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Knowledge gaps in the assessment of species in the wildlife trade

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I very much subscribe to the school of thought that if you do not have anything worth saying then say nothing at all. So, this section will be brief and to the point.

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Abstract

The international trade in wildlife is a major threat to biodiversity, driving some species to the brink of extinction. Trade includes species of all IUCN Red List categories from Critically Endangered through to Data Deficient, and is predicted to impact thousands more. Knowledge gaps prevent the assessment of extinction risk of traded Data Deficient species, and potentially cause them to be ineligible for international trade regulation. The Convention of International Trade in Endangered Species (CITES) aims to protect species from unsustainable trade, however certain biological criteria must be met for a species to be listed. As such, many species predicted to become impacted by trade may lack the necessary biological data. This thesis contributes to filling two knowledge gaps: the extinction risk for traded Data Deficient species, and whether they are currently protected by CITES; and if species predicted to become present in trade have sufficient biological data to be listed in CITES. First, I analyse the new threat category of all IUCN Red List Data Deficient species reclassified between 2007 and 2021, and compare the overall results to the subset of traded Data Deficient species. Second, I review the literature for two sample families of species predicted to become impacted by trade: Alsodidae, a family of frogs from South America; and Gerrhosauridae, lizards distributed across Madagascar and sub-Saharan Africa. I synthesise the current knowledge, and assess it against the CITES biological criteria for listing in Appendices I and II. The results indicate that traded Data Deficient species are likely to have a higher extinction risk than Data Deficient species as a group, with 56.2% and 45% reclassified species respectively now considered threatened. Only one traded Data Deficient species (*Pudu mephistophiles*) is CITES listed at species level but others inherit protection through three different taxonomic level listings. Whilst data gaps exist for many species predicted to become impacted by trade, threatened species should meet the CITES biological criteria. Data

Deficient species, and some species already present in trade, are ineligible for CITES or may only gain protection through the ‘lookalike’ criteria of Appendix IIb. Most traded Data Deficient species are located in the tropics, where data is also scarce for species likely to become present in trade. Future research efforts on filling data gaps should focus on tropical Data Deficient species that are already traded or predicted to become so, particularly amphibians, reptiles, and species that do not resemble any others, in order to protect potentially threatened species from overexploitation.

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Chapter 1 - Introduction

1.1 Background and development of wildlife trade

The trade in wildlife has existed for thousands of years. The ancient Egyptians obtained ivory for jewellery and carvings (Naylor, 2005), leopard skins for priests' attire (Budge, 1934), and an array of exotic animals for the menageries of pharaohs, rulers, and wealthy inhabitants (Kisling, 2000; van Uhm, 2016). The elites of Greek and Roman empires followed suit, with monkeys, giraffes, snakes and birds, such as cranes, flamingos, and nightingales kept as pets (Kisling, 2000; Hughes, 2003); a parrot that could speak Latin was more expensive than a slave (van Uhm, 2016). Trade increased significantly with the emergence of the Roman games, with wildlife including lions, leopards, crocodiles and elephants collected and exhibited for gladiatorial contests and public entertainment (Whatmore, 2002; Jennison, 2005). Wildlife trade was structured and lucrative (an African lion was worth today's equivalent of £4 million) and demand resulted in local extirpations of some species, including elephants in Libya and hippos from the Nile (Hughes, 2003; Bomgardner, 2013).

In the medieval period, demand for wildlife was relatively low but trade still existed for menageries, entertainment, artefacts, and clothing (van Uhm, 2016). But trade then escalated during the colonial era; with European imperialist exploration came trade of animals from Africa, Asia, and South America for royal menageries and private collections (Kalof, 2007; van Uhm, 2016). It was during this time that Dutch sailors were allegedly responsible for perhaps the most famous of all extinctions, by using the dodo (*Raphus cucullatus*) as a source of free meat on voyages (Duffy, 2010). Trade was not restricted to live imports; feathers and other bird products were increasingly popular in fashion trends, whales were hunted for lubricant oil, meat, and their baleen, and elephant ivory continued to be in demand (Boekhout van Solinge, 2008; van Uhm, 2016).

A key driver of wildlife trade during this time (~1500 – 1800 CE) was the demand by the middle classes in order to copy the trends of the elite, and this continued into the 19th century (van Uhm, 2016). Menageries were no longer the preserve of royalty and upper classes, and with the rise of the science of natural history and zoology came a fascination with exotic animals (Simons, 2012). The first zoos and circuses appeared, and even exhibitions of indigenous people from North America, Australia, and Africa in makeshift depictions of their natural habitat (van Uhm, 2015, 2016). During the 20th century, trade escalated significantly as a result of technological innovation, and availability is reflected by the low prices in 1903: an elephant would cost you around £120, a lion £20, and a wolf only a mere £4 (Simons, 2012). Demand for animal products was also booming. Trade in feathers and bird skins, for instance, resulted in hundreds of thousands of birds being hunted for the hat industry (Doughty, 1975). In the latter half of the century, wildlife such as monkeys and lions could be purchased from department stores, and women of all statuses wore fur coats, made from skins of big cats and bears (van Uhm, 2016).

1.2 Why overexploitation is an issue

The scale of trade during the 1900s started to take its toll on wildlife populations. For example, elephants were extirpated from many parts of Africa, three sub-species of tiger were eliminated, and a number of macaw and parrot species were driven to the brink of extinction (Blanc, 2003; Abbott and van Kooten, 2011; Halle, 2018). But the scale and diversity of wildlife trade has quadrupled over the last 40 years, and it is now a leading cause of biodiversity loss across the globe (Maxwell *et al.*, 2016; Harfoot *et al.*, 2018). Around 25% of terrestrial mammal, bird, reptile, and amphibian species are now subject to trade (Scheffers *et al.*, 2019) and are often harvested from the wild (Marshall, Strine and Hughes, 2020; A. C. Hughes, Marshall and Strine, 2021). The drivers of trade are not new, with animals in demand as pets, luxury meat, and products, including fashion and jewellery (Hughes, 2021). Although trade can be sustainable, and provides a vital source of income for many people living in poverty (Nijman, 2010), current levels are unsustainable for many species. For instance, pangolins (Manidae) are now the most trafficked mammal on the planet, with relentless demand for both their meat for consumption and scales for traditional medicine (Challender, Waterman and Baillie, 2014; Heinrich *et al.*, 2016; Ingram *et al.*, 2018). Three of the eight Red List assessed species are now Critically Endangered but 30 years ago, these mammals were widespread and largely unknown (Heinrich *et al.*, 2016; *The IUCN Red List of Threatened Species*, 2023). While the Bali Myna (*Leucopsar rothschildi*) has been subject to illegal trapping for the cage bird trade since the 1970s, however, in 2015, a survey found only 12 wild individuals of the species remained (IUCN, 2020b).

In addition to wildlife population declines and extinctions, overexploitation can negatively impact on the benefits humans derive from ecosystems, known as ecosystem services. These benefits can be provisioning, (e.g., food and timber); regulating, (e.g., affecting the climate); supporting, (e.g. pollination); and cultural (e.g. recreational or aesthetic benefits) (MEA, 2003). Overexploitation can negatively impact seed dispersal, crop pollination, and biological pest control (Bradshaw, Sodhi and Brook, 2009; Sodhi, Brook and Bradshaw, 2013), carbon storage (Effiom *et al.*, 2013; Bello *et al.*, 2015; Berzaghi *et al.*, 2023), availability of food and medicinal products (Laurance, 1999), and revenue from ecotourism (Smith and Porsch, 2015), to name a few.

1.3 Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES)

These potentially devastating impacts wildlife trade can have on biodiversity and ecosystems, combined with the global nature of trade, call for international regulation and monitoring to ensure trade is sustainable. One such agreement is the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), an international regulatory framework for wildlife species subject to trade. It currently has 184 Parties (state Governments), which agree to be bound by the Convention, and adopt legislation to ensure that CITES is implemented at national level. Each Party must have one or more Management Authorities that administers a licensing system for the import and export of CITES-listed species, and one or more Scientific Authorities to advise them on the effects of trade on the status of the species. The process for a species to be added to an Appendix of CITES is via a proposal from a Party or group of Parties which is considered at the Conference of the Parties (COP), which is held every two – three years. Parties discuss the proposal then vote on whether it should be listed on that CITES Appendix.

Appendix I offers the most protection from trade impacts, with trade in wild collected species threatened with extinction being banned. Appendix II provides less stringent regulation, for species not necessarily now threatened with extinction but may become so unless trade is regulated. This appendix also provides protection for non-traded species that resemble other species that are listed, known as the ‘lookalike criteria’. Appendix III provides for national level protection for species.

In order for a species to be proposed for listing on Appendices I, it must be present in trade and meet, or be likely to meet, at least one of the biological criteria. For Appendix II, the regulation of trade in the species must be required to: avoid it becoming eligible for inclusion in Appendix I in the near future; or ensure harvesting is not reducing the wild population to an unsustainable level. The full criteria are set out in Appendix 1 to this thesis, but the key biological criteria are that a species must have a small population, restricted area of distribution, and/or a marked decline in population size, characterised by a decline in the area or quality of habitat, or a high vulnerability to intrinsic or extrinsic factors. However, this information is absent for many species – for example, very little is known about newly discovered species, and those that are poorly studied. Yet these species are not immune from trade, often the reverse. The Psychedelic Rock Gecko (*Cnemaspis psychedelica*) for instance was only described in 2010 and was offered for sale in Europe in 2013 for approximately €2500 - €3000 a pair (Auliya *et al.*, 2016). It was added to CITES Appendix I in 2017.

Amphibian and reptiles feature heavily in wildlife trade, with 3943 (35%) reptile and 1215 (17%) amphibian species traded (Marshall, Strine and Hughes, 2020; A. C. Hughes, Marshall and Strine, 2021). These taxa also have the highest rates of newly discovered terrestrial vertebrate species, with an average of 155 new species of amphibian and 178 reptiles described per year in the last decade (*AmphibiaWeb*, 2023; *The Reptile Database*, 2023) although this is in part due to discoveries that some cryptic species are in fact complexes of species. The average time lag between being discovered and being traded is only 8 years for reptiles and 6.5 years for amphibians (Marshall, Strine and Hughes, 2020; A. C. Hughes, Marshall and Strine, 2021). If these current trends continue, the number of species of these taxa traded will significantly increase but a lack of knowledge may prevent them accessing protection under CITES.

1.4 Data Deficient (DD) species

Species that are poorly studied (or simply difficult to study) are often categorised as Data Deficient by the International Union for Conservation of Nature (IUCN) Red List of Threatened Species (the Red List), a comprehensive source of information regarding species' extinction risk. A species is considered Data Deficient (DD) if there is inadequate information to make a direct, or indirect, assessment of its risk of extinction based on its distribution and/or population status (*The IUCN Red List of Threatened Species*, 2023).

Excluding fishes, DD species account for 10% of assessed vertebrate species on the Red List but this is not equal between taxa; only 0.4% of birds are DD while 14 - 15% of amphibians, reptiles, and mammals are listed as DD. A wide range of data is required to assess actual or inferred population trend, including population size, area of occupancy, habitat, and threats, and the reasons why a species may be listed as DD vary. For example, the Ghost Gecko (*Hemidactylus lemurinus*) has a very narrow ecological niche in isolated subpopulations, but it is unknown whether they are able to persist in these fragments, or how tolerant it is of disturbance (IUCN, 2012) whereas the Battak Frog (*Pulchrana debussyi*) is listed as DD "in view of continuing doubts as to its taxonomic validity as well as absence of recent information on its extent of occurrence, status and ecological requirements" (IUCN, 2017b). Threats are often unknown, which impact assessors' ability to determine likely population trends.

The DD category is probably the most controversial of the Red List (Butchart and Bird, 2010). There are limited resources available for biodiversity conservation, and government agencies and conservation organisations at global and national scales often refer to the Red List extinction risk of species to guide financial resource allocation (Rodrigues *et al.*, 2006; Betts *et al.*, 2020; Reed *et al.*, 2020). Species classified as threatened (Critically Endangered, Endangered, or Vulnerable) are prioritised, whilst those that are DD are usually overlooked (Bland *et al.*, 2017; Cazalis *et al.*, 2022). This is despite the IUCN stating that DD species should also be a priority for the scientific community, in order to generate data that will enable assessment of their true extinction risk and threat status (refs). A number of studies (e.g., (Jetz and Freckleton, 2015; González-del-Pliego *et al.*, 2019; Borgelt *et al.*, 2022)) have attempted to predict the true extinction risk of DD species, with the overwhelming majority concluding that DD species are likely to be more threatened than their data sufficient counterparts. For example, the machine learning-derived probabilities in Borgelt et al. (2022) predicted more than half of the 7699 DD species analysed are in fact threatened with extinction, including 85% of DD amphibian species. Thus, thousands of genuinely threatened species may not be getting the conservation action they need.

Around 10% of amphibian species in trade are DD and 5% of reptile species (Marshall, Strine and Hughes, 2020; A. C. Hughes, Marshall and Strine, 2021), and 20% of DD terrestrial birds and 9% of DD terrestrial mammals feature in trade (Scheffers *et al.*, 2019). As there is an overlap of the biological knowledge required to designate a species into a red List threat category, and the biological criteria required to list a species on CITES, many threatened traded species currently classified as DD may also be excluded from CITES due to knowledge gaps.

1.5 Outline of this thesis

Only with sufficient biological knowledge can traded species be assigned a true threat status, and regulated via CITES. Identifying knowledge gaps of traded species, and those projected to become impacted by trade, are the key objectives of this thesis.

The specific aims are:

- Identify whether traded DD species are more threatened than DD species as a whole
- Identify the knowledge gaps that prevent DD species being assigned a Red List threat category
- Identify if traded DD species have sufficient knowledge to be listed on CITES

These issues are addressed in Chapter 2.

The purpose of Chapter 3 is to

- Identify knowledge gaps for a sample of species predicted to become present in trade
- Assess if current knowledge is sufficient for such species to be listed on CITES

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Chapter 2 Knowledge gaps and extinction risk of traded Data Deficient species

2.1 Introduction

An overwhelming body of evidence suggests that biodiversity on Earth is at the start of – or already undergoing – a Sixth Mass Extinction (Barnosky *et al.*, 2011; Ceballos *et al.*, 2015; Ceballos, Ehrlich and Raven, 2020). According to one estimate, 617 known vertebrate species have become extinct since 1500, with around 77% of those having become extinct since 1900 (Ceballos *et al.*, 2015). These are just the species that we know of, with many species going extinct before they are scientifically described (Mora, Rollo and Tittensor, 2013; Lees and Pimm, 2015). The International Union for Conservation of Nature Red List of Threatened Species (hereafter the Red List) is a widely used and accepted measure of extinction risk to the world's species, which uses data such as global range, key threats, and population size to assign a species to a threat category (Mace *et al.*, 2008; *The IUCN Red List of Threatened Species*, 2023). If this data is lacking, there may be inadequate information to make any assessment of extinction risk, and these species are defined in the Red List as Data Deficient (hereafter DD). Currently, a total of 20,835 species are categorised as DD, however this figure is not divided proportionately among taxa. Whilst only 46 species of birds (0.4%) are DD, 14-15% of mammals, amphibians, and reptiles (839, 1145, and 1487 species respectively) are assigned to this category (*The IUCN Red List of Threatened Species*, 2023). Other taxa are even less understood; 20% of bony fishes (Actinopterygii and Sarcopterygii) are DD, and over a quarter of arthropods, although only 16,347 species – a metaphorical handful – of these invertebrates have been assessed.

The precautionary recommendation is for DD species to be afforded the same degree of protection as threatened species (Mace *et al.*, 2008). In practice, DD species are often overlooked in conservation policy, commonly designed to only safeguard formally threatened species (Cazalis *et al.*, 2023). Studies analysing biodiversity impacts also generally exclude DD species, as do metrics of change, such as the IUCN Red List Index (Bland *et al.*, 2017; Cazalis *et al.*, 2022). In addition to a lack of protection, DD species have limited access to conservation funds (Bland *et al.*, 2017), causing thousands of species to be neglected in global conservation efforts to tackle biodiversity declines.

