia viridis*) (Lyons and Natusch, 2011), giant blue-tongued skink (*Tiliqua gigas*) (Janssen and Leupen, 2019), tokay gecko (*Gekko gecko*) (Nijman and Shepherd, 2015; Ardiantoro et al., 2021), and Southeast Asian porcupine (*Hystrix brachyura*) (Brooks et al., 2010). This is likely the category for many species, for example, most species in Southeast Asian bird trade, such as blue-crowned hanging parrot (*Loriculus galgulus*) and several species of white-eyes (*Zosterops* spp.). Despite this general classification of intersecting threats across four classes, interventions would be obligatory for species groups that, due to their restrictive geographic distribution and possibly also unfavourable life history traits (e.g., late sexual maturity, low reproductive output, etc.) to sustain viable populations.

Our examples (Table S1) highlight 183 species potentially threatened by trade that fit in different Categories and, in most cases, show evidence of shrinking populations. Whilst these examples are an indicative subset, they represent all geographic regions and span major taxa, including 22 mammal species, 24 birds, 63 reptiles (30 lizards, 17 chelonians, and 16 snakes), 27 amphibians, 22 fish, and 25 invertebrates. Of these, 52 of the species are classified by the IUCN Red-List as Critically Endangered, 77 as Endangered, and 54 as Vulnerable. Of these species, 62 were listed in CITES Appendix II, 8 in App. III, and 113 are not included in any CITES Appendix prior to CITES-COP19, while 25 are endemic species and are nationally protected in their sole range state. Ten of the species are currently included in EU Annex D, which does not regulate trade, but monitors EU import and export data. As most of these species have declining populations, none can be regarded as sustainable, though the majority of trade for most of them is legal.

3. What is true sustainability in wildlife trade?

"*Direct use is complex and multifaceted and often it is difficult, if not impossible, to tease apart those different facets. At times we simply do not have the information that allows us to know where the ever-shifting line between exploitation and overexploitation lies*" (Spicer, 2006).

The concept of sustainability in natural resource use, and specifically of wildlife, has been widely used in major policy initiatives since the term 'sustainable development' was coined by the IUCN, UNEP, and WWF in 1991 (IUCN, 1991), and its subsequent adoption at the Rio de Janeiro Earth Summit in June 1992 (see Supplementary Text for the history of 'sustainability' use in international agreements). However, holistic consideration of multifactorial drivers of threat in sustainability assessments has lagged behind declarations of 'sustainability'. They may fail to monitor sufficiently frequently to accommodate the shifting baseline and gauge what might actually be a sustainable offtake. Thus, whilst frameworks champion access to resources, they often neglect outlining explicit measures to ensure such use will not see diminishing returns. Understanding the intersections between threat, sustainability, and legality are critical to determine the impacts of trade on species survival (Fig. 1), and this must also be considered within the context of other threats. Assessing what is sustainable is complex, and the use of single indicators often continues despite providing a poor index of sustainability or inaccurate Maximum sustainable yield (Weinbaum et al., 2013).

The concept and goal of sustainability is so commonly used that the majority of Multilateral Environmental Agreements (MEAs) currently have various sustainability standards and benchmarks integrated in their initiatives and mandates (Fig. 1). Yet, its widespread use as a legal mandate in the absence of an agreed upon definition results in two complications: 1) it obscures the true meaning of sustainability and the prerequisite information necessary to achieve it (see Supplemental text 1); and 2) it gives the superficial appearance of successful implementation. Critically, the anthropocentric and short-term definitions of sustainability often prioritise human access to resources (e.g., ecosystem services: Lele et al., 2013) or even emphasise climate change mitigation measures, but neglect measures to assess the impacts of exploitation on wild populations and other sustainability spheres (i.e., economic). A holistic understanding of population viability, threats, and reproductive rates is necessary to ensure offtake is sustainable (Supplemental text 1, 2). Furthermore, approaches to gauge sustainability are considerably more developed in North America and Europe, whereas in many developing economies there is a greater tendency to miscalculate sustainable offtake (Weinbaum et al., 2013).

For sustainability standards to be meaningful, mandatory guidelines are needed to enable both clear communication and comparability between different organisations using them. Definitions on sustainable use of biodiversity from the major MEAs (i.e., CITES, CBD, IPBES, IUCN, and MSC) all stipulate that use for human needs does or should not lead to a decline of biodiversity (Supplemental text 1) (Stolpe and Fischer, 2004). Importantly, all Parties, definitions, and conventions claim to be evidence-based, yet many of these frameworks lack criteria or benchmarks for assessing the impact of offtakes on wild populations (Table S1). In this section, we first review expectations for sustainability in wildlife trade, and then review examples where trade has caused severe declines and those in which trade has been managed sustainably, and the factors necessary to enable sustainable trade.

3.1. Interpretations of sustainability

Different organisations/MEAs use different metrics and benchmarks to define and measure sustainability. Different measures of interdependent sustainability can be considered, including ecological sustainability (to maintain ecosystem function in the face of wildlife extraction) and economic sustainability (not undermining long-term profits from the extraction of animals/plants), with offtake for both needing to be sustainable (harvest should be below the rate of annual replacement once mortality is considered). Even with good governance and oversight, and before considering genetic diversity, sustainable offtakes must reflect taxonomic status and population dynamics, alongside practical methods that prevent overexploitation such as individual regional species-level quotas, curtailing illegal offtake, and intensive management for population restoration if sustainability is compromised. In addition, the impact of a species offtake for its ecosystem must be understood. For example, frogs' legs trade from India and Bangladesh in the 1970–80s increased agricultural pests and thus use of pesticides (Fugler, 1984; Abdulali, 1985). Management tools used to ensure sustainability should include standards for setting quotas for capture and export, monitoring populations, clear reporting standards, and mechanisms for specific management schemes (that cannot be misused) to ensure long-term population persistence.

Having clear metrics for each of these is the gold standard in other nature-based extractive sectors of the economy, such as sustainable fisheries, and is captured in definition by leading organisations equally governing the trade and conservation of species. However, despite standards set to ensure sustainability, many MSC fisheries are not actually sustainable (e.g., Opitz et al., 2016; Kourantidou and Kaiser, 2019) and a precautionary approach needs to be more strongly applied (Hadjimichael and Hegland, 2015; Hønneland, 2021; Karim et al., 2020). Furthermore, 'sustainable fishing' like other sectors of 'sustainable wildlife harvest' is plagued by no central definition of sustainability, and issues in interpretation, communication, and economic interests hinder the ability to make commercial fisheries genuinely sustainable (Baumgartner and Bürgi Bonanomi, 2021; Sims et al. 2021). This contributes to the lack of sustainability across the industry (Steadman et al. 2014; FAO, 2018), and may have devastating consequences on the ability to maintain offtakes into the future (Hughes, 2021).

Sustainability is central to maintaining long-term yield in natural resource management, being practiced by many indigenous groups for thousands of years (Spangen et al., 2015). However, this often relied on highly controlled offtake with traditional tools in a relatively closed system, and adaptations may be needed even within these communities to maintain access to wildlife resources as a consequence of habitat loss, smaller populations, and external demand (Vilá et al., 2020). No viable business could fail to account for resource supplies to be sustainable. Thus, the argument that sustainable livelihood provision can occur in the absence of basic regulatory data is deeply flawed, and has the potential to harm incomes of beneficiaries and the species on which they rely without more precautionary approaches (Hønneland, 2021). From a management perspective, obtaining the largest offtake while maintaining the collected population at a given size indefinitely – the Maximum Sustainable Yield (MSY) (Pe'er et al., 2014; Tsikliras and Froese, 2019) – could be seen as optimal, though it neglects other important dimensions such as genetic diversity. Yet, whilst large offtakes are more valuable economically, maximum yields close to the viability of a population are undoubtedly risky, with population dynamics often too complex (e.g., unknown resilience of species) to predict changes in a timely manner (Hilborn et al., 2021). Sustainability and MSY are not only dependent upon population size and reproductive rates, with common species sometimes depleted by intense and long-lasting offtakes, or smaller populations and those with low reproductive rates facing a higher level of extinction risk (e.g., Steadman, 1997; Kempf et al., 2016). In addition, MSYs often fail to account for other threats, such as land-use and climate change, pollution, diseases, or invasive species.

Beyond quantity (population size and trend), sustainability is also related to quality (genetic pool, genetic diversity, ecosystem, extirpation of local populations) (Rutledge et al., 2011). Biased selection can change demography, physiology, or sex ratios of remaining individuals, but such traits are essential for long-term population viability (cf. Knittweis, 2008; Sung et al., 2013, Ohlberger et al., 2017, and see below), especially under changing climatic conditions (cf. Knell and Martínez-Ruiz, 2017; Ayllón et al., 2020). Thus, from an ecological perspective, an approach based on management tools, such as developing and relying on annual offtake quotas (Trouwborst et al., 2020), without sufficient safeguards and monitoring is not an economically viable model and may have significant negative ecological consequences that fail to be recognised. Additionally, while an established annual quota system needs to be adjusted yearly with regard to monitoring, modelling of specific trends, and a 'threshold harvest approach' for quota setting to sustainably maintain viable populations (cf. Lande et al., 1997; Dee et al., 2014; Andrén et al., 2020), continuous monitoring and review of monitoring methods is essential to adjust existing quotas in a timely manner (cf. Wilder, 1995; Martin, 2017; Andersson et al., 2021).

3.2. Trading towards extinction versus sustainable management

Some regions have developed specific approaches to facilitate the sustainable trade and harvest of wildlife. Of the seven principles that form the foundation for wildlife conservation in Canada and the U.S.A., the keystone component is that wildlife is owned by no one and is considered a public trust (Organ et al., 2012). However, for the management of utilized wildlife populations to persist for future generations and to prevent privatisation of a common resource (which threatens the 'public trust' mandate), all markets for game species were eliminated. This cornerstone principle recognizes the difficulty in sustainably utilising populations of species where a market exists. By regulating and managing trade – adapted to the respective species – via developing specific management tools such as annual catch/export quotas, limiting seasons when hunting can occur, and requiring hunters to be registered, it is possible to make trade sustainable under an objective and stringent management system (White et al., 2015). However, such approaches are not applied universally in trade, and further work is needed to avoid unsustainable trade more broadly.

Trading towards extinction – Trade can impact demographics plus trigger shifts in biology, phenotypes, and genetic diversity of plants and animals, ultimately leading to extinction if trade pressure is not moderated. The impact of under-regulated trade on the structure of species population has been known for centuries. For example, Eurasian otter (*Lutra lutra*) populations in the UK crashed from the combined impacts of hunting for fur and agricultural chemicals, driving otters almost to extinction in most parts of the UK (Chanin and Jefferies, 1978). Elsewhere, the impacts of unsustainable utilization of species have resulted in extinction with, for example, models of Steller's seacow (*Hydrodamalis gigas*) showing hunting rates were approximately seven times greater than the sustainable limit, resulting in extinction just 27 years after its scientific discovery (Turvey and Risley, 2006).

More recently, red coral *Corallium rubrum*, heavily collected in the Mediterranean Sea, have become ecologically and functionally extinct (Garrabou et al., 2017, see Suppl Tab. 1), while two attempts to protect them via listing under CITES failed. Similarly, sea cucumbers have shown severe declines following over-exploitation, with populations in the Red Sea decreasing by over 82% between 2000 and 2016 (Hasan, 2019), and the collapse of Galapagos populations leading to a five-year fishing ban to attempt to allow population recovery (Ramírez-González et al., 2020). In response to these threats, three *Holothuria* spp. were listed in CITES Appendix II in 2019 (*H. fuscogilva, H. nobilis,* and *H. whitmaei*). Yet ~37 other sea cucumber species remain intensively fished and, until the CITES CoP19 in 2022, including endangered and vulnerable species (e.g., *H. lessoni*, *Thelenota ananas;* see Table S1, *Stichopus hermanni*, and *Actinopyga mauritiana*). Late listing may result in irreversible harm to species survival, calling into question the slow mechanisms and application of the precautionary principle within CITES.

On land, a hunting concession in the Republic of Congo had rapid declines in the lowland bongo antelope (*Tragelaphus eurycerus*), with recent quota being five-fold higher than sustainable levels (Koopmans et al., 2021). Leopard (*Panthera pardus)* trophy hunting in Namibia, Botswana, and Zambia is of conservation concern, and could drive regional extinction (Stein et al., 2020), with Trouwborst et al. (2020) stating "*the way in which the CITES leopard quota regime has been operating is fundamentally at odds with the principles of sustainable use, precaution, and adaptive management*." These declines continue despite past evidence showing that under-regulated trade was responsible for major population crashes. Furthermore, ungulates, such as argali (*Ovis ammon*), have seen population crashes as a consequence of unregulated hunting, and only through managed, quota-based hunting have populations recovered whilst providing revenue for local communities (Stuart and Bas, 2016), though other subspecies have been uplisted to higher CITES appendices (CITES, 1997).

Targeted harvest and collection can also result in physiological changes, shifts in demographic traits, and loss of genetic diversity. Various plants subjected to high levels of wild collection have shifted specific traits, for example, snow lotus (*Saussurea laniceps*) and American ginseng (*Panax quinquefolius*) decreased in average size over the past 100 years, and this change is particularly significant in areas with high levels of collection (McGraw, 2001; Law and Salick, 2005). In animals, hunting is not just linked to changes in population demography, but also reduced body and horn size in markhor goat (*Capra falconeri)*, Iberian wild goat (*Capra pyrenaica*), and aoudad (*Ammotragus lervia*) (Pérez et al., 2011), and loss of tusks in African savannah elephant (*Loxodonta africana*) populations in Mozambique (Campbell-Staton et al., 2021).

Hunting also causes changes in behaviour (Allen et al., 2021) and regional movement patterns (and population declines), as seen in African savannah elephants and lions (*Panthera leo*) (Suppl. Table S1) (Chase et al., 2016), with removal of older elephant bulls increasing aggressive behaviour in younger bulls, exacerbating human-elephant conflict (Allen et al., 2021). Such changes in morphology and behaviour highlight that without enforcing current regulations to ensure selection of individuals for hunting does not remove the fittest animals, it may have long-lasting negative implications for populations (Festa-Bianchet, 2018; Khan et al., 2019; Sheikh, 2019; Adhikari et al., 2021).

3.3. *Enabling sustainable harvest*

Eliminating scientific and economic uncertainties is vital to developing well-managed quotas that fall within population growth rates, enabling sustainable trade offering long-term economically viable livelihood provision. Legislation should include the development of regulations to both monitor trade and provide approaches to ensure that the harvest and collection of wild-caught individuals is sustainable (Arnold et al., 2018; Roberts et al., 2021). In Western nations, crashes in hunted wildlife populations in the early-mid 1900s led to the development of regulations, which enabled population recovery and sustainable offtakes in some species (e.g., Geis et al., 1969; Decker et al., 2017; Holopainen et al., 2018; Liljebäck et al., 2021). This led to the formation of highly regulated markets with rigorous evidence-based approaches showing offtake falls within normal population fluctuations, for example, fur trade of muskrat (*Ondatra zibethicus*), raccoons (*Procyon lotor*), and seals (Phocidae spp.), yet the application of this information to setting new quotas in other taxa is highly variable.

Adaptive management and development of best-practice guidelines can enable profitable industries, whilst promoting long-term species survival (Nakamaru and Onuma, 2020). For example, in Australia, sea cucumbers are being sustainably harvested (Webster and Hart, 2018), while in Southeast Asia, cave swiftlet (*Aerodramus fuciphagus*) nests are collected sustainably and provide a stable economic return. In these examples, catch quotas are based on population data, with monitoring ensuring that quotas can be adapted to address unforeseen impacts on populations (Gaston and Robertson, 2010). Other examples of sustainable trade are known, with crocodilians (e.g., *Alligator mississippiensis*) showing population growth despite offtakes, but this is contingent on well-enforced management and regulation (Joanen et al., 2021). These examples also reveal how models can support and manage populations and set offtake levels (Eversole et al., 2018), although these species are generally valuable and funds exist to facilitate genuinely sustainable management on a local basis (`t Sas-Rolfes et al., 2022; Weaver and Pieterse, 2019), whereas the necessary volume of data is unavailable for most traded species.

Engagement of local communities is critical for achieving sustainability in trade. Community-based conservation and resource management (CBCRM), for instance, has resulted in the sustainable capture and trade of yellow-spotted Amazon river turtles (*Podocnemis unifilis*) in the Peruvian Amazon (Pacaya-Samiria National Reserve) (Harju et al., 2018). Populations of this species plummeted due to overexploitation and, in response, a CBCRM project was established to aid population recovery, and sustainable and legal trade (Rivera et al., 2021).

Although often overlooked, in part to their large commercial scale, fisheries should be considered more in discussions on wildlife trade. While the majority of marine fish in the aquarium trade still originate from wild populations (Teletchea, 2016), the freshwater aquarium industry has largely transitioned to breeding species under captive conditions, which is a promising shift towards sustainability. However, the sustainable trade in freshwater fish varies significantly between regions (Hughes, 2021); wild populations (e.g., Lakes Malawi and Tanganyika) are still vulnerable without effective regulation (Table S1). Similarly, Project Piaba aims to ensure that aquarium trade from the Amazon is sustainable (https://projectpiaba.org/; Chao and Prang, 1997). The project combines assessments of native fish populations, socio-economic assessments of local communities, and develops best-practice guidelines for harvesting. Community programs that yield shared local benefits disincentivizes unsustainable offtakes (Norris et al., 2018), leading to greater efficiencies in the industry (e.g., reduced mortality in captured and sold fish) (Chao, 2001), especially when clear principles are defined and followed (Evers et al., 2019). Such approaches have prevented overexploitation of species, including cardinal tetra (*Paracheirodon axelrodi*), which was formerly captured in the millions to stock the aquarium trade (Iyer et al., 2016, McFarland, 2018). Project Piaba estimates to have positively impacted over 40,000 people (with local people receiving ~60% of revenue), exports up to 40 million fish annually (~90% derived from captive breeding), and has protected 74, 000 km of forest.

In these cases, sustainable trade was only possible due to various conditions being met: 1) engagement and incentivization from communities that are harvesting (Stout et al., 2013; Pomeranz et al., 2014; Pezzuti et al., 2018); 2) an estimate of population size relative to offtake (i.e., data); 3) continued monitoring to ensure long-term sustainability; and 4) enforcement or incentivization for accountability. Without these conditions being met, species may continue to decline because their collection/hunting (despite annually set quotas) continues outside the quota system. If populations decline at levels assumed to be sustainable, this is unlikely to be noticed until major losses have occurred. Thus, sustainability requires regularly updated quality data and successful engagement to prevent damage to the long-term viability of populations.

4. Legal trade as a threat to species

Legal trade (i.e., following national and international regulations) is often equated/conflated with sustainable trade (Oyanedel et al., 2021). A species can be collected sustainably or unsustainably in the absence or presence of regulation (see Fig. 1). For example, in legal commercial fisheries there is a serial harvest pattern termed "fishing down the food web" (Pauly and Palomares, 2005), where over-exploitation of high-value species can lead to rapid population declines, followed by a shift to exploit more abundant, less-valuable species. Trading across the tree of life has been observed in legal and illegal forms of wildlife trade (Scheffers et al., 2019), whereby one species is substituted for another as seen between pangolin species, or from tiger bones to lion bones in some wine (Williams et al., 2017; Coals et al., 2020). Trade shifts to other species can be observed after CITES listing of a species, leaving other look-alike or useable species unprotected. For example, after EU trade restrictions in 2014 and CITES Appendix I listing in 2016 of turquoise dwarf gecko (*Lygodactylus williamsi*), closely related but unprotected species, including Cameroon dwarf gecko (*Lygodactylus conraui*) and painted dwarf geckos (*L. picturatus*), became increasingly available in the international pet trade (Altherr et al., 2020). This is why some CITES-listing initiatives aim to cover a full genus/family and look-alike species.

In this section, we first review the risks to species posed by un- and under-regulated legal trade occurring domestically, internationally, and in rare and newly available species. We then review the risks posed by the regulated international trade under CITES.

4.1. *Unsustainable trade in non-CITES species*

4.1.1. *Domestic and regional trade*

Much legal wildlife trade occurs domestically or within an economic block (e.g., EU), but is often under-regulated. Species are collected within the country and traded at local markets for various purposes including consumption, medicine, and pets (Harrington et al., 2020; Mendoza and Francke, 2020). Although some nations set annual quotas for domestic capture and trade (e.g., quotas for bushmeat), much of this trade, albeit legal, is undocumented. In regions with poor monitoring or porous borders, domestic trade can spill-out over borders and enable uncontrolled international trade of species with no monitoring ((Svensson et al., 2016), McEvoy et al., 2019; D'Cruze et al., 2020; see also Table S1). Once animals are within a country (or some trading zones, e.g., EU) they are non-CITES plus often not subject to any monitoring. Thus, any animal or plant within a country (or trade zone) may be traded with little or no oversight, and no data collation. This also means that wildlife laundered or smuggled into a country (even if subject to international protections) can be openly traded as they are unlikely to be detected.