The uncertainty around the true level of extinction risk for DD species can also bias estimated proportions of threatened species. For example, in 2009, 25% of mammals were assessed as threatened but this number would have fallen to 21% if all DD species were not threatened or increase to 36% if all DD species were threatened (Hilton-Taylor *et al.*, 2009). Several studies have attempted to predict the Red List status of DD species through modelling Red List parameters then used to apply Red List criteria, or by using correlates of extinction risk to predict 'true' Red List status (Cazalis *et al.*, 2022). Estimates vary from 14% of DD birds being threatened with extinction (Butchart and Bird, 2010), 19% - 29% of reptiles (Bland and Böhm, 2016; Caetano *et al.*, 2022), and 47% -85% of amphibians (Howard and Bickford, 2014; González-del-Pliego *et al.*, 2019; Borgelt *et al.*, 2022). Yet no studies have fully assessed what category of threat DD species are placed in following Red List reassessment, or whether any subsets of DD species are more threatened than others, such as those subject to overexploitation, a leading cause of biodiversity loss (Butchart, Stattersfield and Collar, 2006; Hoffmann *et al.*, 2010; Maxwell *et al.*, 2016).

Wildlife is hunted and collected to sell for an array of motives, including pets, luxury meat, fashion, and medicine (Scheffers *et al.*, 2019; Hughes, 2021). In many instances trade can be at sustainable levels, and provide a vital source of income for people (Scheffers *et al.*, 2019; Hughes, 2021; Prasad, Rausser and Zilberman, 2022), but when a species becomes overexploited, it can cause dramatic declines in wild populations and increase the risk of extinction (Bennett, 2011; Auliya *et al.*, 2016; Morton *et al.*, 2021a). The Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) provides a regulatory framework that prohibits and/or regulates trade in endangered species but certain biological criteria must be met before a species can be afforded protection. The study of CITES protection for DD species is limited to one recent study (Morton *et al.*, 2022), which determined that 346 listed species were first traded when they were either not evaluated/recognized or assessed as DD.

Determining the subsequent Red List assessed threat status of DD species would significantly contribute to understanding their true extinction risk, and identify if traded DD species in particular are more threatened. Understanding if the CITES biological criteria is an obstacle to traded DD species could identify a problem in protecting them from excessive trade, and highlight a priority for data collection, particularly if this subset of DD species are more threatened than their non-traded DD counterparts. The IUCN Red List Categories and Criteria have remained the same since publication of version 3.1 in 2001, as have the guidelines for using them, other than mostly additions of detail and clarifications (IUCN Standards and Petitions Committee, 2024). A new section on the transfer of a species from one category to another was added in 2004, which pre-dates the datasets available from the IUCN, providing a unique opportunity to analyse the reclassification of DD species into other Red List categories against a background of stable criteria, assessment process, and guidelines. In this study, I analyse the reclassification of all DD species between 2007 and 2021 using datasets from the IUCN, and determine the extinction risk of mammals, birds, reptiles, and amphibians that have been moved from the DD category. I then analyse whether traded DD species are more threatened, identify the knowledge gaps hindering the assessment of their extinction risk, and consider if a DD status is a barrier to listing species on CITES.

2.2 Method

On 28th November 2022 I downloaded datasets of Red List species that have been recategorized every year from 2007 to 2021 and converted them into one dataset. I used R version 4.2.2 to filter species initially listed as DD and for analysis of new category and taxon. I also identified species present in wildlife trade that changed category from DD, using the published dataset of traded terrestrial vertebrates (Scheffers *et al.*, 2019) for mammals and birds, and more recent datasets of traded amphibians (A. C. Hughes, Marshall and Strine, 2021) and reptiles (Marshall, Strine and Hughes, 2020). I used the data from these later studies for amphibians and reptiles as both used a more comprehensive methodology than Scheffers et al. (2019) to identify traded species. I searched for later studies of traded mammals and birds on Web of Science but did not locate any. On the 27th November 2023, I consulted the Red List to determine the threat category of species in each taxon. I performed a Chi-Square goodness of fit test to determine if the new threat category of traded species was representative of recategorised DD species as a group. I applied simulated p values, as some of the proportions (e.g. EX species) were small.

To analyse the data gaps for traded species of terrestrial vertebrates currently listed as DD, I downloaded Red List assessments between 24th October 2022 and 15th November 2022 for all species of mammals and birds listed in the published dataset of traded terrestrial vertebrates (Scheffers *et al.*, 2019). The amphibian and reptile datasets (Marshall, Strine and Hughes, 2020; A. C. Hughes, Marshall and Strine, 2021) include the Red List category of each species, therefore I was able to restrict the Red List downloads to the species these studies listed as DD. I downloaded Red List assessments for DD reptiles and amphibians on the 15th and 16th November 2023. I then merged the Red List assessments with the relevant dataset of traded species and first checked if any amphibian or reptile species had changed category since publication in 2020 (Marshall, Strine and Hughes, 2020) and 2021 (A. C. Hughes, Marshall and Strine, 2021).

I read a random selection of five of the assessments for each taxon to understand how they were structured and what terms were used, and then used R to perform keyword searches for the Red List assessment categories of ‘rationale’, ‘habitat’, and ‘threats’. For ‘rationale’, I identified six broad categories of reasons for a DD listing from my initial scans of Red List assessments: taxonomy, population status, distribution, ecology, threats, and low number of specimens. I used the following search terms to identify listed data gaps in rationale: ‘taxonom’ to identify taxonomical issues; ‘population’ for population status; ‘ecolog|natural history|habitat’ regarding a species’ ecology; ‘occurrence|distribution|range’ for distribution; ‘threats’ for threats; and ‘holotype|specimens’ for rationale regarding limited number of records. All results were checked for accuracy. I identified six categories for threats to DD species: deforestation/habitat loss, fire, logging/degradation of habitat, disease, invasive species, and no information/no known threats. I used the following search terms to identify threats: ‘deforest|habitat loss|loss of habitat|slash|agricul|infrastructure’ to identify species threatened by habitat loss; ‘chytrid|disease’ for disease; ‘fire’ for fire; ‘logg|degrad’ for habitat degradation; ‘exotic|introduced|invasive’ for invasive species; and ‘no known|no information|no threat|no information’ to identify species with no known threats. All results were again checked for accuracy. Finally, for habitat, I identified five categories inhabited by DD species: forest, desert, shrub, grassland/savanna, other habitats, and nothing known/no data available. I used the following search terms: ‘unknown|not known|no data’ to identify species whose habitat is not known; ‘forest’ for forest; ‘grass|savan’ for grassland/savanna; ‘shrub|bush’ for shrubland; and ‘desert|arid’ to determine desert species. As with rationale and threats, all results were checked. The Red List assessments use categories for the realm and population status of all species, and this was also analysed using R.

To assess how many DD species are listed on CITES, I used the same merged datasets I created to filter DD species and those identified by the authors as being listed on CITES. I then looked at each species on Species+ (*Species+*, 2023) to determine whether it was a species, genus, family, or order listing.

2.3 Results

2.3.1 Red List changes to DD species

Between 2007 and 2021 there was a total of 3035 Red List reclassifications pertaining to 2973 species. Of these, 1032 species were reclassified from DD, and 20 of the 1032 were subject to a further change. Amphibians represent more than half of the changes with 568 species reclassified, and 50.5% were either declared Extinct (EX) or moved into the threatened categories Critically Endangered (CR), Endangered (EN), and Vulnerable (VU). The number of reclassified reptiles (n = 222) and mammals (n = 212) were similar but 45.3% of mammals became threatened or were declared EX compared to 34.7% of reptiles. There were very few DD bird species (n = 30) recategorised, and 23.3% were reclassified as threatened. Overall, 464 species (45.0%) that were reclassified from DD between 2007 and 2021 are now considered Threatened (CR, EN or VU), 101 species (9.7%) are Near Threatened (NT), 464 species (45.0%) are Least Concern (LC), and three species (0.3%) have gone extinct (Fig 1a).

The dominance of amphibians is not echoed in the numbers of DD species subject to wildlife trade that have undergone a Red List assessment category change, with only 23 amphibian species being reclassified from a total of 105. Mammals and reptiles have 41 and 36 traded species' changes respectively, and just 5 birds. All traded DD taxon except birds see an increase in the proportion of species that have moved into threatened categories compared to all DD species. Amphibians rose slightly to 52.2%, but reptiles increased considerably to 50.0%, and mammals jumped to 68.3%. Traded DD birds slightly dropped to 20.0%. Overall, out of 105 traded species that have changed Red List category from DD between 2007 and 2021, 59 species (56.2%) are now threatened (none EX), 35 species are LC (33.3%) and 11 (10.5%) are NT (Fig 1b).

The Chi-Square test result was significant (X^2 = 18.04, p = <0.01), thus the proportion of recategorised DD traded species in threatened categories is significantly different to recategorised DD species as a whole.

The Red List currently categorises 35.3% of amphibians as threatened, 18.4% of reptiles, 23.9% of mammals, and 14% of birds, considerably smaller proportions than reclassified DD species (Fig 2).

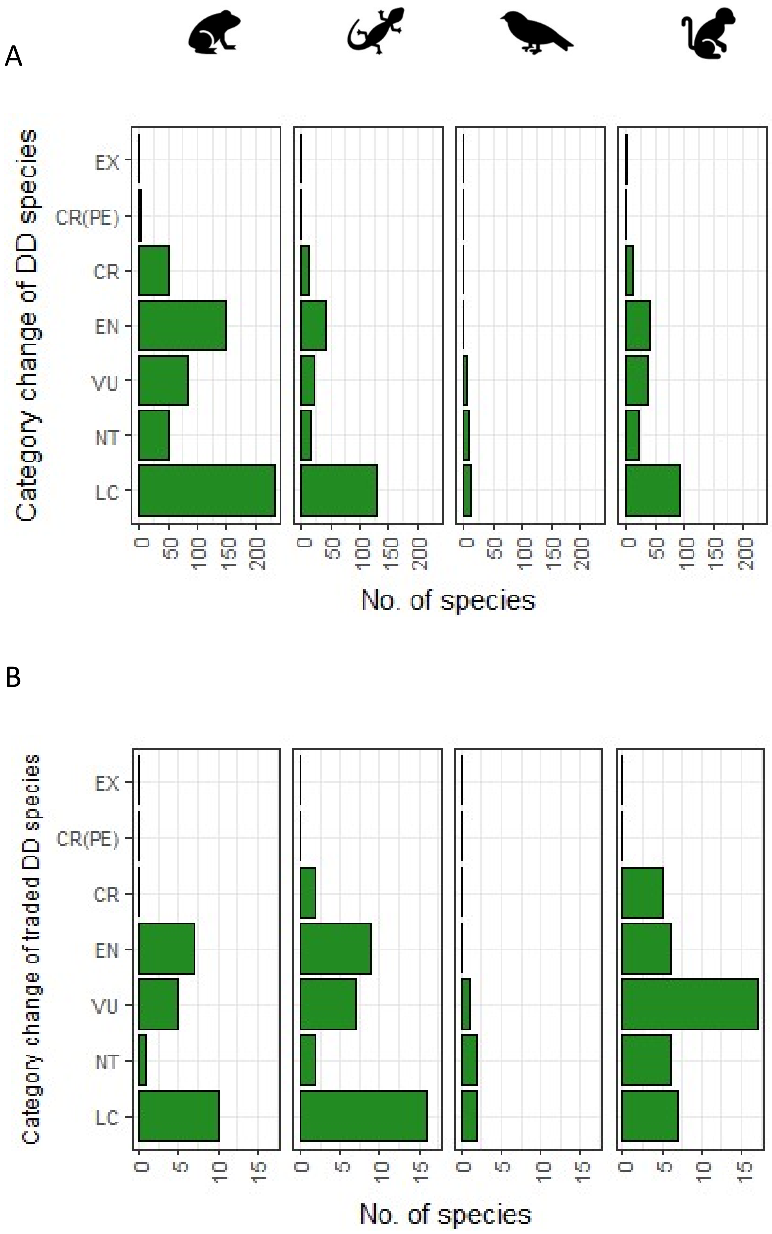

Figure 1. The numbers of species of amphibians, reptiles, birds, and mammals, reclassified from DD to other Red List categories between 2007 and 2021. A) all DD species B) species subject to wildlife trade (Scheffers *et al.*, 2019; Marshall, Strine and Hughes, 2020; A. C. Hughes, Marshall and Strine, 2021).

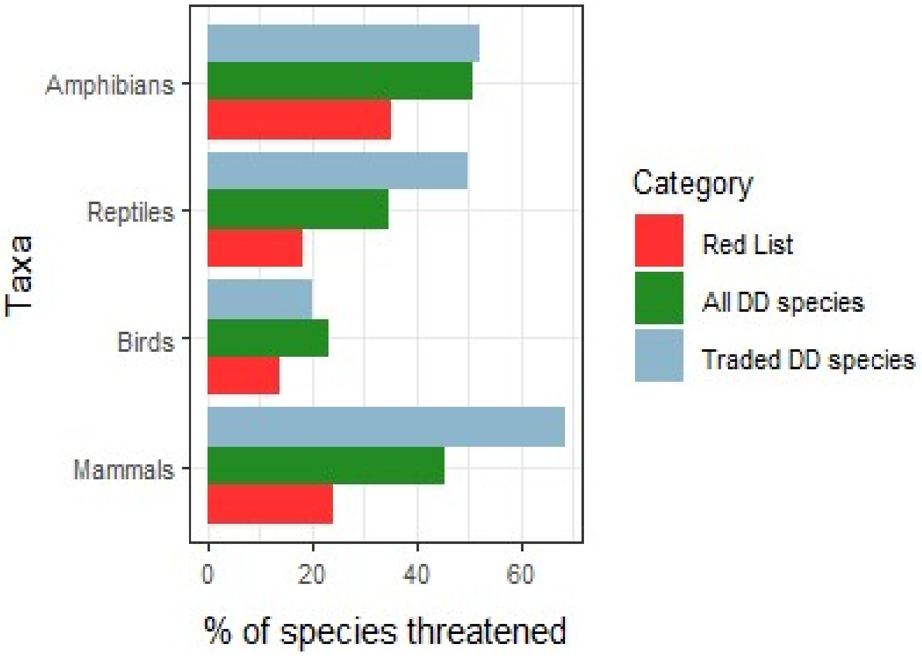

Fig 2. The proportion of species of amphibians, reptiles, birds, and mammals, currently categorised as threatened in the Red List (red bars), in all DD species recategorised between 2007 and 2021 (green bars), and traded DD species recategorised in the same timeframe (blue bars).

2.3.2 Data gaps in traded DD species

Hughes et al. (2021) listed 39 species as DD in their 2021 publication. At the time of writing, 21 are still classified as DD, 7 are now Highly Threatened (CR or EN), 1 NT and 10 LC. The remaining species, *Scaphiophryne verrucosa*, is considered a synonym of *S. obscurata* so was excluded from any further analysis. Marshall et al. (2020) listed 110 traded squamate reptile species as DD in their 2020 publication. At time of writing, 96 are still DD, 9 are now Threatened, 1 NT, and 4 are LC. I identified nine bird and 39 mammal species subject to trade currently categorised as DD using the Scheffers et al. (2019) dataset. I used the current Red List categories for amphibians and reptiles; hence the total number of terrestrial vertebrate DD species currently traded is 165.

The tropical regions (Afrotropical, Indo-Malayan, and Latin America) contain the vast majority of DD traded species, with Oceania and Palearctic regions only notable for having traded reptiles (Fig 3a). Unsurprisingly, habitat is dominated by forest, which contains 100 (60.0%) species (Fig 3b). Grassland/savannah was the second most common, with 24 (14.5%), and habitat is unknown in 17 species (10.3%). Habitat loss threatens nearly half of species (44.2%) although a similar number (38.2%) have no threat information available (Fig 3c). Invasive species and disease are currently known to be a threat to only 4 traded DD species.

The population status is listed as unknown for 133 species (80.6%), with 26 (15.8%) decreasing and 6 (3.6%) stable. This data gap is not always highlighted in the rationale for listing a species as DD in the Red List assessment, with population status only featuring in the rationale for 85 species (Table 1). Uncertain distribution is listed in the rationale most frequently (130 species) followed by threats (98 species). Taxonomy uncertainties and lack of specimens feature for 39 (23.6%) and 29 (17.6%) species respectively.

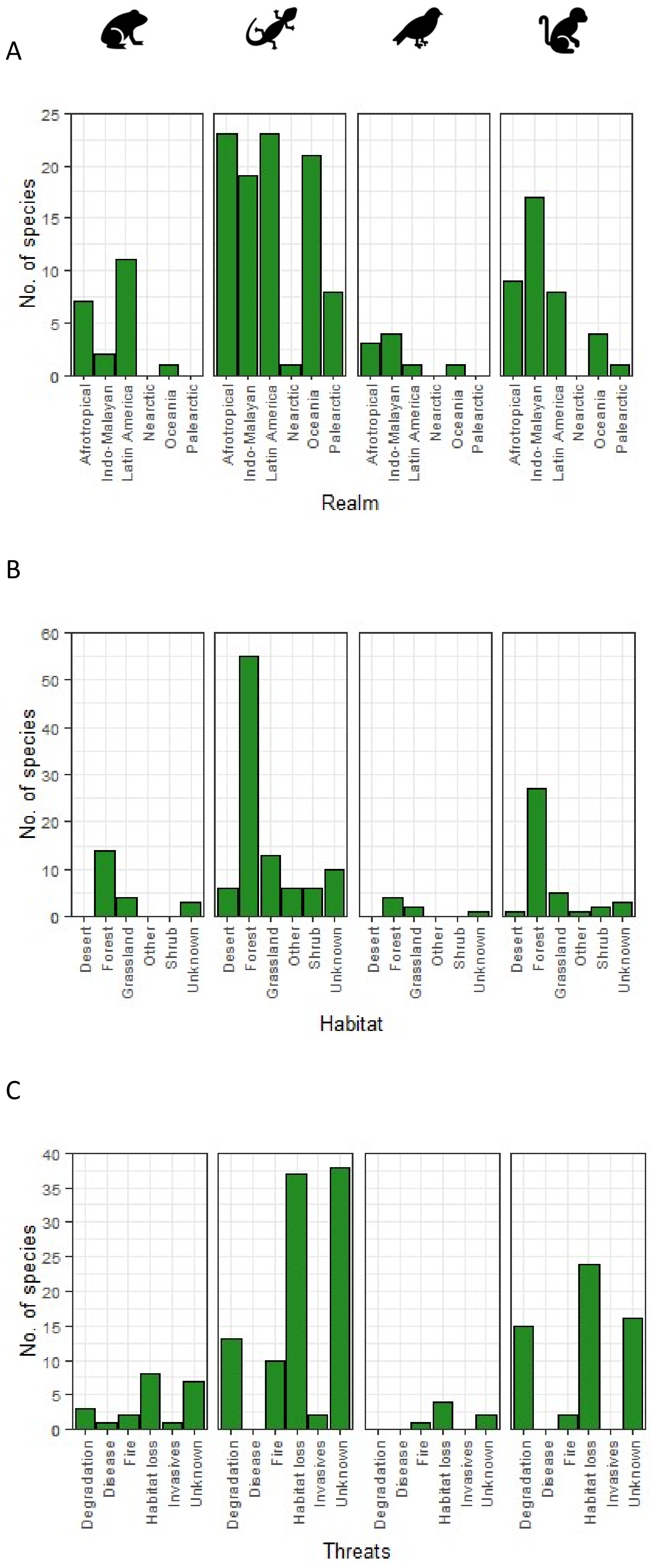

Figure 3. The distribution, habitat, and threats of DD traded species of amphibians, birds, mammals, and reptiles. A) the location of traded DD species by geographical realm B) the habitat of traded DD species. C) the known threats facing traded DD species. Species with unknown, or no known threats, are represented in ‘unknown’.

Table 1. The data gaps as listed in the ‘rationale’ section of Red List assessments for numbers of traded Data Deficient species of terrestrial vertebrates. Trade status was determined using datasets of Scheffers et al. (2019) for birds and mammals, Hughes et al. (2021) for amphibians, and Marshall et al. (2020) for reptiles. Red List status was determined using Red List assessments.

Taxa	**Taxonomical**	**Population status**	**Distribution**	**Ecology**	**Threats**	**Lack of specimens**
Amphibians (total n = 21)	9	20	18	21	6	0
As %	*42.9%*	*95.2%*	*85.7%*	*100%*	*28.6%*	*0%*
Birds (total n = 9)	0	6	8	1	3	5
As %	*0%*	*66.7%*	*88.8%*	*11.1%*	*33.3%*	*55.5%*
Mammals (total n = 39)	11	22	32	25	22	6
As %	*28.2%*	*56.4%*	*82.1%*	*64.1%*	*56.4%*	*15.4*
Reptiles (total n = 96)	19	37	72	38	67	18
As %	*19.8%*	*38.5%*	*75%*	*39.6%*	*69.8%*	*18.8%*
Total species	**39**	**85**	**130**	**85**	**98**	**29**
As %	***23.6%***	***51.5%***	***78.8%***	***51.5%***	***59.4%***	***17.6%***

2.3.3 CITES listings of DD species

There are six species of amphibian currently assessed as DD, and present on CITES according to Hughes et al. (2021). All six were formerly included under the genus *Dendrobates* in 1987, and are now listed under the genera *Ameerega, Andinobates, Epipedobates,* and *Ranitomeya* following nomenclature changes adopted at COP16 (Fig 4). The 15 species of DD reptiles on

CITES according to Marshall et al. (2020) are mostly included in genus listings. I could not find two species, *Boiga wallachi and Hydrophis melanocephalus* on any CITES appendices despite looking under known synonyms and relevant genus listings, including Species+ (*Species+*, 2023). One reptile species features under a family listing (*Simalia boeleni*, under Pythonidae) and the remaining 12 species feature under their relevant genus listing. There are only three traded DD birds on CITES, with two falling under order listings (Accipitriformes and Strigiformes) and the other under the family Trochilidae. The traded DD mammals feature in four different taxonomic levels – *Mazama temama* is included only at sub-species level, *Mazama temama cerasina* and only in Appendix III. *Pudu mephistophiles,* the smallest deer in the world (Bubenik *et al.*, 2000), is the only currently traded DD terrestrial vertebrate species to be listed at species level. Five other DD mammals feature under genus listings, and four under order listings.

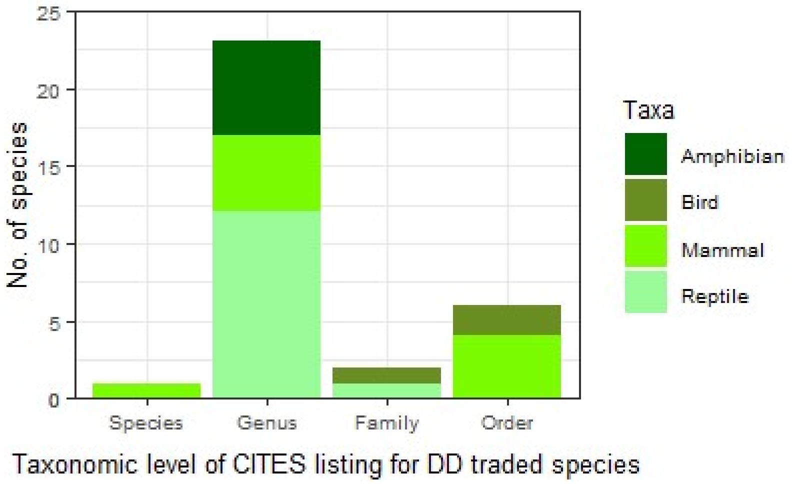

Figure 4. The currently traded DD species listed in CITES appendices. The total number of species is 33 (13 reptiles, 11 mammals, six amphibians, and three birds).

2.4 Discussion

2.4.1 Reclassified DD species

This is the first analysis of all DD species and their subsequent Red List assessed extinction risk, and the results support studies (Howard and Bickford, 2014; Bland *et al.*, 2015; Jetz and Freckleton, 2015; González-del-Pliego *et al.*, 2019; Borgelt *et al.*, 2022; Caetano *et al.*, 2022) that suggest DD species are likely to be more threatened than their fully assessed counterparts. The 50.5% of DD amphibians that have been reclassified as threatened is significantly less than two predictions of 85% (Borgelt *et al.*, 2022) and 63% (Howard and Bickford, 2014) of DD species but is almost identical to one prediction of 47% (González-del-Pliego *et al.*, 2019). Two studies have comparable estimates of the proportion of threatened DD mammals of 61% (Borgelt *et al.*, 2022) and 64% (Bland *et al.*, 2015), both considerably higher than the 45.3% identified here. Conversely, the 34.7% of DD reptiles reclassified as threatened is higher than the predictions of 19% (Bland and Böhm, 2016) and 29% (Caetano *et al.*, 2022), but lower than another estimate of 59% (Borgelt *et al.*, 2022), and recategorised birds outperformed the prediction of 14% (Butchart and Bird, 2010) with 23% of DD species now threatened.

Despite these inconsistencies, my overarching finding concurs with these studies: a substantial proportion of DD species are likely to be threatened with extinction, and this has a considerable impact on the ratios of threatened species. If the percentages of reclassified DD species are applied to the number of current DD species, this equates to 43% of amphibians, 23.4% of reptiles, and 30.3% of mammals now being threatened or extinct, an increase of 7.7%, 5%, and 6.4% respectively (birds see no change due to the low number of

DD bird species). It also means around 1483 threatened species are potentially being excluded from conservation action and funding.

2.4.2 Reclassified traded DD species

The future appears even more gloomy for traded DD species. My results indicate that this subset of DD species faces a higher risk of extinction than DD species as a whole, particularly reptiles and mammals. Whilst the level of exploitation of these species is unknown, results suggest that merely being present in trade increases the threat risk to DD species, supporting the premise that wildlife trade is a driver of extinction risk (Scheffers *et al.*, 2019). The assessed data gaps do not present an alternative explanation; although 60% of traded DD species are forest-dwelling, this is likely to be the case for DD species as a whole, given that most terrestrial biodiversity inhabits forest (Watson *et al.*, 2018). Nor does habitat loss explain the higher threat risk, as this too will affect the entire group of DD species to the same degree.

Fortunately, this increased extinction risk likely only affects around 56% of the 165 traded DD species, a figure overshadowed by the hundreds of threatened species affected by trade (Scheffers *et al.*, 2019; Marshall, Strine and Hughes, 2020; A. C. Hughes, Marshall and Strine, 2021). But it also presents a realistic opportunity to prioritise DD species data collection. Traded DD species with recent sightings could be a priority, to minimise fruitless efforts to locate specimens and to gain some ‘quick wins’. Those known to be threatened with habitat loss should also be a priority, given this remains the number one driver of biodiversity loss (Maxwell *et al.*, 2016), and the combined threats of habitat loss and wildlife trade can significantly increase extinction risk (Symes *et al.*, 2018). Time restrictions did not permit me to analyse any overlaps in the ranges of traded DD species but if they exist, they could also present an opportunity to maximise time efficacy in collecting data. And if Red List assessments could employ justification tags for DD species, as recommended by Bland et al. (2017), this would enable researchers to quickly identify knowledge deficiencies and relevant research actions. A focus on a species' distribution – the most prevalent knowledge gap for traded DD species – could also provide input on population status and key threats, and this should be the focus of research efforts. Whilst conservation funding is limited in the tropics (Reed *et al.*, 2020) (where most traded DD species are located), embracing local ecological knowledge would be a cost-effective method of data collection.

2.4.3 Limitations

I identified three limitations with my results. Firstly, there were not enough DD birds recategorised to draw reliable conclusions regarding the threat status for DD birds, and especially traded DD birds. Given that only 46 species of bird are currently categorised as DD, and only nine of those are traded, this limitation has little practical consequence for this taxon. Secondly, around a third of DD mammal species reclassified were lemurs, which are endemic to Madagascar, a country notorious for historical and ongoing deforestation, and this may have influenced the resulting threat ratio. Lemurs represent 15 of the 41 traded DD species that were recategorised, and 14 of those were reclassified as threatened. If I exclude lemur species from the analysis, 14 mammal species from 26 are now threatened, which reduces the proportion of threatened species to 53.8%. This is still higher than recategorised DD mammals as a group with 45.3%, and neither reptiles or amphibians are dominated by a species group and maintain the pattern of a higher extinction risk for traded

DD species. Finally, I am unaware whether any DD species were prioritised for improved knowledge prior to Red List reassessment, which could bias the results. Those considered to be facing a higher extinction risk could have been targeted, in order that they be afforded a priority conservation status. That said, it is also entirely possible that DD species with larger ranges and those with few data gaps were prioritised to reduce the DD numbers, and this could result in more species being assessed at a lower risk of extinction. Overall, the results are sufficiently robust to determine that DD species, particularly traded DD species, face a higher extinction risk than their fully assessed counterparts.

2.4.4 Traded DD species on CITES

The presence of traded DD species on CITES at various taxonomic levels suggests that being DD is not a barrier to accessing international protection against excessive trade. This is particularly evident for the mammal *Pudu mephistophiles*, a species listed in its own right despite being assessed as DD. That said, most traded species feature under a genus listing, so other DD species proposed for CITES in due course may have to rely on others in its genus being affected by trade to benefit from CITES protection.

Only 33 from 165 DD traded species (20%) are currently listed on CITES. As 56.2% of traded DD species may be threatened, around 75 traded species currently DD but potentially threatened are not afforded CITES protection. It is possible that levels of trade in these species are sustainable but approximately half could be highly threatened (CR or EN) and traded without international regulation. This adds weight to my argument for prioritizing traded DD species for research efforts over non-traded DD species.

2.5 Conclusion

Current knowledge gaps make it impossible for Red List assessors to determine the extinction risk of many species, which are placed into the Red List category Data Deficient. Previous studies have predicted that DD species are likely to be more threatened than their fully assessed counterparts, and my assessment of DD species that have been reclassified in the Red List between 2007 and 2021 support their findings. Overall, almost half those DD species are now threatened, which is double the proportion of threatened species of assessed amphibians, birds, reptiles, and mammals.

DD species which feature in wildlife trade have an even higher risk of extinction than DD species as a whole, and 80% do not benefit from international trade regulation via CITES. Many traded DD species are also threatened with habitat loss, and we risk losing these species to anthropogenic pressures before we have the chance to employ suitable conservation actions. Research efforts directed at filling DD species data gaps should focus on traded species in the tropical biome, and utilise local ecological knowledge to maximise data gains. With the Sixth Mass Extinction already underway, swift action to understand and protect traded DD species is vital.

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Chapter 3

Wildlife species predicted for future trade: biological knowledge gaps and CITES eligibility

3.1 Introduction

The IUCN Red List of Threatened Species (hereafter the ‘Red List’) is a global, widely used measure of extinction risk (Rodrigues *et al.*, 2006; Barnosky *et al.*, 2011). Red List assessments use knowledge of a species, such as distribution and population size, but also any known or potential threats to their survival (Mace *et al.*, 2008). One significant driver of extinction risk for thousands of species is overexploitation for subsistence and trade, and demand for wildlife products and pets has propelled many species to the brink of extinction. For instance, the Malaysian Giant Turtle and Brown Spider Monkey, both Critically Endangered, are highly sought after for meat, medicinal use, and the pet trade (IUCN, 2018, 2020a). Charismatic species such as the tiger (*Panthera tigris*) also suffer impacts of trade, with local population extinctions in Vietnam, Cambodia and Laos PDR due to poaching for skins, bones, meat, and organs (IUCN, 2021). This big cat now occupies only 7% of its historical range and its population has halved in little over 20 years (IUCN, 2021). This dramatic decline in population size appears to be mirrored in other traded species too, with one recent report of abundance of mammals, birds, and reptiles declining by 61% due to wildlife trade (Morton *et al.*, 2021b).