Domestic trade does not always equate to low quantities, sometimes occurring in such high numbers that even once common species can reach the verge of extinction. Javan pied starlings (*Gracupica jalla*) were legally traded as pets within their native range (Table S1) to supply domestic demand. Once considered one of the commonest birds of the Javan countryside, with flocks of over 1000 birds roosting in urban areas, populations were overexploited (estimated 80,000 yr^{-1} (Nijman et al., 2021)) such that it is now considered extinct in the wild (Van Balen and Collar, 2021; Van Balen et al., 2011). Thus, even common species can be impacted by unsustainable domestic trade (Rentschlar et al., 2018), and whilst passenger pigeon (*Ectopistes migratorius*) and Carolina parakeet (*Conuropsis carolinensis*) are famous symbols of once common species legally harvested to extinction, humans continue to manage species poorly (Fuller, 2013; Stanton, 2014).

4.1.2. International trade

Many mismatches exist between species evaluated by the IUCN Red-List as being threatened by trade, and those currently regulated via CITES (Scheffers et al., 2019; Hutchinson et al., 2021), with hundreds of endangered species traded without any oversight from CITES (Marshall et al., 2020). The majority of traded species are not listed by CITES, being traded without regulation or assessment of trade-induced threat, comprehensive population data, or monitoring of trade volumes. The risks of international trade without oversight are clear: The previously unlisted electric blue day gecko *Lygodactylus williamsi* was legally and heavily traded internationally for pets with at least 15% of the potential population collected within a period of 4.5 years (Flecks et al., 2012), and seven years later was listed on CITES Appendix I. Of over 7638 traded terrestrial vertebrates (as per IUCN 2022 (see Scheffers et al., 2019), 4545 were not included on the Appendices of CITES (Scheffers et al., 2019), with the majority of traded wildlife neither CITES listed nor subject to any overarching international regulations (Auliya et al., 2016a,b; Marshall B et al., 2020, Hughes et al., 2021).

Documenting or estimating trade volume is arguably the biggest challenge in delivering legal and sustainable international wildlife trade. Obtaining the true number of internationally traded species is near-impossible because there is no centralisation of comprehensive trade data, except for species listed by CITES (even then, regional cross-border trade of CITES-listed species is not necessarily documented in the CITES trade database; Maldonado et al., 2009; Subedi et al., 2013; To and Mahanty, 2019; Dunn et al., 2021) and national-level databases such as the U.S.A's Law Enforcement Management Information System (LEMIS). Most studies on the trade of non-CITES species use online data, surveys from individual markets, or individual country databases (e.g., LEMIS), to roughly estimate trade volume and potential impact (Altherr et al., 2020; Eskew et al., 2020; Marshall et al., 2022; Latinne et al., 2020; Gong et al., 2009; Stringham et al., 2020), though this limits studies to the few countries that routinely collect data. Other factors complicating and obfuscating the legal trade of species include fraudulent trading, via illegally laundering species through legal trade routes by altering quotas, source codes, species names, etc. (Musing et al., 2019; Janssen and Gomez, 2021).

Songbirds highlight the current challenge in assaying traded species. None of 6659 traded species was listed in all of five major trade databases, including even the most frequently traded birds, highlighting the need for centralisation of trade data to obtain a true understanding of diversity in trade (Juergens et al., 2021). Similarly, for reptiles and amphibians, only 9% and 2.4% of species are covered by CITES, yet over 36% and 17% of species, respectively, are traded, most with no information on volumes or regulations to ensure sustainability (Marshall B et al., 2020; Hughes et al., 2021). While this does not mean trade represents a threat to these species, without data on populations or offtake it is impossible to determine trade impact and sustainability. To obtain the true number of internationally traded species requires centralisation of comprehensive wildlife trade data, but for non-CITES species there is no mandate for monitoring. The limited collated data do not reflect domestic trade and cannot quantify the degree of wild offtake, especially as many species are traded both internationally and domestically, and thus harvest quotas must account for both. Studies find wild offtake typically varies between 45 and 75% of individuals based on LEMIS data (Marshall B et al., 2020; Hughes et al., 2021). Thus, while data clearly show some species are traded at unsustainable levels (Table S1; Morton et al., 2021, 2022), without evidence-based information on populations and offtake it is impossible to quantify impacts on species and communities in their ecosystems.

4.1.3. Rare and newly available species in trade

Rare species are often in particularly high demand (Brook and Sodhi, 2006, Courchamp et al., 2006; Angulo et al., 2009; Krishna et al., 2019), with higher extinction risk according to the IUCN Red-List triggering targeted collection and international trade (Hall et al., 2008). Species traded as exotic pets may disproportionately impact recently described or unusual species, yet threats from trade may not be detected due to a lack of monitoring (Marshall et al., 2020, 2022; Hughes et al., 2021). Such demand is noticeable through reduced availability on the international market and, in parallel, rapidly rising prices (Slone et al., 1997; Tournant et al., 2012; Altherr and Lameter, 2020). In 2018, specimens of Wallace's giant bee (*Megachile pluto*)—the world's largest bee and recently re-discovered after being presumed extinct for >100 years—were sold in an online auction for up to US$9100 (Vereecken, 2018). High international demand has decimated and extirpated populations, especially in rare species and those with small populations (Hinsley et al., 2018, Crespin et al. 2021). Moreover, the removal of individuals from island communities poses a particular problem, as such species are often particularly sensitive to disturbance (Simberloff, 1974; Graham et al., 2017) and, when assumed extinct, are likely to have particularly small populations.

Common practises in taxonomic science can initiate exploitation and fuel overexploitation of species perceived as rare. When (semi-)precise locality data is mentioned, scientific description of new taxa, rediscovery of lost species, or new populations can all result in rapidly marketisation (Stuart et al., 2006; Kramer et al., 2011; Altherr et al., 2020; Marshall B et al., 2020). For instance, scientific description of Persian striped skink (*Eumeces persicus*) in September 2017 (Faizi et al., 2017) was followed three months later with animals offered at the reptile trade show Terraristika in Hamm, Germany (Altherr et al., 2020).

Trade in new, endemic, or range-restricted species normally occurs in the absence of even rudimentary data on population size, trends, or threats (Stuart et al., 2006; Janssen and Shepherd, 2018; Altherr and Lameter, 2020), risking potential overexploitation. For example, in plants, scientific description of Chinese and Vietnamese lady slipper orchids (*Paphiopedilum* spp.) resulted in over-collection of wild populations almost to extinction (Cribb, 2005; Averyanov et al., 2014). In response, an increasing number of scientists warn against or refrain from publishing detailed type localities in scientific publications (e.g., Stuart et al., 2006; Menegon et al., 2011; Yaap et al., 2012; Lindenmayer and Scheele, 2017), while some taxonomists refrain from revealing the type locality of newly described species (e.g., snakes, Nilson et al., 1990, Tang et al. 2021; orchids, Metusala et al. 2010; Liu et al., 2020; geckos, Yang and Chan, 2015). Even without this information, localities are identified by other means after description (O. Turkozan *pers comm.*, to B. Stuart, *in litt.* to M. Auliya, Oct. 2011, Table S1), with newly described species frequently in trade within a year of description (Marshall B et al., 2020; Hughes et al., 2021).

Under the nomenclatural code of the International Commission on Zoological Nomenclature (ICZN) there is no requirement to mention the collecting localities when describing new species. There are, however, recommendations about the type locality of a species; while even this is not required as part of the original description, its exclusion could be a barrier to publishing descriptions of new species (D. Notton of the ICZN Secretariat to M. Auliya, May 2010). Thus, it is often perceived that location information must be available, especially for species first described in peer-reviewed literature, providing the challenge of enabling further research whilst not threatening species future survival.

4.1.4. International trade in nationally protected non-CITES species

Wildlife trade may be viewed as legal with regards to international trade regulation (e.g., CITES), despite being caught or exported in violation of national law in the country of origin. For example, pygmy bluetongue (*Tiliqua adelaidensis*) initially occurred in the European pet trade in 2017 with no legal exports from its sole range state Australia (Altherr et al., 2019), and the Sri Lankan endemic Pethiyagoda's crestless lizard *Calotes pethiyagodai* was available in pet stores in 2016, two years after its scientific description in 2014 with no legal exports from Sri Lanka (Janssen and de Silva, 2019). Similarly, the endemic Philippine forest turtle (*Siebenrockiella leytensis*) became available in domestic and international black markets (e.g., in China, Malaysia, Thailand, Japan, Europe, U.S.A.) a few months after publication of its rediscovery in 2004, although no collection or export permits were issued by authorities (Diesmos et al., 2012; Sy et al., 2020, 2021; Sy, 2015). While it has been argued, e.g., by the European Commission (European Commission, 2018), that countries of origin could list their nationally protected species in CITES Appendix III to ensure international protection, this is seldomly used - mostly because countries are unaware that their nationally protected species are illegally caught and internationally marketed (Altherr and Lameter, 2020b). Furthermore, countries in biodiversity hotspots and with strict national protection, such as Australia, Brazil, Mexico, or Sri Lanka, would then need to list into CITES Appendix III thousands of native species potentially attractive for wildlife traffickers. Yet this does not facilitate effective regulation outside range states due to trafficking and laundering, providing little protection once outside the native range.

Legislating to ensure sustainable trade without data on trade volumes, basic species population data, and other factors that may decimate wild populations is extremely challenging and de facto inappropriate. While LEMIS is the most comprehensive database on wildlife trade globally, it only pertains to wildlife imports and exports to and from the United States. For a given taxon (except for fish and invertebrates, which are often not listed by species), LEMIS often includes orders of magnitude more species listed in trade than those listed as CITES-traded, despite only pertaining to US trade. This underscores how incomplete our understanding is of species in trade, especially in similar markets such as Europe. Given that the Lacey Act in the US may reduce the import of protected wildlife into the US, the number of unrecorded species imported into Europe may be even higher.

4.2. Unsustainable trade in CITES

CITES is tasked with preventing unsustainable international wildlife trade, though recently UNCTAD (United Nations Conference on Trade and Development) has started to provide a more overarching approach to both domestic and international trade of wildlife. But this also implies that CITES-listed species may be used domestically and internationally, even if they have arrived in the country illegally (D'Cruze et al., 2020; White, 2021). Unlike non-CITES species, CITES-listed species legally require permits for import and/or export, are centrally databased, and, in some cases, are subject to collection/export quotas. However, for CITES Appendix II species (ca. 97% of all CITES species), the communication of national quotas is non-binding for CITES Member States with the CITES Secretariat.