The scale of trade is vast, impacting species across the animal and plant kingdoms. One recent study indicates 7638 (24%) terrestrial vertebrate species are subject to trade (Scheffers *et al.*, 2019) and this is likely an underestimate (Marshall, Strine and Hughes, 2020; A. Hughes, Marshall and Strine, 2021). In the 40 year period to 2014, the volume of reported legal trade quadrupled to 100 million individual organisms (Harfoot *et al.*, 2018). Up to 1.1 million pangolins (Family: Pholidota) are now hunted and sold across Central Africa alone (Ingram *et al.*, 2018). And the global reach of trade is projected to grow by over 50%, affecting a further 4064 species of terrestrial vertebrates (Scheffers *et al.*, 2019). If the current pattern of around 25% of Threatened species being traded (Scheffers *et al.*, 2019) continues, this will equate to over 2900 species of mammals, birds, amphibians, and squamate reptiles threatened with extinction being traded.

One international trade mechanism to safeguard endangered species is the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). Adopted at national level almost universally, CITES provides a regulatory framework that prohibits (species listed in Appendix I) or regulates (species listed in Appendix II) trade in species worldwide. For a species to be added to an Appendix, a Party (or Parties) must submit a Proposal, which is then considered at a Conference of the Parties but certain biological and trade information is required before global CITES protection can be considered. Although 2.3 million species, or 25% of the estimated total number on Earth (Mora *et al.*, 2011) have been formally described (Bánki *et al.*, 2023) we often know very little about these ‘known species’. Knowledge gaps for geographic ranges, abundance, species’ traits, and abiotic tolerances are just some of the ‘biodiversity shortfalls’ befalling many known species (Hortal *et al.*, 2015; Diniz Filho *et al.*, 2023) and these data can take years to accumulate, hindering conservation action and accurate prediction of species’ extinction risk (Whittaker *et al.*, 2005; Bini *et al.*, 2006)

These knowledge gaps may create a challenge in protecting many species that may become threatened through trade; if the biological criteria for CITES Appendcies I and II is not met, the international trade of these species cannot be regulated and monitored. Here , I look at the gaps in knowledge of species predicted to become impacted by trade using two families as case studies. I review the current knowledge for Alsodidae (Spiny-chested frogs), a family of amphibians from South America, and Gerrhosauridae, or plated lizards, distributed across Madagascar and sub-Saharan Africa, against the CITES biological criteria, and determine, for each species, if there is sufficient information for each to be considered for listing on CITES Appendix I or II.

3.2 Methods

3.2.1 Selection of sample taxa families

Scheffers et al. (2019) predicted between 405 and 4064 terrestrial vertebrate species (amphibians, squamate reptiles, mammals, and birds) would become impacted by wildlife trade using four assessment schemes: body size, existing highly traded families, phylogenetic similarity to conspecifics, and evolutionary distinctiveness. The strongest predictor by far across taxon was phylogenetic similarity, which suggested 367 species at risk of trade with a >95% probability, and 3691 species with >90%. As this accounts for the vast majority of species strongly predicted to become impacted by trade, I used phylogenetic similarity to existing traded species to select the two sample families to review.

Birds and mammals are both relatively well-studied and already feature heavily in CITES appendices, and only 0.4% Red List assessed bird and 14% assessed mammal species are classified as Data Deficient (DD). I also considered it more likely that publications would use the scientific names of amphibians and reptiles, so searches for literature would be more comprehensive. I thus narrowed the selection of sample families to reptiles and amphibians.

In the Scheffers et al. (2019) dataset, each species predicted to become impacted by trade based on phylogenetic similarity had a probability value between from 0.266 to 0.995. I filtered out species with a probability of less than 0.75 as if the predictions hold true, the 'lower probability' species are less likely to appear in trade. I then grouped the remaining species by family, resulting in seven amphibian and eight reptile sample families. I consulted AmphibiaWeb (*AmphibiaWeb*, 2023), The Reptile Database (*The Reptile Database*, 2023), and the Scheffers et al. (2019) datasets of 'traded' and 'at risk of trade' to establish for each family 1) how many species there are, 2) how many species are at risk of trade, and 3) how many species are already traded. I also consulted the CITES Appendices and Species+ (*Species+*, 2023) to see if any species in the fifteen families are already listed. I discounted any families with over approximately one hundred species as time constraints would have prevented a thorough literature review of families this size. I also discarded families with more than ~ 5 - 10% species already traded as existing trade could bias research focus. This left three potential amphibian and five reptile families.

I then consulted The Reptile Database and the IUCN Red List to establish the geographical distribution of these eight families and discarded one reptile family distributed in Australia and Papua. This was because Australia has strict controls over import and export of wildlife and therefore could bias any analysis. I then consulted the IUCN Red List to establish how many species in the remaining families were Threatened (categorized as Critically Endangered, Endangered, or Vulnerable) or DD. I discarded any families with less than ~10% or more than ~ 25% of species categorized as DD, and families with less than ~15% or more than ~50% Threatened. This was to ensure my sampled families represented the overall proportion of Threatened species (16.7% of squamate reptiles, 34.8% amphibians) and DD species (14.9% squamate reptiles, 15.3% amphibians) in both taxa (*The IUCN Red List of Threatened Species*, 2023). This left only one amphibian family, Alsodidae. I wanted to study families with different geographical distributions to evaluate any impact this had on data currently available, so I discarded one of the remaining two reptile families. This left Gerrhosauridae as my sample reptile family.

3.2.2 Literature review

For Alsodidae, I reviewed publications retrieved from Web of Science, SciELO and Google (including Google Scholar) using keywords 'Alsodidae' and the names of the three genera, *'Alsodes', 'Eupsophus'*, and *'Limnomedusa'.* For Gerrhosauridae, keywords were 'Gerrhosauridae' and the seven genera names *'Zonosaurus', 'Tracheloptychus', 'Gerrhosaurus', 'Tetradactylus', 'Matobosaurus', 'Cordylosaurus'*, and '*Broadleysaurus'*. I included publications dated 1973 onwards as my review focuses on what is currently known about the sample families. References from included publications were cross checked with search results to ensure no relevant documents were omitted. I downloaded Red List Assessments for all species and cross-checked the Red List bibliographies of each species, and data retrieved from AmphibiaWeb and The Reptile Database, with search results. I excluded theses to avoid duplication with subsequent published scientific articles, and all generic websites such as Wikipedia and Animaldiversity.org.

I read all publications, with any written in Spanish translated using translation software. I used Excel to create a database and recorded the year of publication, location of lead author, location of study if the publication was field-based, and the species involved. I defined six broad research categories and identified which category or categories each publication addressed (Table 1). I recorded topics of publications that did not fall into any of the six defined research areas in the field 'Notes.' I also used this field to record the publication topic more specifically. For example, if a study was listed as addressing 'Distribution' and 'Threats' and it described a new locality for a species and identified the upcoming hydroelectric dam as a threat, this detail was recorded in 'Notes'. I also recorded anything else I considered relevant in 'Notes', for example if the paper described a new species, or disputed previous findings. If a publication addressed more than one topic, all topics were recorded. For instance, if a study surveyed herpetofauna species in a particular area and described those species' morphology and where they were found, I recorded that study as being relevant to 'Ecology', 'Physical Biology', and 'Distribution'. Similarly, if a publication covered multiple species, all species were recorded. If a study focused on the entire family or order, I recorded this as 'All Alsodidae', 'All Gerrhosauridae' or 'All'. I excluded any 'All' publications when calculating the number of publications per species.

I quantified the number of publications in each category for each species in my database using R version 4.2.2 (R Core Team, 2022). I downloaded Red List assessments for Alsodidae on 10th July 2023 and Gerrhosauridae on the 21st September 2023 , extracted population size and trend data, and cross-referenced with publications that were categorized in “Population”. I quantified species specific threats from my own dataset and Red List assessments using keyword search terms in R, such as “deforest”, “fire”, “agricult”, and “pollution”. I used multiple search terms to determine specific threats, for example, for infrastructure, keywords “infrastructure” “dam”, “hydro”, “development”, “urban”, and “road”, and all results checked to ensure they were correct.

3.2.3 Application of CITES criteria

The CITES biological criteria for listing a species in Appendix I or IIa was extracted from the Convention. I then condensed it into four broad categories: population size, decreasing population trend, restricted distribution, and decreasing habitat area or quality. This was because these factors are intertwined in all three of the criteria. For example, criteria A can be met if the wild population is small, and characterised by a decline in the area or quality of habitat. The criteria are available in full in Appendix 1 to this thesis. I then applied the data in the reviewed literature to a) establish if data existed for each of the four categories for each species, and b) if data did exist, whether the species was potentially eligible for listing on CITES Appendix I or II.

3.3 Results

For Alsodidae, the Web of Science search yielded 114 results, and Google scholar a further 64 documents after removing duplicates. A search of SciELO provided no additional publications. Analysis of references in the 178 publications, and the Red List bibliographies, provided a further six relevant documents. The number of publications I reviewed was thus 184. Of these, 169 (92%) were journal articles, seven (4%) were book sections or chapters, three (2%) newsletter articles, and the remaining 2% comprised two conservation assessments/strategies, one Ministry of Environment publication, one National Red List proposal, and one field guide. Twenty-six (14%) were written in Spanish, all others in English. The Gerrhosauridae search produced 52 results on Web of Science and 98 on Google Scholar. There were no results on SciELO but references in publications provided a further 13 documents. Of the total 163 publications, 155 (96%) were journal articles, and the remaining 4% comprised of three book sections, two biodiversity assessments, and one unpublished independent study project. All publications were in English. The full list of publications reviewed for both families is available at Appendix 2 to this thesis.

There are currently 30 known species in the Alsodidae family: 19 in the genus *Alsodes*, 10 in the genus *Eupsophus* and a single species in the genus *Limnomedusa*. The IUCN Red List has assessed 29 species; it currently lists 30 although this includes *Eupsophus queulensis*, which was synonymized with *E. septentrionalis* in 2018 (Suarez-Villota *et al.*, 2018). *E. altor,* described in 2012, has not yet been assessed (it was synonymized with *E. migueli* in 2017 (Correa *et al.*, 2017) but revalidated as a distinct species in 2018 (Suarez-Villota *et al.*, 2018)). AmphibiaWeb lists 26 species, adopting the taxonomy of Correa et al. (2017). Half of the 30 recognised species have been discovered since 1978, five in the last 20 years (*AmphibiaWeb*, 2023). Three species could be considered *nom inquirenda* as their taxonomic validity is unclear, all Red List assessed as Data Deficient (*A. monticola, A. australis*, and *A. vittatus*). *A. monticola* was described in 1842 but has not been observed or collected since, with the species only being known from a desiccated specimen (Formas, Nunez and Cuevas, 2008). Similarly, *A. vittatus* was described in 1902 and has not been collected since (Cuevas and Formas, 2005; IUCN, 2015). Finally, *A. australis* is currently accepted but is potentially a synonym for *A. coppingeri* (Blotto *et al.*, 2013). Twenty-eight species are distributed in Chile, twenty-three are endemic only to Chile. Seven are distributed in Argentina although only one (*Alsodes neuquensis*) is endemic to Argentina. The sole representative of the *Limnomedusa* genus, *L. macroglossa*, is distributed in Argentina, Brazil, and Uruguay. The distribution is reflected in the location of the lead author of publications, with 141 based in Chile, 29 in Argentina, six in Brazil, four in the USA, two in Uruguay, and one in China. The Red List categorizes 17 species as Threatened, one Near Threatened (NT), six Least Concern (LC), and six Data Deficient (Figure 1a).

The Gerrhosauridae contain 39 species although The Reptile Database does not currently recognise *G. intermedius* as a distinct species due to some uncertainty around its distinction from *G. nigrolineatus* since 2013 (Bates *et al.*, 2013; *The Reptile Database*, 2023). In contrast to *Alsodidae*, only seven species (17.9%) have been discovered since 1978, two in the last 20 years. *Z. boettgeri* was rediscovered in 1993, over 100 years since the holotype was described (Raselimanana, Nussbaum and Raxworthy, 2006). There are currently seven genera of Gerrhosauridae: *Zonosaurus* (17 species) and *Tracheloptychus* (two species) are endemic to Madagascar and the Seychelles; and *Gerrhosaurus* (eight species), *Matobosaurus* (two species), *Tetradactylus* (eight species), *Cordylosaurus* (one species), and *Broadleysaurus* (one species) are located in mainland Africa. Also in contrast to Alsodidae was the location of the lead author, with the majority not based in species' range countries. Europe and the UK represented 60 of the published papers (36.8%), USA 45 (27.6%), South Africa 24 (14.7%), Madagascar 11 (6.7%), mainland Africa nine (5.5%) and the remaining 11 (6.7%) from the rest of the world. There are only two taxonomic points of note. The genus *Anglosaurus* (containing one species, *Anglosaurus skoogi*) was synonymised with *Gerrhosaurus* in 2003 (Lamb *et al.*, 2003), and ten years later, the genera *Broadleysaurus* and *Matobosaurus* were erected for *G. major* (*Broadleysaurus*), and *G. validus* and *G. maltzahni (Matobosaurus)* on discovery of their divergent lineage from *Gerrhosaurus* (Bates *et al.*, 2013). All 39 species have been Red List assessed with seven Threatened species, three NT, 27 LC, and one DD. The single DD species, *Z. maramaintso*, may be a colour variant of *Z. boettgeri*, and its habitat requirements remain unclear (Glaw and Vences, 2007; IUCN, 2011).

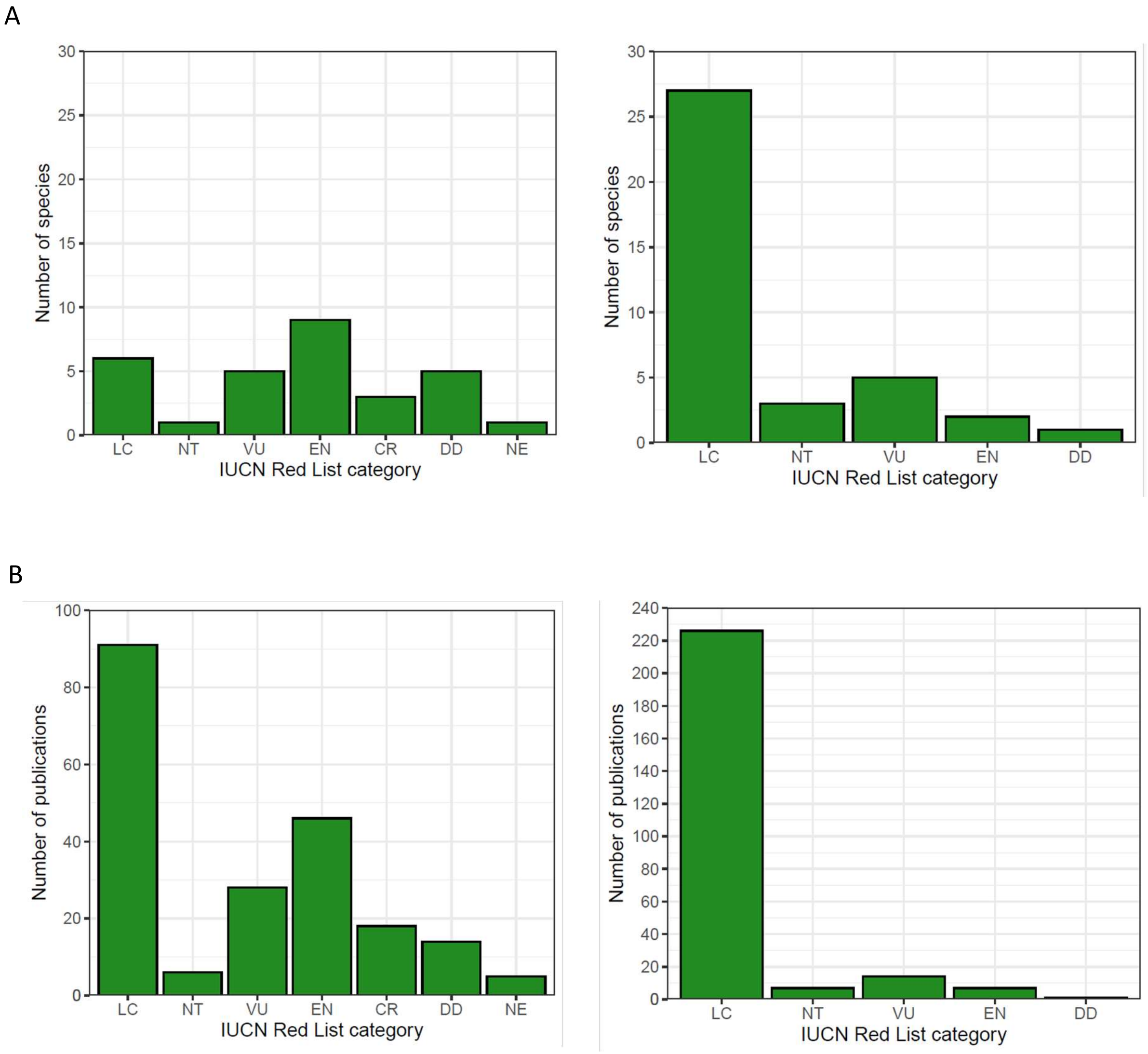


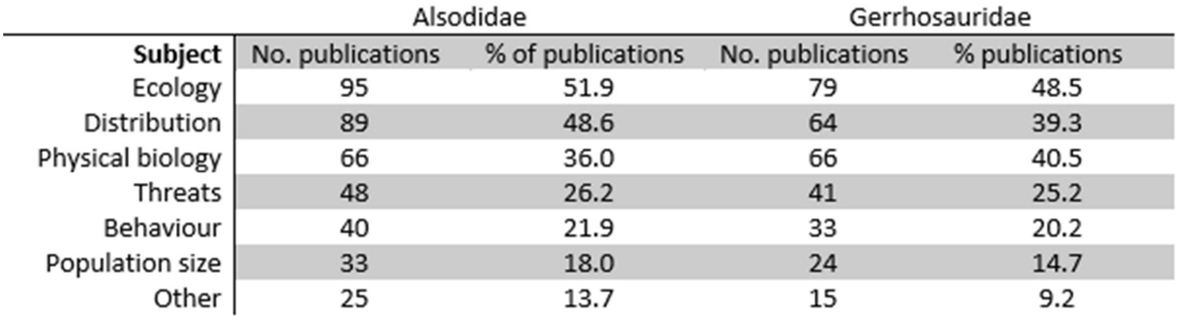
Figure 1. A) The number of species in Alsodidae and Gerrhosauridae in each IUCN Red List category. B) The number of publications for species of Alsodidae and Gerrhosauridae by IUCN Red List category.

Of the 183 publications for Alsodidae, ecology was the topic most widely included with 95 publications (51.9%) that provided data (Table 1) then species' distribution with 89 (48.6%). In both cases, this was often just a basic description of the habitat or location where a specimen had been collected for a study on another topic. Similarly, the 66 publications

(36.1%) that covered physical biology included those that made general observations of a specimen's phenotype or morphology. Of the 48 publications (26.2%) that mentioned or described threats, only 11 (6%) studied those threats directly. Three threat topics (diseases such as chytrid, impacts of climate change, and the threat from exotic or invasive species) were each the subject of three publications. A total of 25 publications (13.6%) only covered topics that are not directly relevant to the biological criteria required for listing a species on CITES, such as taxonomy, immune responses, genetics, and parasites. *Eupsophus calcaratus* was the most studied species with 27 publications, and three species were included in only one publication (Figure 2). The mean number of publications per species was 5.3.

Ecology was also the most widely covered topic for the Gerrhosauridae family, with 79 publications (48.5%) contributing information, which included surveys of disturbed habitats, such as logged forest and plantations, as well as protected nature reserves (Table 1). Physical biology was included within 66 publications (40.5%), although this was often just a description of a specimen found in a survey. Of the 163 publications, 20 (12.3%) studied at genus level or higher, and 15 publications covered topics such as evolution and phylogeny. The number of publications per species ranged from 35 (*Broadleysaurus major*) to 0 (*Tetradactylus fitzsimonsi*) (Figure 2). The Malagasy species had a mean of 6.16 papers per species, and species distributed in mainland Africa 8.32. The mean number of papers per species overall was 7.0.

Table 1 The number of publications for Alsodidae and Gerrhosauridae by subject area



	Alsodidae		Gerrhosauridae	
Subject	No. publications	% of publications	No. publications	% publications
Ecology	95	51.9	79	48.5
Distribution	89	48.6	64	39.3
Physical biology	66	36.0	66	40.5
Threats	48	26.2	41	25.2
Behaviour	40	21.9	33	20.2
Population size	33	18.0	24	14.7
Other	25	13.7	15	9.2

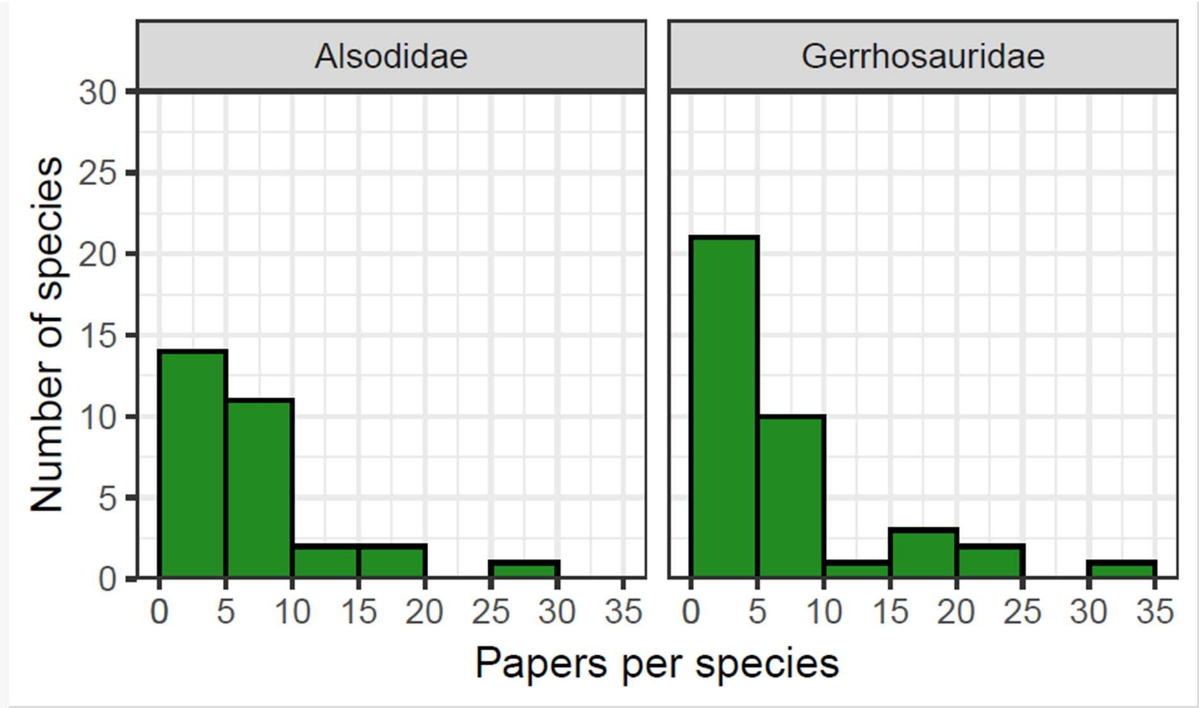


Figure 2. The number of species with number of publications.

CITES biological criteria for Appendix I and Appendix IIa

3.3.1 Population size and trends

The physical population size for Alsodidae is, unsurprisingly, unknown in all species but is often categorized in Red List assessments using terms such as ‘common’, ‘abundant’, ‘uncommon’ and ‘rare’ (Fig. 3). Some DD species do have some population size data, for example the Red List assessment for *E. septentrionalis* states *‘Nineteen specimens were reported in the original description’*, and *‘it is considered a rare species given that is found in low densities’* (IUCN, 2008). Six species have little data available for population size; two have not been seen for over 100 years (*A. monticola and A. vittatus*), and one, *E. altor*, is yet to be assessed. A number of publications described or studied the population declines of amphibians at national (e.g., Ubeda and Grigera 2007, Kacoliris et al. 2022) or global levels (e.g., Catenazzi 2015) but only one paper (Corbalán, Debandi and Martínez, 2010) directly calculated the population size of a species, *A. peuhenche*. The population trend has been Red List assessed in fourteen species as decreasing, four are stable, and eleven are unknown (Fig 3). Of the eleven unknown species, six are Data Deficient, and one is the synonymized *E. queulensis*. The remaining species of unknown population trend are *A. cantillanensis* (CR), *E. contulmoensis* (EN), *A. tumultuosus*, and *A. hugoi* (both VU).

Population size data is similarly sparse for Gerrhosauridae, with nine species having ‘no information available’ on Red List assessments (Fig. 3). Seven of the nine are located in Madagascar but 17 of the 19 Madagascan species were assessed in 2010 or 2011, and my review unearthed nine publications dated 2011 or later that contributed population size data

(Conradie *et al.*, 2011; D'cruze and Kumar, 2011; Durkin, Steer and Bell, 2011; Rakotondravony and Goodman, 2011; Robinson and Barrows, 2013; Conradie, Bills and Branch, 2016; Blumgart, Dolhem and Raxworthy, 2017; Nopper *et al.*, 2017; Manhice, Simões and Zondane, 2020). Combined with personal communications that are often included within Red List assessments (e.g., *Tracheloptychus madagascariensis*), there may now be more information on population size available for the nine currently 'unknown population' species. The remaining species have populations ranging from 'widespread range and abundance' through to 'rarely observed'. Obtaining accurate population data for *T. udzungwensis* is challenging; it is only known from one locality, where it occurs alongside *T. ellenbergeri* and the two species are indistinguishable in the field (Salvidio *et al.*, 2004; IUCN, 2014). The 24 publications contributing population size data were largely surveys of areas with an indication of abundance for each species found there. There were also surveys of disturbed habitats (e.g., logged forest, plantations) with species noted as present or absent. One publication estimated the population size of *Z. madagascariensis* on Cosmoledo atoll, Seychelles (Gerlach, 2006). The population trends have been Red List assessed as decreasing in 10 species, stable in 16, unknown in 12, and one species (*T. eastwoodae*) is considered extinct. The 12 species with unknown population trend are split equally between the Malagasy endemics and mainland species with six of each. Two species with unknown population trend are assessed as Threatened (*Z. quadrilineatus*, *Z. boettgeri*), one NT (*Z. haraldmeieri*), eight LC, and one DD (*Z. maramaintso*).

3.3.2 Distribution and fragmentation of populations

The distribution of all 29 Alsodidae species in Chile was updated in 2019 (Correa, 2019), and the Red List and Charrier (2019) also provided recent information on distribution. Only six species are considered widespread, or not having a restricted distribution (*A. nodosus, E. emiliopugini, E. calcaratus, E. vertebralis, E. roseus,* and *L. macroglossa*). Two species, *A. montanus* and *A. tumultuosus*, are known from 10 locations and the remaining 21 species are limited to five or fewer locations. Eight species are only known from the type locality area. Four species, *A. norae, A. coppingeri, A. cantillanensis,* and *A. hugoi*, are postulated to occur more widely than their currently known distributions (Charrier, 2019; *The IUCN Red List of Threatened Species*, 2023). The only species endemic to Argentina, *A. neuquensis*, has little data available (four publications) but the Red List assessment of 2017 states it is only present in Neuquén Province and '*all individuals are expected to occur within five or fewer threat-defined locations*' (IUCN, 2017a).

There were 64 publications with distribution data for Gerrhosauridae, with 75% dated in the last 20 years, and 47 (73.4%) reported results of biodiversity or herpetofauna surveys. As is the case for population size, data for 'range' on Red List assessments for 17 of the 19 Madagascar species may not be current. The 27 species assessed as LC either have a wide or restricted but unfragmented distribution, and the remaining 11 species (not including the extinct *Tetradactylus eastwoodae*) all have a restricted extent of occurrence and six have a severely fragmented population. Seven species (*Tracheloptychus petersi, Z. subunicolor, Z. boettgeri, Z. haraldmeieri, Z. quadrilineatus, Z. anelanelany,* and *Tetradactylus udzungwensis*) are known from 10 or less locations. The only DD species, *Z. maramaintso*, is currently only known from its type locality.

3.3.3 Decrease in area or quality of habitat

The habitat of Alsodidae is largely forest, with four of the 20 Alsodes species associated with other habitats, such as tundra or meadows (*A. peuhenche, A. monticola, A. tumultuosus,* and *A. montanus*). All nine members of the Eupsophus genus inhabit forest. Five forest species (*A. vanzolinii, A. barrioi, E. septentrionalis, E. roseus,* and *E. nahuelbutensis*) have been found within or on the border of exotic plantations (usually *Pinus* spp.) Four other species are currently believed to tolerate slight habitat disturbance, for example from cattle ranching or firewood collection (*A. gargola, E. neuquensis, A. australis,* and *E. emiliopugini*). The Malagasy species of Gerrhosauridae largely inhabit forest, although some, such as *Z. laticaudatus* and *Z. madagascariensis*, are tolerant of disturbance and will utilise modified habitats. Two *Zonosaurus* species are arboreal (*Z. boettgeri* and Z. *maramaintso*). The species on mainland Africa inhabit a variety of habitats; the threatened *T. udzungwensis* is a grassland species, *G. skoogi* occurs in sand dunes, whereas other species are found in savannah, karst, and sometimes urban areas.

A total of 10 threat categories were identified (Table 2), with the literature providing a considerable additional amount of information to that set out in ‘threats’ in Red List assessments. Trade was excluded from threat analysis as this is covered separately (Fig. 3). The most prevalent threat to Alsodidae is habitat loss and degradation through deforestation and agriculture, affecting 23 species. Only two species, *A. vittatus* and *A. kaweshkari* (both

DD), currently have no known threats, and *E. migueli* faces the highest number of threats with eight. As with Alsodidae, habitat loss is the biggest threat for Gerrhosauridae, from deforestation, slash and burn agriculture, and urban expansion (Andreone *et al.*, 2003; D'cruze and Kumar, 2011; Tolley *et al.*, 2016; Nopper *et al.*, 2017; *The IUCN Red List of Threatened Species*, 2023). Habitat loss affects 27 species, and all Malagasy species except *Z. ornatus*. Ten of the mainland species have no known or significant threats according to the Red List assessments but habitat destruction is considerable in parts of the range of *T. africanus* (Bates and Agama, 2014) and *G. intermedius* (Farooq *et al.*, 2022). The arboreal *Z. boettgeri*, classified as VU in the Red List, has the highest number of threats with five.

Table 2. Threats to each species of Alsodidae and Gerrhosauridae sourced from IUCN Red List assessments (black Y) with additional threats identified in the literature review (red Y).