The risk is that CITES processes fall-short of the requirement to apply the precautionary principle, and very few species have the necessary monitoring in their range States, even when listed. For example, between 2010 and 2016, more than 40 species were selected for Review of Significant Trade, yet only about half had been completed and often unsatisfactorily (CITES AC30 Doc 12.1), meaning that understanding the impacts of trade may be impossible even for species listed. For example, scientifically sound and objective published Non-Detriment Findings (NDF's, for details see III.3.) on Indonesian monitor lizards (*Varanus* spp.) by the relevant Indonesian CITES authorities are currently not known and unavailable on the CITES webpage (https://cites.org/eng/prog/ndf/index.php), yet 'legal' export of more than 20 species native to Indonesia is possible (Koch et al., 2013).

Such issues mean that CITES-listing does not necessarily stop or even detect unsustainable trade. While quotas and export papers may indicate legality and reflect transparency in claiming a sustainable trade, quotas can be unsustainable, e.g., in the absence of solid NDFs (see below) or neglect the impact of other threats. For example, chattering lory (*Lorius garrulus*) has been listed as Appendix II since 1981, yet populations have decreased by as much as 50% in three generations, and domestic trade has continued after international trade was prohibited in 2003, with no permits for international trade being granted despite the species only being listed as Appendix II of CITES (Table S1; Cottee-Jones and Mittermeier, 2015, (BirdLife International, 2019), Poole and Shepherd, 2017; Cottee-Jones and Mittermeier, 2015; Pires et al., 2021). Similarly, Cape vulture (*Gyps coprotheres*) has been listed in CITES Appendix II since 1979, yet a combination of domestic and international trade now threatens the species, especially in conjunction with other threats such as poisoning (Table S1). There are also many examples where there is insufficient data to set reasonable quotas. For instance, Indonesia's export quota for wild tokay gecko *Gekko gecko* was set at almost 6 million individuals in 2022, up from under 2 million in 2021 (KSDAE, 2022), without rigorous regional population data, with decreases in native populations expected Nijman and Shepherd (2015).

The limitations for CITES to manage sustainable trade in Appendix II species are illustrated by Appendix II species needing to be uplisted into Appendix I on a regular basis, prohibiting the vast majority of commercial trade. This occurred in 2016 for Barbary macaque (*Macaca sylvanus*), grey parrot (*Psittacus erithacus*), and all eight species of pangolins. In 2019, small-clawed otter (*Aonyx cinereus*), smooth-coated otter (*Lutrogale perspicillata*), black crowned-crane (*Balearica pavonina*), and several chelonian species were also uplisted from CITES Appendix II to I.

5. The successes and challenges of CITES in regulated trade

5.1. The positive case for legal international trade under CITES

CITES, with its 184 country members, remains an essential tool, and the symbiotic cooperation of relevant stakeholders is significant. It is undisputed that basic biological information is essential for decision-making under CITES, which requires the cooperation of various collaborators to be effective (see Phelps et al., 2010). To work effectively, CITES must demonstrate NDFs (details below), a sustainability assessment to ensure that an export neither endangers the viability of the species' population nor disrupts its role in the ecosystem (Epstein et al., 2016; Lacy, 2019; Roberson et al., 2020). To enable trade, in-depth research and specific measures are required, especially for species with small populations or ranges or if demand levels exceed replacement within a population. These include developing effective management tools such as quotas for species at risk from trade, the establishment of a reliable, permanent monitoring system to accurately document CITES (and ultimately all wildlife) species in trade, and prevention of laundering.

Much progress has been made through the CITES' National

Legislation Project that assesses Parties' implementation of the Convention through four components: (1) designation of at least one Scientific Authority and one Management Authority; (2) prohibition of trade in violation of CITES; (3) appropriate penalties for trade in violation of CITES; and (4) confiscation of specimens that are traded illegally or in illegal possession. This, in itself, has involved a large amount of organisation. However, with a budget of only US$6 million, relative to US$320 billion annual valuation of legal wildlife trade and associated vested interests (Lanius and Johnson, 2020), it has become increasingly challenging to meet the foundational goals of CITES. Furthermore, at CITES' initiation in 1975, only 700 animal species were listed on the Appendices, which has increased over fifty-fold (Tuyen Le, 2019; Lanius and Johnson, 2021) without significant increases in funding or being listed as a GEF-funded convention. Indeed, sufficient funding to manage CITES or even reconcile the vast gap between CITES' budget and profits from legal trade of CITES-listed species has not been properly considered. Using a portion of profits to regulate trade (e.g., funding National species authorities to support their work) may help ensure that trade is genuinely sustainable.

5.2. Limitations of CITES

CITES is often portrayed as regulating trade in threatened species, but only a subset of traded species are included (Scheffers et al., 2019; Marshall B et al., 2020; Hughes et al., 2021). Despite the clear mismatch between species in trade and those covered by CITES, adding further species to CITES requires formal initiatives by range-States to request uplisting of species and may not fund assessments of species considered for listing. This hinders further discussion on CITES-level protection for vulnerable groups, including Asian songbirds and marine ornamental fish (CITES CoP, 2019a, b, c; Marshall et al., 2020; Chng et al., 2015), whose proposed assessments were not allocated funding from CITES, being deemed "too expensive" to implement without species-specific data. Similarly, species listed to Appendix III often include regionally endemic species, including a disproportionate number of reptiles potentially threatened by trade (Hutchinson et al., 2021).

We highlight four key areas in which there are shortcomings of CITES, in particular, in monitoring populations and associated non-detriment findings, a lack of integration with major conservation assessments via IUCN, and issues with the accurate data-basing and compliance of trade. Furthermore, listing species requires engagement from range-States, which may not be interested in listing the species unless they can derive profit, and greater facilitation, coordination, and engagement with Parties may be needed to regulate trade of smaller, less-profitable species, such as recent uplisting of glassfrogs and freshwater turtles (CITES, 2020). Calls to add further requirements to the listing of new species increases the burden on host countries and conservation agencies (Cooney et al., 2021), potentially reducing the willingness of countries to uplist trade-threatened species to CITES (Lanius and Johnson, 2020). Putting responsibility on those trying to protect species rather than those who profit from their exploitation hinders the effective implementation of management.

5.3. Non-detriment findings

CITES requires an assessment of potential risks of trade on species viability (i.e., NDFs; Article IV - https://cites.org/eng/disc/text.php#IV) and subsequent monitoring to provide a basis for development of sustainable quotas for exploited populations while retaining ecological functioning, yet NDFs are neither required for international trade in non-listed species nor domestic trade. Export of Appendix I and II species can only be granted if the Scientific Authority of the State of export has determined that it is not detrimental to the survival of a species (CITES Res. Conf. 16.7). Nevertheless, Appendix II species are frequently traded internationally without corresponding NDF's (e.g., monitor lizards, pythons from Africa and Asia), but EU countries are theoretically required to carry out a sustainability assessment in addition to an NDF (if available) of the exporting country, so that the importing country can exclude a threat to the species (Schepp et al., 2017).

The NDF process and information that may be used is outlined in CITES Res. Conf. 16.7, with no fixed template for conducting NDFs. This resolution instead notes ways a Scientific Authority can make an NDF due to the large variety of taxa and their biological characteristics, with the concepts and guiding principles non-binding, and presenting considerable challenges to develop (Tittensor et al., 2020). There are several varied templates outlining NDF processes (https://cites.org/eng/prog/ndf/Guidance_NDF). For instance, guidelines for perennial plants (Wolf et al., 2018), timber (Leaman and Oldfield, 2014), and turtles or tortoises (AC28 Doc. 15 Annex 2) are based on a 9-step guidance system, for sharks and rays a flowchart places components into a 5-step guidance system (Mundy-Taylor et al., 2014), while the NDF flowchart developed by the IUCN Boa and Python Specialist Group (AC29 Doc. 31.1) does not show a negative NDF as an option.

Whilst the majority of species studied in trade show declines in wild populations (Morton et al., 2021), there are substantial challenges to effectively provision NDFs. They suffer from: (1) insufficient data for most populations or species, precluding the ability to develop meaningful quotas; (2) quality that is rarely assessed; and (3) distorting effects of stockpiling and laundering. While IUCN Red-List data suggests many species may not be impacted (Marsh et al., 2021), at least 21% of threatened species have outdated assessments, plus a high degree of bias and subjectivity in some assessments (Hayward et al., 2015).

(1) *Lack of adequate data to set meaningful NDF quotas* - in July 2007, it was agreed to include the European eel (*Anguilla anguilla*) on Appendix II of CITES, necessitating the preparation of an NDF. Despite being extensively studied, especially when compared to many other globally traded species, after 3.5 years (December 2010), the EU's Scientific Review Group comprising scientists from the 27 EU countries concluded that it was not possible to perform an NDF for the export of European eel. This was due to multiple regional management regimes, fundamental knowledge gaps in the biology and management of the species, inconsistencies in how international trade was reported, and subsequently a ban of trade outside the EU outer borders (Musing et al., 2018), although an illegal trade remains (Richards et al., 2020; Nijman and Stein, 2022). This demonstrates how challenging developing an adequate NDF is, even with large amounts of data.

While NDFs may develop quotas for trade of CITES species, the inability of CITES quotas to maintain viable populations is clear from regular uplistings at CoP meetings based upon demonstrable population declines (e.g., pancake tortoise (*Malacochersus tornieri*; Mwaya et al., 2018) and Bourret's box turtle (*Cuora bourreti;* Turtle Conservation Coalition, 2018)) and/or of extinction risk as evaluated in the IUCN Red-List that is usually not reflected in reduced volumes in CITES trade (Morton et al., 2022). Both suggest that data and processes are inadequate in developing NDFs. This is unsurprising given challenges of obtaining detailed datasets over the long term and lack of capacity for interpreting those data and translating them into rigorously analysed quotas. However, regulatory frameworks remain unchanged to deal with data inadequacies in the development of effective, transparent, and evidence-based NDFs despite the expectation that CITES Parties apply the precautionary principle (Dickson, 1999).