	Habitat loss/degradation										
Species	Deforestation	Agriculture	Fire	Pollution	Fragmentation	Tourist activities	Dams/ infrastructure	Climate change	Invasive/ exotic species	Disease	Total
Eupsophus septentrionalis	Y	Y	Y		Y					Y	5
E. queulensis	Y				Y						2
E. contulmoensis	Y		Y		Y	Y		Y		Y	6
E. nahuelbutensis	Y		Y		Y	Y		Y		Y	6
E. calcaratus	Y	Y	Y	Y				Y	Y	Y	7
E. migueli	Y	Y	Y		Y		Y	Y	Y	Y	8
E. insularis	Y	Y	Y			Y	Y	Y	Y		7
E. emiliopugini	Y		Y					Y			3
E. roseus	Y		Y		Y	Y		Y	Y	Y	7
E. vertebralis	Y		Y					Y			3
E. altor			Y		Y					Y	3
Alsodes monticola							Y	Y	Y		3
A. coppingeri			Y				Y		Y		3
A. gargola	Y	Y	Y				Y	Y	Y		6
A. neuquensis		Y							Y		2
A. cantillanensis	Y	Y	Y				Y	Y			5
A. nodosus	Y	Y					Y		Y	Y	5
A. barrioi		Y	Y			Y		Y			4
A. montanus				Y		Y	Y	Y	Y	Y	6
A. vanzolinii	Y	Y	Y		Y			Y			5
A. tumultuosus				Y		Y	Y	Y	Y	Y	6
A. australis									Y		1
A. hugoi		Y	Y				Y		Y		4
A. kaweshkari											0
A. pehuenche		Y		Y		Y	Y	Y	Y	Y	7
A. valdiviensis	Y		Y		Y		Y	Y	Y	Y	7
A. verrucosus	Y		Y		Y		Y	Y	Y		6
A. vittatus											0
A. norae	Y	Y			Y			Y	Y		5
A. igneus	Y		Y						Y		3
Limnomedusa macroglossa	Y	Y		Y			Y				4
Total	19	14	19	5	11	8	14	19	18	12	

Species	Deforestation	Agriculture	Fire	Pollution	Fragmentation	Tourist activities	Dams/ infrastructure	Climate change	Invasive/ exotic species	Disease	Total
Broadleysaurus major											0
Cordylosaurus subtessellatus							Y				1
Gerrhosaurus auritus											0
G. bulsi											0
G. flavigularis		Y	Y								2
G intermedius							Y				1
G. nigrolineatus											0
G. skoogi											0
G. typicus		Y					Y				2
Matobosaurus maltzahni											0
M. validus											0
Tetradactylus africanus	Y	Y					Y				3
T. breyeri		Y	Y								2
T. ellenbergeri		Y									1
T. fitzsimonsi		Y									1
T. seps											0
T. tetradactylus											0
T. udzungwensis		Y					Y				2
Tracheloptychus madagascariensis	Y	Y	Y								3
T. petersi	Y	Y									2
Zonosaurus aenueus	Y	Y	Y		Y						4
Z. anelanelany	Y	Y					Y				3
Z. Bemaraha		Y	Y								2
Z. boettgeri	Y	Y	Y		Y		Y				5
Z. brygooi	Y	Y							Y		3
Z. haraldmeieri	Y	Y	Y								3
Z. karsteni	Y	Y			Y						3
Z. laticaudatus	Y	Y									2
Z. madagascariensis	Y								Y		2
Z. maramaintso	Y		Y		Y		Y				4
Z. maximus		Y									1
Z. ornatus											0

Z. quadrilineatus	Y	Y									2
Z. rufipes	Y	Y									2
Z. subunicolor	Y	Y									2
Z. trilineatus	Y	Y									2
Z. tsingy	Y										1
Total	17	20	6	0	3	0	4	0	2	0	

3.3.4 High vulnerability to extrinsic or intrinsic factors

There is little information available on whether either Family are highly vulnerable to extrinsic factors. For Alsodidae, of the 30 species, fire and climate change (mainly prolonged drought) both potentially impact 19 species (Table 2). Introduced species, such as exotic salmonids and mink, are known or suspected to threaten 18 species. Diseases such as chytrid may threaten 12 species, with populations further north seemingly more affected (Soto-Azat *et al.*, 2013; Ghirardi *et al.*, 2014; Bacigalupe *et al.*, 2017) although not at all individuals testing positive showed any manifestations of the disease. Climate change could drive around a third of Gerrhosauridae species extinct by 2080 (Sinervo *et al.*, 2010) but no species are believed to be vulnerable to pollution or disease.

I found no publications highlighting any intrinsic factors that may make any Alsodidae species vulnerable. There were 21 publications that described or studied tadpoles or larvae and seven that featured diet data but none suggest high vulnerability. Five species are semi-aquatic or have a strong association with water, all of the Alsodes genus. There was similarly very little information on the vulnerability of Gerrhosauridae species to intrinsic factors. The first foraging data for the family was published in 1997 (Cooper, Whiting and VanWyk, 1997) and other than the high reliance of *G. skoogi* on plants (Pietruszka *et al.*, 1986), and to a slightly lesser degree *G. Validus* (Cooper and Vitt, 2002), there are very few data regarding diet, particularly any specialisms. Only one publication provided reproduction information, of *G. major*, and in this case was in captivity (Haagner and Morgan, 1992).

3.3.5 Other CITES criteria for Appendix I and Appendix IIa

I found no data regarding the geographical concentration of individuals during one or more life phases for either family, other than the reliance of five Alsodidae species on water. The published data gives no indication of any large short-term fluctuations in populations, or large fluctuations in distribution or number of sub-populations.

3.3.6 Appendix IIb - Physical 'lookalikes'

There is a high degree of morphological similarity across Alsodidae, with *Eupsophus* species extremely difficult to distinguish by morphological features alone (Charrier, 2019; Correa and Duran, 2019) (Fig 4). Many *Alsodes* species resemble each other in addition to sharing features with other genera, such as chest spines (*Insuetophyrnus, Telmatobufo* and *Telmatobius*) and a vertebral line (*Pleurodema*) (Charrier, 2019). The very thick forearms of *A. nodosus* has led to it having the nickname 'Popeye Toad' but other species across the family exhibit this characteristic (Charrier, 2019) and species differentiation appears based on genotypic and karyotypic analysis rather than any morphological features. There is also a high degree of morphological variability in many species (Charrier, 2019).

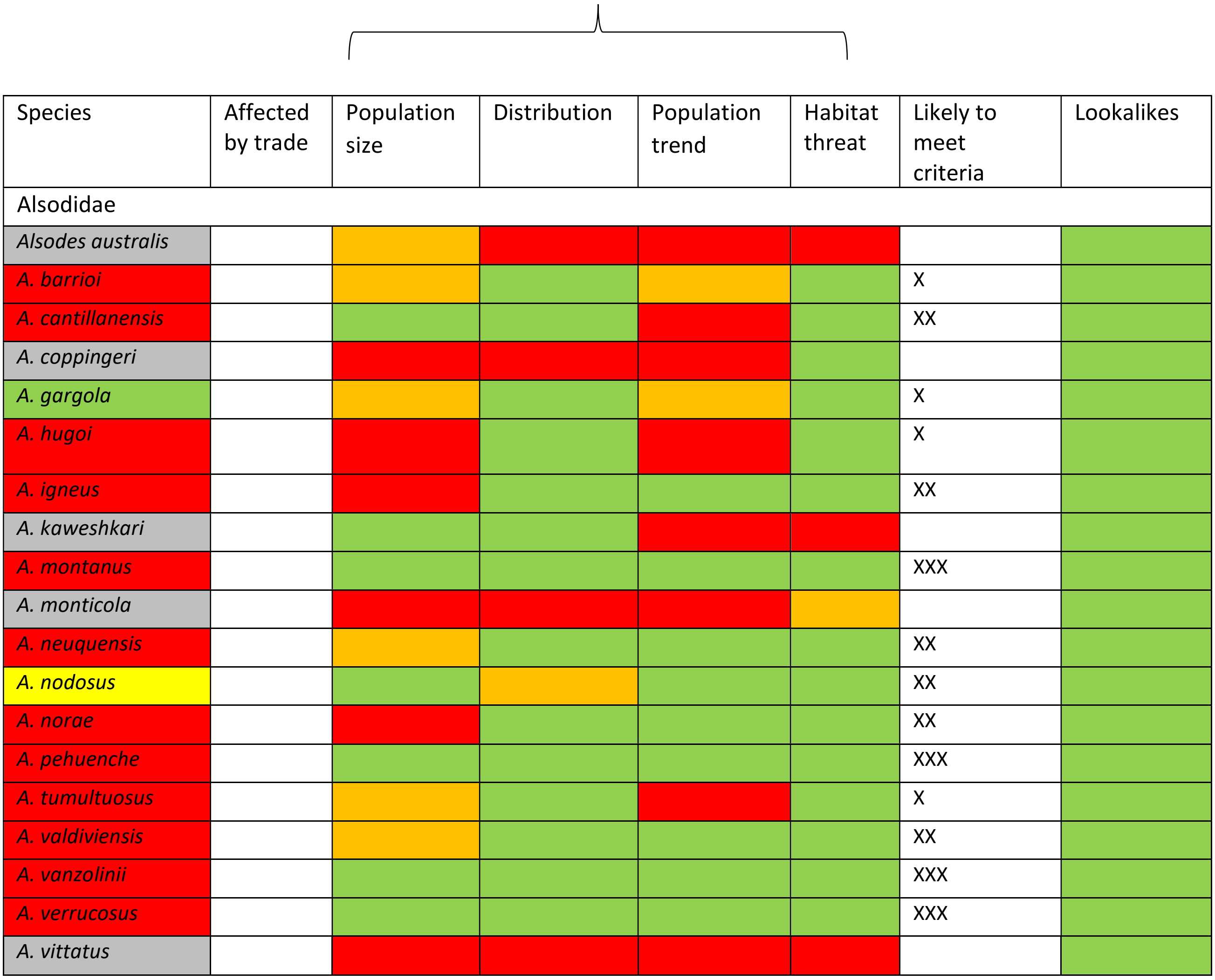
The resemblance is not as conspicuous between Gerrhosauridae species but there is still scope for confusion. *Gerrhosaurus* species and *Broadleysaurus major* are superficially similar and *Matobosaurus* only differs from them by size. *Tetradactylus* species differ from other Gerrhosaurids in being serpentiform but four species (*T. ellenbergeri, T. africanus, T. fitzsimonsi,* and *T.breyeri*) are very similar. In the *Zonosaurus* genus, *Z. haraldmeieri* closely resembles *Z. madagascariensis,* and *Z. tsingy* and *Z. subunicolor* are also physically alike.

3.3.7 Wildlife trade

One publication (Lobos, Hernandez and Jaksic, 2014) refers to trade of Alsodidae: *"Ortiz in 1988 indicated that many species of amphibians of the genera Alsodes, Batrachyla, Rhinella, Calyptocephalella, Eupsophus and Rhinoderma suffered intensive trade in the 1980s, with an estimated 24,064 specimens traded between 1985 and 1988"* (translated from Spanish). Despite extensive searches, I could not locate the Ortiz paper. The Red List assessments and Scheffers et al. (2019) list seven species of Gerrhosauridae as traded, whereas Marshall et al. (2020) list eleven (Fig 3). At least 14 publications dated between 1990 and 2014 studied specimens that were either already purchased as pets or were purchased from pet shops or commercial dealers for the study. These studies occurred in locations across the USA and Italy, and involved eight species. Seven other publications studied or mention trade. One (Kopeckỳ *et al.*, 2019) identifies 10 Gerrhosauridae species as traded within EU from customs data, and Ziegler et al. (2022) identifies nine Malagasy species that are kept in captivity in zoos worldwide. Jenkins et al. (2014) states *"The extent to which Malagasy reptile species that are not currently listed on CITES, such as skinks, the gerrhosaurids, some geckoes and most of the snakes, are traded internationally is poorly known because quantitative information on export* *quantities are difficult to obtain"*. In 2006, one study stated that of all Gerrhosauridae, *Gerrhosaurus* was probably the most frequently kept in captivity but captive breeding was not widespread (Loehr, 2006), and an earlier study stated the collection of wildlife is a significant industry in Madagascar (Ramanamanjato, Mcintyre and Nussbaum, 2002). Two papers refer to collection of specimens for trade from Montagne d 'Ambre (Raxworthy and Nussbaum, 1994), and Nosy Be (Andreone *et al.*, 2003), both in Madagascar, and cloth bags used by wildlife collectors were observed in Lokombe special reserve, also in Madagascar (Raselimanana, Nussbaum and Raxworthy, 2006).

Appendix I and II

Appendix IIb



Species	Affected by trade	Population size	Distribution	Population trend	Habitat threat	Likely to meet criteria	Lookalikes
Alsodidae							
▨ *Alsodes australis*		🟧	🟥	🟥	🟥		🟩
🟥 *A. barrioi*		🟧	🟩	🟧	🟩	X	🟩
🟥 *A. cantillanensis*		🟩	🟩	🟥	🟩	XX	🟩
▨ *A. coppingeri*		🟥	🟥	🟥	🟩		🟩
🟩 *A. gargola*		🟧	🟩	🟧	🟩	X	🟩
🟥 *A. hugoi*		🟥	🟩	🟥	🟩	X	🟩
🟥 *A. igneus*		🟥	🟩	🟩	🟩	XX	🟩
▨ *A. kaweshkari*		🟩	🟩	🟥	🟥		🟩
🟥 *A. montanus*		🟩	🟩	🟩	🟩	XXX	🟩
▨ *A. monticola*		🟥	🟥	🟥	🟧		🟩
🟥 *A. neuquensis*		🟧	🟩	🟩	🟩	XX	🟩
🟨 *A. nodosus*		🟩	🟧	🟩	🟩	XX	🟩
🟥 *A. norae*		🟥	🟩	🟩	🟩	XX	🟩
🟥 *A. pehuenche*		🟩	🟩	🟩	🟩	XXX	🟩
🟥 *A. tumultuosus*		🟧	🟩	🟥	🟩	X	🟩
🟥 *A. valdiviensis*		🟧	🟩	🟩	🟩	XX	🟩
🟥 *A. vanzolinii*		🟩	🟩	🟩	🟩	XXX	🟩
🟥 *A. verrucosus*		🟩	🟩	🟩	🟩	XXX	🟩
▨ *A. vittatus*		🟥	🟥	🟥	🟥		🟩

E. altor		🟥	🟥	🟥	🟧		🟩
E. calcaratus		🟧	🟧	🟩	🟩	X	🟩
E. contulmoensis		🟩	🟩	🟥	🟩	XX	🟩
E. emiliopugini		🟧	🟧	🟩	🟩	X	🟩
E. insularis		🟧	🟩	🟩	🟩	XX	🟩
E. migueli		🟩	🟩	🟩	🟩	XXX	🟩
E. nahuelbutensis		🟧	🟩	🟧	🟩	X	🟩
E. roseus		🟧	🟧	🟩	🟩	X	🟩
E. septentrionalis		🟩	🟥	🟥	🟩	X	🟩
E. vertebralis		🟧	🟧	🟩	🟩	X	🟩
L. macroglossa		🟧	🟧	🟧	🟩		🟩
TOTAL						23	
Gerrhosauridae							
Broadleysaurus major	X	🟧	🟧	🟥	🟧		🟩
Cordylosaurus subtessellatus		🟧	🟧	🟧	🟧		🟩
Gerrhosaurus auratus		🟧	🟧	🟧	🟧		🟩
G. bulsi		🟧	🟧	🟧	🟧		🟩
G. flavigularis	X	🟥	🟧	🟥	🟧		🟩
G. intermedius		🟥	🟧	🟥	🟩		🟩
G. multilineatus		🟧	🟧	🟧	🟧		🟩
G. nigrolineatus	X	🟧	🟧	🟧	🟧		🟩
G. skoogi		🟧	🟩	🟧	🟧		🟩
G. typicus		🟧	🟧	🟧	🟧		🟩
Matobosaurus maltzahni		🟧	🟧	🟧	🟧		🟩
M. Validus	X	🟧	🟧	🟧	🟧		🟩
Tetradactylus africanus		🟧	🟧	🟧	🟩		🟩
T. breyeri		🟩	🟩	🟩	🟩	XXX	🟩
T. ellenbergeri		🟥	🟧	🟥	🟧		🟩
T. fitzsimonsi		🟩	🟧	🟥	🟩	X	🟩
T. seps		🟧	🟧	🟧	🟧		🟩
T. tetradactylus		🟧	🟧	🟧	🟧		🟩
T. udzungwensis		🟥	🟩	🟥	🟩	X	🟩
Tracheloptychus petersi	X	🟧	🟩	🟩	🟩	XX	🟩
T. madagascariensis	X	🟥	🟧	🟩	🟩	X	🟩
Zonosaurus aeneus	X	🟥	🟧	🟩	🟩	X	🟩
Z. anelanelany		🟩	🟩	🟩	🟩	XXX	🟩
Z. Bemaraha		🟧	🟩	🟧	🟧		🟩
Z. boettgeri		🟥	🟩	🟩	🟩	XX	🟩
Z. brygooi		🟥	🟧	🟩	🟩	X	🟩

🟨 *Z. haraldmeieri*	X	🟥	🟩	🟥	🟩	X	🟩
🟩 *Z. karsteni*	X	🟩	🟥	🟥	🟧		🟩
🟩 *Z. laticaudatus*	X	🟧	🟧	🟥	🟧		🟩
🟩 *Z. madagascariensis*	X	🟧	🟧	🟧	🟧		🟩
▨ *Z. maramaintso*	X	🟥	🟥	🟥	🟥		🟩
🟥 *Z. maximus*	X	🟩	🟩	🟩	🟩	XXX	🟩
🟩 *Z. ornatus*	X	🟥	🟧	🟥	🟧		🟩
🟥 *Z. quadrilineatus*	X	🟥	🟩	🟥	🟩	X	🟩
🟨 *Z. rufipes*		🟧	🟩	🟩	🟩	XX	🟩
🟥 *Z. subunicolor*		🟩	🟩	🟩	🟩	XXX	🟩
🟩 *Z. trilineatus*	X	🟧	🟩	🟧	🟧		🟩
🟩 *Z. tsingy*		🟧	🟩	🟧	🟧		🟩
TOTAL						14	

Figure 3. Indication of which species in Alsodidae and Gerrhosauridae may meet the biological criteria of CITES for listing in Appendix I or IIa. The colour fill on the species name relates to the IUCN Red List category: green = LC, yellow = NT, red = Threatened, grey = DD, no colour fill = Not Evaluated. Presence of trade is indicated by X in 'affected by trade' column. The colour fill for population size, distribution, population trend, and habitat threat indicates whether data is available and likely to meet CITES biological criteria (green), available but unlikely to meet criteria (orange), or not available (red). The number of X marks in 'likely to meet criteria' column indicates how many of the three criteria a species meets. All species are filled in green under Appendix IIb due to the high level of morphological similarity between many species.

3.3.8 Application of data to CITES criteria

After reviewing all available literature, I considered that species described as 'rare' or 'not often encountered' would likely meet the definition of a 'small wild population', and species described as 'abundant or 'common' would not. Species with a distribution smaller than

~25000km^2 I considered to have a restricted distribution, using the Red List assessment criteria for classifying a species as Vulnerable (*The IUCN Red List of Threatened Species*, 2023). I used the Red List assessed population trend to identify species with a decreasing population. Forest specialist species threatened with deforestation qualified for the habitat loss and degradation criteria but any species using modified or urban habitats in addition to forest, and those in habitats that were not under threat did not.

Applying all data available in my review, I assessed a total of 23 (76%) Alsodidae species as potentially eligible for listing on CITES, if they were considered to be (or potentially be) impacted by trade (Fig. 3). Thirteen species meet two or more biological criteria for Appendices I or IIa, and all species classified as Threatened by the Red List are eligible. At present, only four of the DD species, and *E. altor* and *L. macroglossa* would not qualify. Due to the high levels of morphological similarity between the species, all would qualify under the 'lookalike' criteria of Appendix IIb. A smaller proportion of Gerrhosauridae meet the biological criteria, with 14 (35.9%) species and seven meet two or more criteria. As with the Alsodidae, all Threatened species are eligible but only two species from mainland Africa, and six of the 16 species currently traded (Fig 3). All species are potentially eligible for listing under Appendix IIb, depending on which species is the subject of trade. For example, *T.breyeri* is serpentiform so other *Tetradactylus* species may be eligible for listing if *T. breyeri* becomes impacted by trade but not the limbed *Gerrhosaurus* species.

Figure 4. Examples of four species of *Eupsophus* demonstrating the morphological similarity between species. A) *E. roseus* B) *E. insularis* C) *E. contulmoensis* D) *E. septentrionalis.* Note that individual morphology varies significantly in Alsodidae species.

3.4 Discussion

3.4.1 Literature review

There is a clear lack of recent published data on both Alsodidae and Gerrhosauridae; both families had a mean of less than 10 papers per species. By comparison, a cursory search on Web of Science for two species distributed in wealthier countries with more research efforts (Titley, Snaddon and Turner, 2017) had substantially more publications. *Pelobates cultripes,* a toad species classified as Vulnerable and distributed across Spain, Portugal, and pockets of France yielded 72 results. The Florida Sand Skink, also Vulnerable and occupying less than 2000km^2 in North America, had 26. Whilst there has been a large increase in fieldwork in Madagascar since the 1990s (Raselimanana, Nussbaum and Raxworthy, 2006), and South Africa contributes a reasonable percentage of publications for Gerrhosauridae (14.6%), some mainland countries in Africa were conspicuous in their absence. The range of many species of Gerrhosauridae include countries such as Zambia, Uganda, Botswana, Malawi, and the Democratic Republic of Congo (DRC), however I found only one publication from all these countries; a survey in Western DRC from 2013 (Nagy *et al.*, 2013). The lack of native language publications for Gerrhosauridae was also notable, and this may hinder sharing of knowledge and advancement of understanding in their range countries.

Threatened species of Alsodidae account for a similar number of publications as those classified as LC on the Red List (Fig 1c) but there is a more obvious bias towards LC species for Gerrhosauridae. This is predictable given their larger population and/or wider distribution, and may be partially explained by 47 publications being biodiversity surveys, and the more common species being observed more frequently. However, a focus on LC species may be unhelpful in the context of wildlife trade. The aim of CITES is 'to ensure international trade does not threaten the survival of the species', and in many cases, trade will only be unsustainable for threatened species. As such, it is these threatened species that require sufficient biological knowledge to benefit from CITES protection. The DD species in both families also attracted relatively few publications but given the only DD Gerrhosaurid (*Z. maramaintso*) and many of the DD Alsodidae species have not been located since first described, this is not surprising. All of the DD species were classified as such due to questions over their taxonomic validity, and this is unlikely to be representative of all DD species (see chapter 2).

Amphibians are understudied in many world regions (Howard and Bickford, 2014), with many species lacking some basic natural history data (Womack *et al.*, 2022), therefore the current inadequate state of knowledge for Alsodidae is unsurprising, and acknowledged in the literature (Correa, Pablo Donoso and Carlos Ortiz, 2016; Charrier, 2019). Similarly, reptile research is skewed towards taxa such as crocodilia and pythons, and large-sized species, with socioeconomic factors impacting research output (Guedes, Moura and Alexandre F. Diniz-Filho, 2023), therefore the published data for Gerrhosauridae is perhaps predictable. Whilst fundamental ecological data such as general habitat and reproductive strategy is known for both families, there are glaring omissions in the literature. Dispersal distances, use of modified or degraded habitats, territory size, and reproductive capacity and output are just some of the data gaps for many species, particularly Gerrhosauridae. These baseline data would no doubt greatly assist Red List assessors in estimating population size and distribution.

3.4.2 Red List assessments and CITES

Despite the paucity of natural history information, there is sufficient data to allocate a Red List threat category for most species, and at least one of the three key biological criteria for CITES listing (population size, distribution, and population trend) is met for all threatened species. Only seven of the Alsodidae and nine of the Gerrhosauridae had unknown data for two of the three categories, and only the DD species and *E. altor*, described in 2012 and yet to be assessed, were missing all three (Fig 3). My review of the literature did not provide any additional information to Red List assessments regarding population size and trend, but it did provide information regarding the threats facing the two families, predominantly Alsodidae. Climate change, fragmentation, and invasive species (Table 2) in particular were cited as threats to Alsodidae species in the literature but were often absent from Red List assessments. These additional threats may influence the likely population trend, depending on the deemed severity.

The use of categories, such as ‘rare’ and ‘abundant’ in Red List assessments for population size in both families is entirely understandable, and the CITES biological criteria A (’The wild population is small’) is far from ideal for these smaller species. It is feasible to quantify a population size for medium – large sized mammals, reptiles, and birds, but what constitutes a small population size for a medium-sized species of frog? Nor is it practicable to obtain an estimate for the species of Alsodidae and Gerrhosauridae, given that most if not all inhabit inaccessible areas, hugely heterogenous habitats such as forests, are arboreal, or display cryptic behaviours. Nonetheless, the unfortunate wording of criteria A and the existing data gaps for amphibians does not appear to be a drawback for successfully adding them to CITES. At the most recent Conference of the Parties in November 2022 (COP19), a proposal to add Centrolenidae, a family of frogs from Latin America, was passed despite the lack of data. This proposal stated *‘Data on the population size of glass frogs is very limited….. Thirty-three of the 158 species have an unknown population status and lack data related to their state of vulnerability…. There is very little available information describing the population structure of glass frogs.’* (CITES, 2022) The wide distribution was also not a drawback, as Centrolenidae *'are widely distributed throughout Central and South America and can be found in 19 range States.'* It is worth noting however that the European Union and its Member States, supported by Canada, opposed the proposal. The agreement to pass this proposal by consensus may set a positive precedent but it is far from guaranteed that other families of frogs would receive the same outcome.

My results indicate that many amphibian and reptile species may benefit from the 'lookalike' criteria in Appendix IIb, as was the case with the glass frogs at COP19. Thus, sufficient biological knowledge for just one traded species in a genus or family may be suffice to ensure all congeners are regulated and monitored under CITES. This is a significant finding as research efforts could be allocated appropriately; ensure one or two species in genera or families predicted to become impacted by trade have sufficient knowledge, and others that have a physical resemblance will benefit. However, there is a caveat to this. The wording of CITES criteria is such that the species that requires regulation and monitoring must have sufficient biological knowledge, and then others that resemble it can be listed under the lookalike criteria in Appendix IIb. Thus, if it was only a species without sufficient biological knowledge that was impacted by trade, even with congeners that look similar, it would not be able to access CITES. For example, *Z. maramaintso* is a DD species and does not meet the biological criteria due to knowledge gaps. If it was proposed to be added to CITES Appendix IIa, and species that resemble it were not impacted by trade, it would not meet the biological criteria and therefore none of the species could be listed. In this example, *Z. maramaintso* would only benefit from the lookalike criteria if a species it resembles requires listing on CITES, and that species has sufficient biological knowledge to meet the criteria. Without accurate predictions of which species will become impacted by trade, it is a lottery. Pick a species in a poorly known genus or family to fill knowledge gaps, and if it becomes impacted by trade then others that resemble it benefit from lookalike criteria. Yet pick a species to fill knowledge gaps that does not become impacted by trade, and congeners that resemble it cannot benefit. Whether this is likely to occur in reality is debatable. The lookalike criteria exists to aid customs officers, who are not sufficiently trained or familiar with wildlife biology to identify small differences between species. Whether collectors can or will differentiate between species that are physically similar, thus driving demand in a specific species, is not clear.

3.4.3 Geographical bias in data gaps

A notable observation in my results is the geographical differences in data availability. After removing DD species and *E. altor* (not yet Red List assessed), Alsodidae had seven (7.6%) missing data fields from 92 (Fig 3). Gerrhosauridae, with the DD species *Z. maramaintso* excluded, had 23 (15.1%) from 152, double the amount of data gaps. This is unlikely to be explained by it being a different taxon, as the Alsodidae are smaller, and equally as cryptic to survey. The frogs also have more newly described species, which are often lacking basic ecological data (Rodríguez, 2003). The tropics are notoriously deficient in basic biodiversity data (Rodríguez, 2003; Hoffmann *et al.*, 2010), particularly Africa (Collen *et al.*, 2008), and this pattern appears to hold true when considering CITES biological criteria. This is particularly worrying given that the tropics harbour around three-quarters of all the world’s species (Barlow *et al.*, 2018), and are the epicentres of wildlife trade (Scheffers *et al.*, 2019).

3.5 Conclusion

If the trend for increasing numbers of species being traded continues, many species at risk of overexploitation will have sufficient biological knowledge to be considered for CITES. It is likely that many will be eligible for CITES protection if trade becomes an issue in their fight for survival, particularly those already threatened with extinction. Significant data gaps for other species remain, notably those in the tropics, which could leave them unable to access the benefit of CITES regulation, and vulnerable to overexploitation. Collective efforts to fill knowledge gaps of tropical species will be vital to protect many species from the increasing threat of wildlife trade to their survival.

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Chapter 4

General Discussion

4.1 Overview of results

This thesis aimed to identify knowledge gaps in the assessments of species currently subject to wildlife trade, and those projected to become affected by trade in the future. I assessed the recategorisation of Data Deficient (DD) species by the IUCN Red List between 2007 and 2021, and reviewed the published literature for a sample of the thousands of species predicted to become impacted by trade (Scheffers *et al.*, 2019). My results support previous studies (Butchart and Bird, 2010; Howard and Bickford, 2014; Jetz and Freckleton, 2015; Bland and Böhm, 2016; González-del-Pliego *et al.*, 2019; Borgelt *et al.*, 2022) that used a variety of methods to predict the threat status for DD species: as a group, DD species are more threatened than species with sufficient data to be assigned a Red List threat category. My results indicate that traded DD species have a higher risk of extinction than DD species as a whole, and are mainly located in the tropical realm. Key data gaps include their known distribution, ecology, population status, and threats (see chapter 2), a pattern that holds for species predicted to become impacted by trade (see chapter 3). These limitations do not appear to be a barrier to accessing CITES protection for some DD species, or threatened species predicted to become popular in trade, but the results indicate further consideration is warranted.

4.2 Prioritising DD species

Our limited understanding of many described species has long been acknowledged (Hortal *et al.*, 2015; Diniz Filho *et al.*, 2023) and the numbers of species with DD status on the Red List is just one metric of where biodiversity data is lacking. However, the Red List is a powerful tool for conservation planning and decision making, at local, national, and global scales (Rodrigues *et al.*, 2006; Betts *et al.*, 2020), and the threat status of species can have significant impacts on conservation efforts and funding (Betts *et al.*, 2020), with DD species often excluded (Bland *et al.*, 2017). Previous studies have attempted to aid reassessments of DD species, e.g., through identifying a Data Deficiency surface (Brito, 2010), suggesting methods to achieve more strategic assessments (Morais *et al.*, 2013; Bland *et al.*, 2017), and predicting threat status (Borgelt *et al.*, 2022). Yet no guidance exists for which DD species should be prioritised for research efforts and the sheer number of DD species may present as a seemingly insurmountable task.

My results suggest that the 165 DD terrestrial vertebrate species currently traded are more threatened than DD species as a whole, and most are in the tropics. Pantropically, basic biodiversity data is often lacking (Collen *et al.*, 2008; Stroud and Thompson, 2019), which is likely to hinder the efforts of many tropical countries in designing effective conservation strategies to meet the Kunming-Montreal Global Biodiversity Framework (GBF) 2030 targets (Hughes, 2023). Comprehensive understanding of the impacts of wildlife trade on wild populations is also lacking, with existing evidence suggesting trade causes significant population abundance declines of up to 87% but responses of DD species are mixed (Morton *et al.*, 2021b). Targeting tropical locations where traded DD species are distributed could enable multiple wins: improved biological and ecological knowledge of this subset of DD species; similarly improved knowledge of other species that co-exist with traded DD species; increased understanding of trade impacts on DD species (through comparing impacts on populations at control (untraded) and treatment (traded) sites); and advance the achievement of meaningful conservation strategies to hit GBF targets across the tropical realm. There are however some important limitations to this proposal. Conservation funding is notoriously limited, particularly in the tropics (Balmford and Whitten, 2003; Reed *et al.*, 2020), and DD species cannot benefit to the disadvantage of species already known to be threatened. Nor should traded DD species take precedence over other subsets of DD species that may have an equally high threat status (although currently none are known).