(2) *NDF quality is rarely assessed* - In Resolution Conf. 16.3, CITES reaffirmed that the best available scientific information should be the basis for NDFs, yet the quality of available information varies greatly between taxa and the NDF process is plagued with controversy concerning its rigour and transparency (Castello and Stewart, 2010; Nijman, 2015; Cohen et al., 2020). For instance, a

CITES Review of Significant Trade (RST) process in which NDFs were queried for four heavily exported seahorse species resulted in Thailand being unable to produce positive NDFs (Aylesworth et al., 2020) and their trade being classed as an ''urgent concern'' by the CITES Animal Committee (CITES, 2014), while ongoing African rosewood (*Pterocarpus erinaceus*) trade from Ghana has no up-to-date scientific NDF (Dumenu, 2019). More broadly, a 2020 CITES Report of the Secretariat on NDFs was a damning indictment of the lack of quality in NDFs (CITES, 2020a,b), finding, for example, that 64% (23/36) inadequately considered the precautionary principle and 83% (30/36) did not fully consider historical and current patterns of harvest and mortality. The rudimentary nature of many NDFs, which neglect or ignore multiple essential biological and ecological parameters, and lack baseline monitoring, capacity, or standards for further assessment, means that CITES regulations provide inadequate protection for many species. They instead facilitate continued trade, predominantly of internationally lucrative species, with short-term economic dimensions prioritised over biodiversity conservation. There is a clear lack of weighting certain NDF criteria, which, if they do not provide sufficient evidence for a certain level of permissible/sustainable trade, should automatically suspend the existing trade, or the precautionary principle should apply.

There is no mechanism for controlling the quality of NDFs used to inform sustainable offtakes and there is no central repository or peer-reviewed assessment of NDFs outside of the Parties' own scientific authorities, except for species-specific quotas set directly by the Conference of Parties or Scientific Committees for Appendix I species, and by National authorities for other species (Conf. 17.9, Morton et al., 2022). Thus, whilst NDFs should be a critical safeguard to prevent detrimental impacts, the lack of consistent standards or requisite baseline data risks many providing too superficial an understanding to ensure species are sustainably traded. Conflicts of interest in funding bodies are not considered, yet bodies standing to benefit are often involved with the development of NDFs (Mossberg, 2017; Johnson, 2020; Jurkschat, 2020), and better mechanisms for transparency, reducing conflict of interests, and genuine independent oversight are urgently needed.

(3) *Distorting impacts of stockpiling and laundering on NDFs* – Ideally any wildlife trade declared as sustainable should require accredited, objective auditing institutes or bodies to approve origin assurance and traceability of the species/product in trade. In theory, this ensures the tracking of intermediate stops along the trade chain of a species/product from the collection site to final destination. However, CITES documentation alone does not provide assurance. At the same time, regional trade patterns are veiled (business-trade relationships in certain geographical regions remain complex) when, for example, trade from certain countries of origin is suspended (Wu, 2015).

For species with an annual export quota, stockpiling means that high offtakes in previous years may go undetected and prevent active monitoring on the impacts of collecting on wildlife populations (Wyatt et al., 2018). While local authorities can permit the use of stockpiled wildlife products (van Uhm, 2016; EIA, 2020; Hornor et al., 2020), but prevent collection of new items, stockpiles enable laundering of newly collected wildlife into them and reviewed permits 'to trade stockpiled goods', hindering tracking across space and time. For instance, stockpiling reptile skins can mix legal and illegal skins (e.g., Jenkins & Broad, S. 1994; TRAFFIC, 2008; Kasterine et al., 2012; Ashley, 2013), with harvest and export dates of skins often years apart (Wiersema, 2016, 2017) and export certificates potentially issued more than once for the same stockpiled skins (Sharma, 2003). If stockpiled products augment low offtake years, this can camouflage actual removal rates per year, support the (potentially erroneous) notion of a sustainable trade, and communicate the impression of sustainable use to the public. To date, efforts on these parts of trade structure and industry lack full transparency, which would have to guarantee that in reptile skin exports documented annually by WCMC, proof of date and location of capture were provided for each individual skin (Wiersema, 2016, 2017).

Yet stockpiling remains common practice and is justified because it allows harvesting when demand is low, continued payments to supplier (hunter) bases, and exporters to prevent selling into a poor market (Nossal et al., 2016). Nevertheless, the use of stockpiles without adequate monitoring of reporting facilitates laundering and hinders sustainable offtakes of wildlife. In response to this risk, at the 69th meeting of the CITES Standing Committee (December 2017), one recommendation was that "Parties ensure that the inventories of initial stockpiles contain information on the species concerned, stage of processing of the skins (crust, dried, etc.) and corresponding quantities and tag numbers, and also the year of harvest for skins entering stockpiles" (https://cites.org/sites/default/files/eng/com/sc/69/E-SC69-43.pdf). Whether this can be effectively implemented and monitored remains an unanswered question.

5.4. Relationships between IUCN Red-List and CITES

Having timely, specific, and accurate evidence is critical to assaying whether trade is sustainable. One potential solution is to better integrate the IUCN Red-List status of a species into CITES (Marsh et al., 2021a,b; Morton et al., 2022). Information on species evaluated in a threat category by the IUCN indicating any threat (including trade) that could potentially increase extinction risk would automatically inform CITES (although this was rebuffed during the CITES COP19 in Panama 2022). Whilst IUCN Red-List status includes if a species is in trade, assessors may not be aware of trade, and many species lack any rigorous trade assessment. There is currently no standardised integration between CITES and the IUCN, and species listed as threatened by the IUCN can be legally traded without protection. Though many threatened species are eventually listed in CITES, the lag in adequate protection may hinder population recovery of unsustainably collected species (Frank and Wilcove, 2019). Suggestions of automatically including all species listed by the IUCN as threatened into the CITES Appendices has been rebuffed as disproportionate as "not all of these species are threatened by international trade" (Berec and Šetlíková, 2021). This is despite these species already being at risk of extinction and the lack of population data for most species on the impacts of exploitation for trade. Analysis shows that at least 15% of threatened or near-threatened species (2194 species) on the IUCN Red-List are potentially threatened by international trade, of which ~40% are not CITES-listed (Challender et al., 2022). This may represent a significant under-estimate given the lack of inclusion of many species within the Red-List, the age of some listings, species evaluated as Data Deficient (DD), and a lack of knowledge of trade for many species. Thus, integration could streamline listing of species potentially at risk, and requires further consideration.

Species with increasing extinction risk as evaluated by the IUCN Red-List often remain tradable within CITES, taking up to 24 years for such information to be incorporated into CITES listings (Frank and Wilcove, 2019). This suggests the need for a process that directly links IUCN uplisting to higher threat status (or downlisting to lower threat status, i.e., sustainable trade is more plausible) to CITES lists and interrogation of NDFs. In making all decisions on a status change, the IUCN Red-List brings together the best available data, expert oversight, and transparent review, including identifying the major cause(s). Thus, recent and rigorous IUCN assessments can defensibly be used to assay the potential for trade as a driver of extinction risk and potentially of the sustainability of trade, although outdated assessments (Table S1) and those lacking population-level assessments mean caution is required. These issues underpin four core dangers with a blanket approach to applying IUCN assessments as the authority on CITES listing, quotas, and inferences of trade sustainability (Marsh et al., 2021):

(1) *Out-dated or incomplete IUCN assessments.* The IUCN Red-List has incomplete and biased coverage (Bachman et al., 2019). While 100% of birds and 91% of mammal species are assessed (December 2021), many other taxa have not been fully evaluated, with just 37% of fish assessed (IUCN, 2021) and only eight of 23 African snake species recorded in international pet trade assessed (Jensen et al., 2018). Some IUCN assessments are over a decade old, outdated according to IUCN rules, and do not reflect present conservation threats and status (examples in Table S1; Rondinini et al., 2014). Any substantial mismatch between the date of an IUCN assessment and inference of sustainability or lack of trade risk is cause for concern, as outdated IUCN Red-List assessments may provide a false assurance of lack of threat for certain species in trade. Birdlife International reassess all bird species every four years (plus individual species of sudden concern more frequently) to ensure that assessments are up-to-date. This highlights an appropriate window outside of which the use of IUCN assessments requires greater caution.
(2) *Lack of quality data on population trends.* Population sizes can vary greatly across a species' geographical range and not all areas contribute equally to species survival (Hanski et al., 2001; Maurer and Taper, 2002). IUCN assessments vary in data depth and, in many cases, data available for monitoring regionally specific population trends are lacking or limited, especially for geographically wide-ranging species. In such instances, and given that most species are not exploited equally across their range, using IUCN overall population trend assessments to infer sustainability of offtake within only part of that range could falsely conclude that trade is sustainable, whilst causing regional extirpations, population fragmentation, or loss of genetic diversity (Marsh et al., 2021).
(3) *Lack of trade data.* IUCN Red-List assessments may lack information on trade and misclassify risk, as assessments are often led by field experts who may be unaware of trade relevance (Watters et al., 2022). For example, while the Red-List reports no known trade for Guantanamo coastal gecko (*Sphaerodactylus armasi*), Sakishima grass lizard (*Takydromus dorsalis*), Kimberley death adder (*Acanthophis cryptamydros*), and Rio Pescado stubfoot toad (*Atelopus balios*), all of these Endangered or Critically Endangered species were recorded in the European exotic pet trade (Altherr et al., 2020, Table S1). Currently known threats (other than trade) are published in the Red-List species assessments, but population declines that are actually due to trade activities are attributed to other threats. Knowing the difficulty of gaining insight/transparency into trade activities shows the importance of objectively incorporating information of trade (if potentially threatening) into Red-List Assessments. Ascertaining the interplay of different threats impacting the viability of a species/population remains complex. However, all potential threats should be considered and the additive impacts calculated, whilst efforts are made to ensure that quantified trade data is available and added within assessments for trade to be permissible.
(4) *Accurate identification of species.* Linking IUCN into CITES listing is complicated by the different nomenclature committees; even agreeing on which species are listed can be problematic. The slow acceptance of nomenclatural changes by CITES leads to newly described species at imminent risk from unsustainable trade (related to [2] above) being traded under junior-synonyms without NDFs to circumvent quota systems (Lanius and Johnson, 2021). In other cases, new taxa already occur in trade, before they have scientifically described (Marshall B et al., 2020). For example, a Cuban *Anolis* species described in 2017 was detected in the European pet trade only four months later (Zahradníčková et al., 2017), while reptile importers in Germany first drew attention to quince monitor (*Varanus melinus*) from Indonesia resulting in its description (Böhme and Ziegler, 1997). Elsewhere, new species to science were initially detected in markets, not knowing where these species naturally occur, e.g., Vietnamese box turtle (*Cuora picturata*) (Lehr et al., 1998), requiring studies to identify their natural distribution (Ly et al. 2011). Likewise, over 100 potential undescribed arachnid species are traded under unofficial but commonly used names without any degree of regulation or oversight (Marshall et al., 2022).

5.5. Issues with databasing and compliance in trade

The burden of proof is presently on customs officers or conservationists to demonstrate that trade is in contravention of CITES, posing a major challenge to successful implementation. Data within CITES can be inaccurate. For instance, between 2003 and 2012, Appendix I and II exports from Africa had documentation discrepancies in ~92% of records (Russo, 2015). Inaccuracies included mismatches between import and export records, records of wild export from countries where species are not native and without import records, and captive exports from countries with no evidence of breeding (Nijman and Shepherd, 2010; Andersson and Gibson, 2017; Robinson and Sinovas, 2018; Sayektiningsih and Broto, 2021). The use of paper permits means CITES lags behind actual trade patterns, with information often provided late; CITES can then fail to provide an accurate or dynamic metric of trade.

Trade in captive-bred animals is less scrutinized and restricted compared to wild collection (Janssen and Leupen, 2019). This incentivizes the fraudulent labelling of wild animals as bred in captivity to circumvent restrictions (CITES Resolution Conf. 17.7). Significant issues with quota setting indicates that mislabelling of origins provides a false sense of sustainability, masking negative impacts on wild populations and undermining the implementation of wildlife trade legislation (Nijman and Shepherd, 2009; Lyons and Natusch, 2011). A review of Indonesian quota setting for offtakes and export revealed issues with unrealistic biological parameters used in calculations, lack of breeding stock at facilities, and inclusion of animals from previous years, all providing opportunities to launder wild animals (Janssen and Chng, 2018). In 2016, an export quota was set for second generation captive-bred Bornean earless monitor lizard (*Lanthanotus borneensis*), yet no breeding stock was present at the facilities, and better measures are needed to verify when captive breeding is occurring and the source of breeding stock (Janssen and Chng, 2018).

Compliance is essential for CITES to be enforceable and effective, yet issues with compliance are rife. For example, where countries have regional annual quotas, items may be moved to meet the apparent quota, breaching the related regulations. One mechanism for enforcing CITES regulations is through the use of trade bans for non-compliance, which are rarely applied except for a few species (e.g., proposed for the African rosewood tree (*Pterocarpus erinaceus*) in western and central Africa (https://cites.org/eng/news/trade-ban-proposed-conserve-one-africas-exploited-tree-species). Whilst there are many cases of non-compliance (for example, tiger-bone wine in China), only 25 countries have faced trade-bans since 2013 (https://cites.org/eng/resources/ref/suspend.php), of which only five stemmed from compliance-related issues, and even following bans as a consequence of unsustainable trade, no measures to enforce compliance were applied. For instance, 95% of seahorses imported into Hong Kong come from countries where export has been banned (Foster et al., 2019). Beyond bans, additional measures must provide a standard means to prevent trade in contravention of existing regulations.

Within groups monitored by CITES, huge levels of disparity exist in reported exports. For example, trade in sharks and rays from Indonesia vary between \$20.9–43.6 M, with similar disparities across other Southeast Asian countries (e.g., Myanmar) (MacKeracher et al., 2021, Prasetyo et al., 2021). Lack of compliance relates to implementation at both domestic and international levels, with good-practice case-studies needed (Wyatt, 2021). Identifying breaches in compliance for countries permitted to export wildlife within certain quotas needs further work to ensure they do not drive population decreases, with frequent evidence in non-compliance (such as the export of lion bones above the quota or used for laundering; Williams et al., 2021). Corruption also hinders active and effective enforcement at all levels in some regions (van Uhm and Moreto, 2018).

5.6. Further challenges

Beyond primary CITES issues (which are not unique to CITES), there are other challenges to effective regulation and monitoring through CITES. These include: (1) permitting processes being too slow to reflect real-time trade dynamics; (2) the risk that trade restrictions under CITES incentivizes short-term smuggling, e.g., *Lanthanotus borneensis* (Janssen and Krishnasamy, 2018; Altherr and Lameter, 2020); and (3) longer timeframes being needed from listing to derive suitable NDFs for all species, especially for trade in newly described species, for examples, *Eumeces persicus*, Lauhachinda's cave gecko (*Gekko lauhachindai*), and Sylvia's tree frog (*Cruziohyla sylviae*), and trade in species with small ranges or even micro-endemics (which may be limited to a single small forest site, inselberg, limestone karst, canyon, etc.) that lack comprehensive NDFs; The CITES framework remains highly relevant, but should increase effort to reduce non-compliance and exercise legal tools to create consensus. Meaningful improvements require greater financial and political commitment, new partnerships, and development of clear rules and standards for data collection and analysis to detect where trade drives declines in wild populations. Member states of the Convention must be subjected to tougher requirements to ensure the sustainability of trade in CITES species, e.g., within their borders, especially with regard to endemics, where the country bears a high national responsibility. Appropriate mechanisms for making CITES fit for purpose in the 21st century are urgently needed. Developing mechanisms for enforcement is challenging, and efforts to enforce compliance have been very variable, thus new mechanisms are needed, e.g., using sanctions as imposed by conventions such as UNCTAD. Whilst CITES does not have the power to enforce laws, it can suspend trade due to infringements. However, of the 42 sanctions that have been issued (to 31 countries) only 12 were due to compliance-related issues (https://cites.org/eng/resources/ref/suspend.php), and do not include reactions to known infringements such as tiger bone products in China (Martina, 2018) and disproportionately impact lower income countries (23/31 are in low-income African nations).

6. Pathway to improved sustainability in legal and unregulated wildlife trade

Despite acceptance of "sustainable use" as a core mandate within CITES (Hickey, 1998), long-term sustainable use and trade of species is challenging. It not only requires the monitoring and assessment of species' conservation status when collected from the wild, but also that of habitats and ecosystems (Jepson and Ladle, 2010; Supplemental Text 3).

The export of CITES species often lacks NDFs (cf. above) or is based on scientific and economic uncertainties. For example, whilst most internationally traded monitor lizards come from the wild (Marshall et al., 2020) with many species traded in Europe, only one has sufficient data for NDFs to be available (Khadiejah et al., 2020; CITES, 2020a,b). The demand of consumer countries sometimes exploits non-existent structures in exporting countries (Lenzen et al., 2012). Thus, the attraction of consumer countries to import species is out of balance with the conditions provided through exporting countries, allowing trade to take place on the basis of many uncertainties (mainly justified by unequal conditions in finance, capacities, and enforcement). An increasing number of scientists have raised concerns about the consequences of unsustainable wildlife trade, highlighting the knowledge gaps and calling for more stringent regulation of wildlife trade, legal and illegal, national and international (Rowley et al., 2016; Marshall et al., 2020; Cardoso et al., 2021; Edwards et al., 2021; Fukushima et al., 2021a; Macdonald et al., 2021). Others have also suggested the need to consider a shift away from large components of the global trade in wildlife (D'Cruze et al., 2020; Macdonald et al., 2021; Warwick and Steedman, 2021), through the application of measures that would effectively apply the principles of replacement, reduction, and refinement (Russel and Burch 1959).

We identify four core areas in moving towards a transparent and sustainable trade of wildlife. First, rigorous data collection and indicators of populations; second, linking trade quotas to IUCN; third, improved databases and compliance of trade; and fourth, enhanced understanding of trade bans, market forces, and species substitutions. Until these are suitably integrated into CITES and other relevant regulatory measures, the precautionary principle is needed to prevent species moving rapidly from being not at risk to being of critical conservation concern.

6.1. Rigorous population estimates and indicators

The majority of species in trade would currently not meet the rigorous information needs and standards required to formally assess population trends and set offtake limits. For species that do meet this benchmark, executing an information-gap decision model may be useful as populations are not static in time necessitating fixed-term assessments and potentially changes in suitable offtake. In situations where uncertainty exists in estimating species or population abundance and temporal offtake, decisions (e.g., NDFs) concerning population management carry a high risk of failing sustainability and conservation objectives. Therefore, in addition to increasing monitoring and collection of baseline information on species, other approaches are required to derive estimates of sustainable collection levels, followed by standardised population monitoring to ensure quotas are genuinely sustainable (i.e., fall under the level of replacement) and to adjust quotas if not. For this to be effective, the burden of costs should fall upon importers rather than exporters (Macdonald et al., 2021), via development of overarching management systems that ensure funds protect rural livelihoods by ensuring species are traded sustainably and enable necessary monitoring.

When assessing the sustainability of local hunting offtake for wild meat trade, Ingram et al. (2021) demonstrated that theoretical testing of simple sustainability indicators did not perform well under uncertainty, such as natural fluctuations in mortality rates for prey species and imprecise population density and life history estimates (Roberts et al., 2021). More complex socio-ecological models that capture spatial variation and the dynamic nature of populations might give a better representation of the system, but these are often not practicable for local management purposes and most still rely on imprecise life-history data, or other data which may not exist at appropriate levels or sufficient accuracy.

Alternative proposed methods unreliant upon specific population trends try to glean offtake patterns to inform trade and capture trends by integrating different taxonomic, spatial, and temporal data collated from multiple sources. For example, mean body mass indicator (MBMI) and offtake pressure indicator (OPI) (Ingram et al., 2015) used in the assessment of fisheries. Here, MBMI can serve as a proxy for temporal changes in the composition of collected species averaged at a site, whereas OPI serves as a proxy for the relative change in the number of taken individuals indexed across multiple sites and species. While there have been various iterations of exploitation indicators (e.g., utilized species index and offtake index; Tierney et al., 2014; Ingram et al., 2015), the common theme among them is to overcome the lack of long-term monitoring data across multiple spatial and temporal scales for any given species. Nevertheless, there is no true replacement for population-level data to inform offtake and trade levels.

Better mechanisms for including genetic diversity and evolutionary significant units are needed to safeguard the future of species (Frankham et al., 2010), especially as reduced genetic diversity may undermine the ability of species to adaptively respond to environmental change. Selection for a subset of variants, for instance, morphs of *Morelia viridis* and northern green tree python *(M. azurea)*, reduces genetic diversity in the unexploited population (Lyons, 2012), highlighting the need to resolve taxonomic uncertainties (Barker et al., 2018; Natusch et al., 2020) and maintain genetic diversity. For example, the subspecies of reticulated python (*Malayopython reticulatus saputrai*) from the Indonesian province of South Sulawesi and offshore island of Selayar is a morphologically and genetically distinct population, with an unusual colour pattern that is particularly sought in the leather trade (Auliya et al., 2002; Murray-Dickson et al., 2017). In South Sulawesi, a hunting quota of 29,400 animals was set in 2016, and a quota of 23,000 in 2021 the second highest in Indonesia (21,850 skins were earmarked for export; KSDAE, 2022). Under a precautionary approach, the establishment of a regional management scheme focusing on island endemics and the identification of specific conservation units in accordance with highlighted Evolutionarily Significant Units (ESU's) (Moritz, 1994; Robertson et al., 2014; Coates et al., 2018) would be appropriate, combined with genetic studies (e.g., in the case of *M. reticulatus* in all of Sulawesi). Wildlife forensics are increasingly being applied in tracing the origin of traded individuals to verify legal trade, distinguishing between nationally protected and unprotected populations, and assessing the source of individuals either from wild populations or captivity (cf. Frankham et al., 2009; Huffman and Wallace, 2012; Coetzer et al., 2017).