Yet opportunities exist which require minimal funding and avoid these pitfalls. Conservation organisations on the ground (e.g., Wildlife Conservation Society (O'Brien *et al.*, 2010)) and scientific collaborations (e.g., South East Asia Rainforest Research Partnership) collect thousands of records via camera traps, acoustic recordings, and individual sightings, which could contribute valuable records for DD traded species. Local scientists can facilitate access to the considerable amount of information contained in theses and technical reports (Collen *et al.*, 2008), and initiatives such as SPIDA-Web by the American Natural History Museum can improve species data through automated object recognition, if enough images of specimens are available to allow machine learning (Russell *et al.*, 2007). The accuracy of local ecological knowledge is comparable to, or better than, scientific surveys at a fraction of the cost, and can also provide insight into offtake levels and increase conservation opportunities (Parry and Peres, 2015; Camino *et al.*, 2020). And a recent study (Borgelt *et al.*, 2022) predicts threat status of all DD species with ~90% accuracy, which could avoid efforts being directed to traded DD species that are unlikely to be threatened. In the absence of guidance regarding which DD species should be targeted for improved knowledge, a planned focus on those traded DD species most likely to be threatened should be a priority.

4.3 CITES

Although a lack of some biological data or being classed DD is seemingly not a barrier to a species being listed on CITES, only one DD species (*Pudu mephistophiles*) is CITES listed in its own right. The appetite of members states for protecting DD species has not yet been sufficiently tested and my results suggest many traded species lacking data could be protected under CITES listings for higher taxonomic orders, particularly genus (chapter 2). All six traded DD amphibians are included in genus listings, 12 of 13 reptiles, and half of the traded DD mammals. Birds, and four mammals species, feature at higher taxonomic levels (family and order), which suggests that traded DD amphibians and reptiles may be more vulnerable to being excluded from CITES.

In chapter 3, I assess all species in my sample families Alsodidae and Gerrhosauridae as potentially being eligible for CITES under the lookalike criteria for Appendix IIb (chapter 3). But not all future traded species will inherit protection through this route, and my results also indicate that DD species are lacking the biological knowledge for CITES. Efforts to identify traded DD species that would potentially fall under ‘lookalike species’ could be maximized by using expert and local knowledge. This would determine which traded DD species are similar in appearance so only a nominate number of species require biological data, and research can then focus on threatened DD species that are unique in appearance and unlikely to fall under the lookalike criteria. Amphibian and reptile species that are DD, fall in genera not included on CITES, do not resemble other species, and that are predicted to become popular in trade, should also be a priority for filling biological knowledge gaps.

Newly described species may also be vulnerable to exclusion from CITES protection. Newly described species are often classified as DD (Morais *et al.*, 2013; Howard and Bickford, 2014), such as *Zonosaurus maramaintso* in my sample family Gerrhosauridae, and thousands of new species continue to be discovered each year. This includes hundreds of new amphibians, reptiles, and mammals (Liu *et al.*, 2022; *AmphibiaWeb*, 2023; *The Reptile Database*, 2023), which often have a higher extinction risk than species already known to science (Liu *et al.*, 2022), in part as they can quickly become popular in trade (Lindenmayer and Scheele, 2017; Marshall, Strine and Hughes, 2020; A. C. Hughes, Marshall and Strine, 2021). Species descriptions could assist Red List assessors in determining the true threat status by including information relevant to assessments (Tapley *et al.*, 2018), which may also be vital for meeting CITES biological criteria.

4.4 Limitations

I opted to study terrestrial vertebrates as they are relatively well-studied as a group but vary in terms of research effort and Red List status. For example, amphibians receive less research attention than birds (Pawar, 2003; Donaldson *et al.*, 2017) and have a higher proportion of DD species (*The IUCN Red List of Threatened Species*, 2023). This was evident in my results; there was insufficient data to determine the likely threat status of DD birds and traded DD birds, with only 30 and 5 species respectively reclassified between 2007 and 2021. The number of DD birds at present stands at only 46 due to concerted research efforts and sparing use of the DD category (Butchart and Bird, 2010; *The IUCN Red List of Threatened Species*, 2023) but around half of these are likely to be traded now or in the future (Scheffers *et al.*, 2019). Species with colourful plumage and distinctive song are popular in trade (Harris *et al.*, 2017; Senior *et al.*, 2022) so future efforts could focus on species with these characteristics (if known) and/or those that may be threatened as per Borgelt et al. (2022).

Whilst my results shed light on the likely threat status of DD terrestrial vertebrates and the accessibility of CITES for their protection from trade, thousands of species of fish and invertebrates feature in wildlife trade, and have a higher proportion of Not Evaluated or DD species (Fukushima, Mammola and Cardoso, 2020; Marshall *et al.*, 2022; *The IUCN Red List of Threatened Species*, 2023). For instance, there are over 2700 species of scorpion (Order: Scorpiones) (*The Scorpion files*, 2023) with 350 found in trade (Marshall *et al.*, 2022) but only three species have been Red List assessed. Five species feature on CITES (*Species+*, 2023). Fish have been more comprehensively Red List assessed (around two-thirds of the known ~36,000 species) but less than 200 feature on CITES (Fricke, Eschmeyer and Van der Laan, 2018; Hutchinson, Stephens-Griffin and Wyatt, 2022; *The IUCN Red List of Threatened Species*, 2023). Whether these low numbers of CITES listings are due to trade not being considered unsustainable is unclear but some claims suggest a lack of data and a reluctance by CITES Parties to intervene (Vincent *et al.*, 2014; Marshall *et al.*, 2022). The knowledge gaps for all taxon subject to trade are too vast to be reviewed here but there is a clear need for clarity around what data would enable some of these overlooked groups impacted by trade to benefit from CITES protection.

4.5 Recommendations for future study

Despite the magnitude of the threat wildlife trade poses to biodiversity, the current understanding of its impact on wild populations is limited. A recent review found only 31 studies, with only a fraction using treatment versus control comparisons, and no studies on amphibians, invertebrates, cacti, or orchids (Morton *et al.*, 2021b). Their results suggest trade has a substantial negative effect on population size, but quantitative studies would assist in protecting species from overexploitation, and allow for sustainable, well-managed trade as a form of income for many people already experiencing high levels of poverty.

One key unanswered question arises from my results regarding the listing of species on CITES. Each Party to CITES must have one or more Scientific Authorities to advise them as to whether the export will be detrimental to the survival in the wild of the species. Given my results in chapter three, a lack of biological data appears unlikely to be a limiting factor so why are so few amphibians, and arguably reptiles, protected at international level? Do these authorities simply consider trade to be at a sustainable level? This would be difficult to argue for threatened species considering the lack of scientific study highlighted above. Do they lack confidence or knowledge to submit a proposal for taxa that are under-represented? Are they lacking resources? Is it trade data that is insufficient? Are efforts sometimes limited to high profile species, such as tigers and elephants, which draw international attention? This issue requires clarification, as hundreds of amphibian and reptile species are currently subject to unregulated trade (Marshall, Strine and Hughes, 2020; Hughes, Marshall and Strine, 2021). An analysis of proposals by Parties relative to the number of traded species in their country may provide some insight into which countries are less engaged with CITES, and identify those that would benefit from additional support.

4.6 Conclusion

Many traded species lacking sufficient data for an assessed Red List threat status are in the tropics, and are likely to be threatened with extinction, and these species should be prioritized over non-traded Data Deficient species for data collection. Biological knowledge gaps do not appear to be a barrier for many species in accessing international trade regulation via CITES but physically unique DD amphibians and reptiles may not be eligible for inclusion. We urgently need to better understand the impact of trade on wild populations, and ensure Parties to CITES are willing and able to submit prompt Proposals to protect traded species when trade is unsustainable. Failure to do so will result in wildlife trade making a pronounced and unwelcome contribution to the Sixth Mass Extinction.

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Appendix One – criteria for CITES Appendices I and II

Annex I

Biological criteria for Appendix I

The following criteria must be read in conjunction with the definitions, explanations and guidelines listed in Annex 5, including the footnote with respect to application of the definition of ’decline‘ for commercially exploited aquatic species.

A species is considered to be threatened with extinction if it meets, or is likely to meet, **at least one** of the following criteria.

A. The wild population is small, and is characterized by **at least one** of the following: *Resolution Conf. 9.24 (Rev. CoP17) – 4*

i) an observed, inferred or projected decline in the number of individuals or the area and quality of habitat;

ii) each subpopulation being very small;

iii) a majority of individuals being concentrated geographically during one or more life-history phases;

iv) large short-term fluctuations in population size; or

v) a high vulnerability to either intrinsic or extrinsic factors.

B. The wild population has a restricted area of distribution and is characterized by **at least one** of the following:

i) fragmentation or occurrence at very few locations;

ii) large fluctuations in the area of distribution or the number of subpopulations;

iii) a high vulnerability to either intrinsic or extrinsic factors; or

iv) an observed, inferred or projected decrease in any one of the following:

– the area of distribution;

– the area of habitat;

– the number of subpopulations;

– the number of individuals;

– the quality of habitat; or

– the recruitment.

C. A marked decline in the population size in the wild, which has been **either**:

i) observed as ongoing or as having occurred in the past (but with a potential to resume); **or**

ii) inferred or projected on the basis of any one of the following:

– a decrease in area of habitat;

– a decrease in quality of habitat;

– levels or patterns of exploitation;

– a high vulnerability to either intrinsic or extrinsic factors; or

– a decreasing recruitment.

Annex 2a

Criteria for the inclusion of speciesin Appendix II in accordance with Article II,paragraph 2(a), of the Convention

The following criteria must be read in conjunction with the definitions, explanations and guidelines listed in Annex 5, including the footnote with respect to application of the definition of 'decline' for commercially exploited aquatic species.

A species should be included in Appendix II when, on the basis of available trade data and information on the status and trends of the wild population(s), **at least one** of the following criteria is met:

A. It is known, or can be inferred or projected, that the regulation of trade in the species is necessary to avoid it becoming eligible for inclusion in Appendix I in the near future; or *Resolution Conf. 9.24 (Rev. CoP17) – 5*

B. It is known, or can be inferred or projected, that regulation of trade in the species is required to ensure that the harvest of specimens from the wild is not reducing the wild population to a level at which its survival might be threatened by continued harvesting or other influences.

Annex 2b

Criteria for the inclusion of speciesin Appendix II in accordance with Article II,paragraph 2(b), of the Convention

Species may be included in Appendix II in accordance with Article II, paragraph 2 (b), if **either one** of the following criteria is met:

A. The specimens of the species in the form in which they are traded resemble specimens of a species included in Appendix II under the provisions of Article II, paragraph 2 (a), or in Appendix I, so that enforcement officers who encounter specimens of CITES-listed species are unlikely to be able to distinguish between them; or

B. There are compelling reasons other than those given in criterion A above to ensure that effective control of trade in currently listed species is achieved.

Appendix 2 - List of publications reviewed for two sample families of species predicted to become impacted by trade

Alsodidae

1. Alcalde, L., & Blotto, B. L. (2006). Chondrocranium, cranial muscles and buccopharyngeal morphology on tadpoles of the controversial leptodactylid frog Limnomedusa macroglossa (Anura: Leptodactylidae). *AMPHIBIA-REPTILIA*, *27*(2), 241–253. https://doi.org/10.1163/156853806777239959

2. Alvarado-Rybak, M., Valenzuela-Sanchez, A., Cevidanes, A., Penafiel-Ricaurte, A., Uribe-Rivera, D. E., Flores, E., Cunningham, A. A., & Soto-Azat, C. (2018). High prevalence of chigger mite infection in a forest-specialist frog with evidence of parasite-related granulomatous myositis. *PARASITOLOGY RESEARCH*, *117*(5), 1643–1646. https://doi.org/10.1007/s00436-018-5822-x

3. Álvarez, D. R. (2015). Nueva localidad para Alsodes tumultuosus Veloso, Iturra & Galleguillos, 1979 (Amphibia, Alsodidae) en la Cordillera de los Andes, Region de O’Higgins, Chile. *Biodiversity and Natural History*, *1*(1), Article 1.

4. Alveal, N., Diaz-Paez, H., Henriquez, A., & Vergara, O. (2015). Dietary aspects of Alsodes coppingeri Gunther, 1881 (Anura: Alsodidae) in Chile. *GAYANA*, *79*(1), 5–10. https://doi.org/10.4067/S0717-65382015000100002

5. Alzamora, A., & Lobos, G. (2021). Assessing the threat of a South American cichlid on anurans in the Chilean Mediterranean region. *BioInvasions Records*.

6. Araya, S., & Cisternas, J. (2008). Antecedentes sobre el Hábitat, Localización y Anuros asociados a Alsodes hugoi (Amphibia, Leptodactylidae) en su localidad tipo. *Boletín Museo Nacional de Historia Natural*, *57*, 127–131.

7. Araya, S., & Riveros, E. (2008). Ampliación del Rango de Distribución Geográfica de Alsodes montanus (Amphibia, Leptodactylidae) a la Región de O’Higgins. *Boletín Museo Nacional de Historia Natural*, *57*, 117–123. https://doi.org/10.54830/bmnhn.v57.2008.250

8. Asencio, J., Kusch, A., Henríquez, J. M., & Cárcamo, J. (2009). REGISTROS DE ANFIBIOS EN EL BOSQUE NORPATAGÓNICO COSTERO DEL CANAL MESSIER, CHILE. *Anales Del Instituto de La Patagonia*, *37*(1), 113–116. https://doi.org/10.4067/S0718-686X2009000100011

9. Ávila, J. M., Cortés, F. R., & Mella-Romero, J. (2018). Presencia de Eupsophus roseus (Duméril & Bibron, 1841) al interior de la Reserva Nacional Los Ruiles, Región del Maule. *Boletín Museo Nacional de Historia Natural*, *67*(2), Article 2. https://doi.org/10.54830/bmnhn.v67.n2.2018.31

10. Bacigalupe, L. D., Soto-Azat, C., García-Vera, C., Barría-Oyarzo, I., & Rezende, E. L. (2017). Effects of amphibian phylogeny, climate and human impact on the occurrence of the amphibian-killing chytrid fungus. *Global Change Biology*, *23*(9), 3543–3553. https://doi.org/10.1111/gcb.13610

11. Baffico, G. D., & Ubeda, C. A. (2006). Larval diet of the frog Alsodes gargola (Leptodactylidae: Telmatobiinae) and some ecological considerations on its role in alpine and mountain aquatic environments in Patagonia. *AMPHIBIA-REPTILIA*, *27*(2), 161–168. https://doi.org/10.1163/156853806777239986

12. Barrasso, D. A., Alcalde, L., Blotto, B. L., & Basso, N. G. (2016). Description of the tadpole of Alsodes neuquensis Cei, 1976 and comparison with the sibling species A. gargola Gallardo, 1970 (Amphibia, Anura, Alsodidae). *HERPETOLOGICAL JOURNAL*, *26*(1), 21–31.

13. Barrasso, D. A., Ubeda, C. A., Cotichelli, L., & Basso, N. G. (2022). On the presence of Alsodes coppingeri (Anura, Alsodidae) in Argentina, with comments on other southern Alsodes. *NEOTROPICAL BIODIVERSITY*, *8*(1), 21–30. https://doi.org/10.1080/23766808.2022.2029321

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