Advocating widespread integration and reliance on citizen science databases (e.g., ebird or iNaturalist) requires care. While such databases could be used to report wildlife being sold illegally and facilitate enforcement, they could also generate perverse incentives to generate false occurrence data in highly desired species to make populations appear larger or more widespread than they are (e.g., Wildlife Witness). Reliance of research-grade reporting (those complemented with a photo) may be necessary to mitigate this risk. Additionally, a disproportionate proportion of migratory species are impacted by unsustainable offtakes (Coad et al., 2021), requiring additional mechanisms to enhance international collaboration along with the Convention on Migratory Species (Yong et al., 2021).

6.2. Linking to the IUCN Red-List

IUCN Red-List assessments represent an approach for generating global-scale dynamic inference of extinction risk, though whilst IUCN-listed species considered threatened or classed as Data Deficient are particularly at risk, further data is often still needed even for species considered as Least Concern or Near Threatened, which can reflect an extensive distribution range but where regional declines remain masked. By contrast, CITES-based mechanisms are small-scale, such as the World Conservation Monitoring Centre (WCMC), that monitors trade volumes for EU imports and reports back to CITES if trade in a species is two standard deviations over previous levels.

When using IUCN data, attention must be paid to the date, frequency, and completeness of assessment, given that assessment dates of some species no longer reflect the current threat status and may lack information on trade volume. Range-restricted species assessed as threatened or recently moved from Least Concern to Near Threatened, and that have generated international interest must be singled out to receive holistic measures to ensure effective protection. Studies show data deficient (DD) species should generally be listed as threatened, and should be treated with the same degree of caution as threatened species (Butchart and Bird, 2010; Jetz and Freckleton, 2015; Parsons, 2016; Bland et al., 2017, González del Pliego et al., 2019).

6.3. Improved databasing and compliance of trade

In learning lessons from livestock trade, developing standard coherent databases on international trade on a global basis (Mwanga et al., 2020) would include clear mechanisms for traceability. This has benefits for sustainability and minimising the risk of pathogens, pests, and invasive species. Such a method can help monitor illegal trade and prevent laundering, by having centralised facilities that certify and validate species identities (i.e., developing DNA-based tools; Fields et al., 2015) and are then responsible for shipping and databasing wildlife. Such bodies could work within National species authorities (https://www.iucn.org/sites/default/files/2022-07/4-guidelines-for-iucn-ssc-leaders-2021-2025.pdf), allowing a much greater understanding of where species are being exported from, as well as common transport routes (https://fogs-portal.de/en/forensic-genetics-for-species-protection-fogs-2/). Such a mechanism would overcome the 'trade-data' gap, and the 'species-identification' issue, and by putting costs onto the buyer, could remain financially viable. Furthermore, consumers (including zoos, museums, captive-breeding initiatives, and traders) must ensure that any acquired wildlife (whether CITES or non-CITES species) has been sourced legally (taking into account the national legislation of a species in the country of origin) and sustainably (Fukushima et al., 2021a2021b; Nijman, 2021).

Formation of a law enforcement management information system for all international trade (akin to LEMIS) would be a first step towards assessments of trade sustainability. Open-access data on trade would greatly help inform sustainable trade. This might include making NDFs formalized in data reporting and access for both CITES and non-CITES traded species. Digitization of all trade permits, reporting, and transactions for transparency and sustainability, would be possible even with the safeguards required by various entities to prevent privacy violations. For example, if digitized quotas, export and import data, and permits were available in the submission process, it would allow for almost real-time assessments of trade volumes and quick determination if levels begin to appear unsustainable owing to changes in market demand (Wiersema, 2015). This would warrant the timely application of the precautionary principle. Furthermore, these digital permits also provide a means to check and validate identity and legitimacy of items during trade, prevent the reuse of certificates, and therefore reduce the ability to launder items.

Hurdles exist, especially for less wealthy countries, in creating the infrastructure and financing necessary to organize data collation, digitization, and repositories for both CITES and non-CITES species. Furthermore, open access data on trade of species raises privacy concerns. For example, any data related to import/export of flora or fauna within the US must be acquired via a Freedom of Information Act (FOIA) request. Recently, USFWS under executive order 12,600 has begun to narrow their approval of information delivered from FOIA requests owing to "trade secrets and commercial or financial information that may be confidential to a business" (FWS, 2020). This may mean that assessing patterns of wildlife trade will become even more challenging, and developing open-source methods that enable monitoring whilst protecting industries are needed. The lack of transparency in trade data for most of the world means making assessments of the volume of trade, origins, and species impacted are impossible. Thus, centrally databasing trade is critical for sustainable management.

Data from traders is an alternative to NDFs (PERHILITAN, 2021). It even has been suggested to "move away from traditional field studies" and merely rely on data collected at slaughterhouses (Kasterine et al., 2012). While collaborating with traders can enable more sustainable approaches, this would require centralised and standardised approaches to collate data, provide oversight, validate identities, etc. At present, such data are not viable in the majority of circumstances, and to increase quotas traders would effectively be incentivised to lie (Nijman et al., 2012). First, it can provide a veneer of sustainable trade, via swapping of quotas between regions or the more or less equal handover of realised and maintained export quotas distributed over a specific annual period (Janssen and Chng, 2018; Fletcher, 2020; Mandy, 2021). Second, there is no policing mechanism or independent assessment of the reliability of such data. Even in the USA, the regulated trade of captive-bred animals lack oversight and is beset by laundering, infringement on business sovereignty (Black, 2007; Schneider, 2012). Third, although there are records of animal shipments, accurate understanding on collection localities (i.e., population level) can be challenging to trace. Yet claims of captive breeding could, in cases of doubt, be verified by DNA analysis of parental stock or isotopic diet checks, which could facilitate standardised assessments or random checking of parentage.

At present, international policies for reducing the global wildlife trade embody inequalities between signatory states. We can expect low compliance and accountability in wildlife supply from poorly resourced nations, pointing towards incentive and compensation-driven programs modelled on other transnational environmental initiatives (e.g., REDD+). Accountability in trade requires the following: Proof of species identity, which can be validated later using established methods for assessing identity (i.e., DNA barcoding) (Kumar et al., 2018; da Silva Ferrette et al., 2019), clear trade routes, and databases to document what is being recorded and traded. This must occur at several levels, ranging from the supply (collector, breeder, seller, export country) and the demand side (vendor and import country). Laundering of wild caught animals through captive breeding facilities is expected to be widespread but very difficult to monitor, enforce, and legally prosecute.

While there are methods in development (e.g., stable isotope and genetic sequence analysis) for determining wild-sourced animals laundered as captive bred (Natusch et al., 2017; Andersson et al., 2021a), they are time consuming, expensive and not always financially viable, but in such cases avoiding trade is likely the best solution. They also show variable accuracy and may not be executable at a scale needed to address the problem. However, with decreases in the price of genetic analysis, increases in the speed (i.e., Minion technology from Oxford Nanopore), and an appropriate involvement of consumers in the costs, these approaches could potentially be implemented. Such an approach also circumvents the reuse of permits, helping to reduce the likelihood of species laundering.

6.4. Comprehensive understanding of bans, market forces, and substitutes

Wildlife trade regulation can include bans applied across different temporal and spatial scales, risk drivers, and extinction risks (Fig. 2). Whilst some scientists and game-oriented NGOs (trophy hunting, etc.) decry trade-bans as a violation of access and benefits sharing (Roe et al., 2020), they can be effective and useful tools for reducing unsustainable wildlife trade. For example, the EU Birds Directive is estimated to have decreased global bird trade by 90% (Cardador et al., 2019), through preventing the import of wild-caught birds to reduce the risk of disease and invasive species associated with trade. Similarly, the US ban on imports of wild-birds (CITES Appendices I and II) had a positive impact (e.g., neotropical parrots) (Pain et al., 2006). This underscores the impact regional bans can have on global wildlife trade, and the positive impact on taxa targeted for pet trade (such as reptiles, various invertebrates; Marshall et al., 2020, 2022).

In other instances, independent or intergovernmental bodies have instituted partial or complete trade-bans for groups of species. For example, the International Whaling Commission (IWC), whose mission is to "*provide for the proper conservation of whale stocks and thus make possible the orderly development of the whaling industry*", has adopted a complete ban on commercial whaling with almost global membership (Andresen, 2019; Palmer, 2021). The commission's work and subsequent recovery of whale populations showcases how effective bans can be, and the challenges of working on such issues on a transnational basis (Jefferies, 2018). Similarly, global and regional commissions on tuna aim to prevent unsustainable fishing through coordination between the Regional Fishery Management Organisations (https://www.iccat.int/en/; https://www.iotc.org/; https://www.iattc.org/). These examples show bans are useful tool to enable wild population recovery, provide time for IUCN assessments to be conducted, or a transition to captive breeding (with mechanisms to prevent laundering of wild specimens), and enable sectors to remain economically viable for species that can withstand well-managed sustained offtake.

The effective application of trade bans has challenges. Bans need to be well thought-through, efficiently executed, and caution taken to avoid unintended negative impacts (Novak et al., 2015). Like any tool or

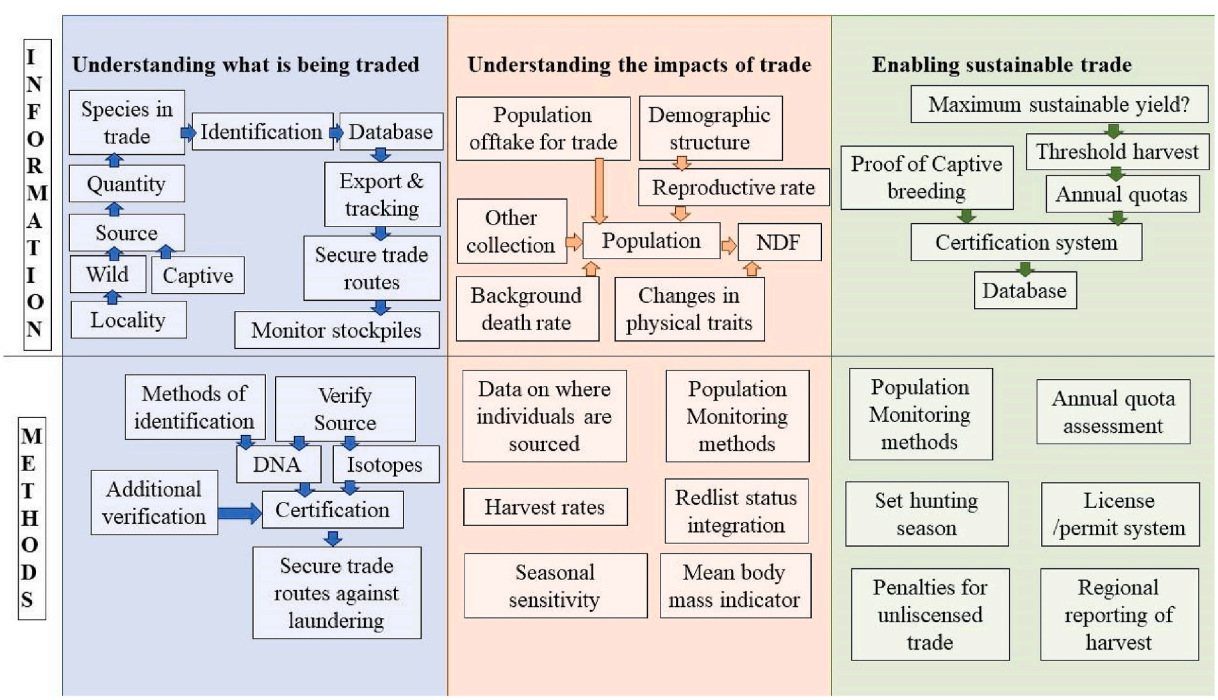

Fig. 2. Understanding dimensions of trade, its impacts, and measures to mitigate against impacts of unsustainable trade and how these relate to information and methods.

approach, trade bans need careful consideration to reduce unsustainable trade and how they can be applied to circumvent potential risks, including of alternative livelihood provisions if necessary (Sanya and Fischer, 2021; Di Minin et al., 2022). Ideally, to prevent the rerouting of legal trade flows and shifts to unprotected threatened substitute species, trade bans should be global and take potential analogue species into account (Macdonald et al., 2021). To prevent any subsequent rise in illegal trade or corruption, wildlife trade bans should be accompanied with effective enforcement and political will to implement targeted interventions. Furthermore, how bans and regulations are implemented has a huge impact on their effectiveness (Challender et al., 2019; Dickman et al., 2019). For example, whereas regulation for mammals generally halts further declines in IUCN threat status, in reptiles trade increases in anticipation of CITES uplisting and status can continue to decline afterwards (Mialon et al. 2022; Rivalan et al., 2007). Yet whilst this may appear to suggest CITES bans vary in effectiveness across groups, it may be more a reflection of other factors such as what criteria are used to apply CITES (as the motivation for listing and threats to species listed may be very different for different taxonomic groups) or the propensity of different markets to anticipate trade restrictions.

Despite the economic nature of wildlife trade and importance of market forces for establishing and ensuring sustainable use (Challender et al., 2015, 2015a), detailed information regarding wildlife markets is lacking for the vast majority of commodified species (both CITES and non-CITES listed) (Harrington et al., 2021; Hughes, 2021). This is particularly an issue for demand-side factors, including consumer preferences, social norms driving consumption, and demand elasticity, though population and range data is also frequently lacking for many vulnerable taxa, and is almost never available at the population level. Current systems that facilitate a largely legal unregulated trade generally function under the assumption that steady or increased supply of wildlife products (through wild capture, ranching, and farming) will best serve the continued survival of wild populations (Macdonald et al., 2021). Consequently, in lieu of supporting evidence of sustainability, this current status quo runs the risk of favouring trade, and the short-term profits therein, over wildlife conservation, despite the potential negative consequences both ecologically and economically in the longer term (D'Cruze et al., 2020).

Given that wildlife exploitation is a major driver of biodiversity loss (IPBES et al., 2019), demand-related information is urgently required to determine sustainability and because conservation marketing has huge (unrealized) potential for redirecting or reducing unsustainable demand for wildlife products (Macdonald et al., 2021). For example, Traditional Chinese Medicine consumers when offered herbal substitutes for animal-based medicines, regular consumers were the most enthusiastic group: 89% said they would buy them (Moorhouse et al., 2020). Holistic approaches are needed to ensure demand-reduction campaigns address the drivers of demand and uses modes of communication appropriate for the demographics using wildlife (Margulies et al., 2019; Thomas-Walters et al., 2020; Veríssimo and Glikman, 2020). Making such information more readily available for other wildlife products can also enable people to make more sustainable decisions (Moorhouse et al., 2017), and standards are being developed to enable sustainable production of plants for traditional medicine (Antosch and Morgan, 2017).

Public understanding, attitudes, and ethical standards are evolving to the extent that, in some markets, the potential negative impacts of wildlife trade on animal welfare, public health, and equitability across trade chains are becoming increasingly socially and culturally unacceptable (Baker et al., 2013; Borsky et al., 2020; D'Cruze et al., 2020; Wyatt et al., 2021). Given the effectiveness of changing consumer demand for wildlife as a conservation strategy, an increased understanding of how these factors complement market-based conservation strategies would be beneficial. It would enable all the benefits that can be associated with trade whilst mitigating risks.

For trade to be sustainable, a multifaceted approach is needed (Fig. 2). This includes understanding levels of harvest, population range, health, and sensitivity, and developing modes of management to avoid harvest during periods which could undermine species future survival prospects. It also includes methods to control quotas to prevent trade reaching unsustainable levels or streamline a system reliant on captive breeding with safeguards to prevent laundering. All of these elements have certain methods or technologies needed to implement them, plus the need for tools for reporting and validating. Without such approaches and considerations there is a genuine risk of trade being unsustainable, threatening both species and any livelihoods dependent upon them.

7. . Conclusions

1. Without data to inform population management or understand the impacts of wildlife harvest, contrary to general perception, a large portion of legal trade is likely to be unsustainable. Creating mechanisms to mandate sharing of trade data, determine what species can be traded, under what circumstances and conditions, are critical to preventing negative impacts on species, the viability of populations, and their function in the ecosystem (Fig. 2).
2. Most countries do not record most wildlife exports and imports at species level, if they fall outside of CITES Appendices (Auliya et al., 2016a; Scheffers et al., 2019; Marshall B et al., 2020). Offtakes are often unregulated, without information on status and trend of the targeted population, impact on ecosystem, and/or role of other threats, preventing development of mechanisms to ensure sustainability. In short, the removal of species from their native ecosystem is often based on ignorance of relevant parameters for monitoring the sustainable viability of a species (Fig. 2).
3. Unsustainable trade depletes wild populations, undermining potential future profits and biodiversity conservation goals. Waiting for species to become vulnerable to extinction before providing safeguards is too high risk, and we risk losing genetic diversity or even species given the lack of monitoring. NDFs may be conducted by those with active interests in trade, making open review of NDFs, working with organisations such as the IUCN to find assessors with no conflicts of interest, and developing adequate monitoring approaches critical to ensuring trade does not drive population decreases. CITES should require NDFs for the export of Appendix II species (mandatory from exporting countries), which must be checked by an objective independent scientific working group (consisting of e.g. agencies, universities, NGOs) before export; the requested export can only take place if this group evaluates the planned export as sustainable verified, and if no conflicts of interest exist between regulators and exporters.
4. Creating awareness among decision makers of the lack of sustainability in large parts of legal wildlife trade is urgently needed. Monitoring needs to account for other factors (habitat loss, species' role in ecosystem, climate vulnerability) that combined with trade pressure can generate substantial extinction risk (Symes et al., 2018). The Nagoya protocol on access and benefit sharing and sustainable livelihood provision is often evoked as a reason for not regulating trade. Yet for countries without the data or tools to sustainably manage their wildlife, international markets that facilitate unsustainable exploitation of wildlife contravene those rights by reducing equitable access to wildlife benefits in the longer-term. Thus, livelihood-based justifications cannot stand without ensuring processes to maintain access to those resources into the future, especially if they are used (often at high profit) in markets in the developing world that may export large volumes of wildlife under the guise of 'sustainability'. Mechanisms to ensure sustainability by promoting data access and trade regulation to ensure species survival are critical, as unsustainable harvest will remove access to that livelihood in the future without intervention.
5. In many cases, it is difficult to distinguish between legal and illegal trade. First, species may be nationally protected in its country of origin, but not included in the CITES Appendices. Accordingly,

international trade in this species is legal in most importing countries, even when the animals have an illegal origin. Second, trade may be regulated by catch or export quotas, with official permits; however, quotas may be exceeded or permits may be faked, which is difficult to prove for authorities in importing countries. Third, a species may be neither protected by national or international legislation, but may be caught in a protected area/National Park, making its' collection a poaching activity. Fourth, regulations of different authorities may be in conflict, such as between CITES and fisheries authorities.

6. A precautionary approach is needed to halt biodiversity declines, underpinned by a revised burden of proof. This must place the need on traders and importers to illustrate sustainability to allow trading, not conservation scientists and practitioners to reveal unsustainability, or customs officers to prove export contravenes regulations. Without better systems, which at a minimum ensure species can only be traded when it is demonstrated that trade does not to harm survival prospects, unsustainable trade will continue to pose one of the greatest risks to many species. Understanding what is being traded, where from, and at what volumes, in addition to the impact on the long-term viability of species, will be critical to slowing the loss of species from across the planet.

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.

However, the authors are members of the following IUCN/SSC specialist groups: Asian Songbird Trade (VN, CSR), pigeon and dove (CSR), hornbill (CSR), primates (VN), bears (VN, CSR), pangolin (CRS), small carnivores (CRS), otter (CRS), tortoise and freshwater turtles (CRS, MA, SA), skinks (JJ), monitor lizards (MA, JJ, ES), molluscs (VN). Their views may or may not represent those of some members of the IUCN/SSC.

Some of the authors are previous (VN) or current members (JJ) of national CITES Scientific Authorities. This manuscript represents the views of the authors and does not necessarily reflect that of the respective CITES Scientific Authorities.

Data availability

in supplements

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Appendix A. Supplementary data

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