Zoonotic potential of international trade in CITES-listed species

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Executive summary

Zoonoses represent a major global health challenge. They are responsible for billions of cases of human illness and millions of deaths each year, and the fallout from zoonotic diseases has the potential to have profound economic and social impacts on human society. Moreover, zoonoses account for a disproportionately large number of new infectious diseases that have emerged or become widespread over the last 50 years – including HIV, West-Nile fever, Zika virus disease, Ebola virus disease, SARS, MERS and, most recently, COVID-19. With the COVID crisis ongoing, and with evidence that the rate of emergence of new zoonotic diseases is increasing over time, there is an urgent need to address and minimise the risks of zoonotic disease spill over.

In this context, wildlife trade has been identified as one of the important potential pathways of zoonotic disease emergence, as well as an activity that plays a role in maintaining existing zoonoses in circulation. The scale of the global wildlife trade is difficult to quantify, with the nature of transactions varying from informal and highly localised domestic markets to well established international trade routes. Documented legal trade is also supplemented by poorly documented (or entirely undocumented) illegal trade; and, while no estimates of the full scale of trade are available, the volume of animals involved is known to be extremely high. A range of responses have therefore been suggested to mitigate the risk of zoonotic spill over across a wide range of trade types and points in the supply chain.

One of the avenues through which it has been suggested that the zoonotic risk of wildlife trade could be mitigated is the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), which regulates a defined subset of wildlife trade worldwide: namely, legal, international trade in around 6,000 animal and 33,000 plant taxa. Public health considerations, however, are beyond the Convention's current mandate and its clearly defined focus on the legality and sustainability of international wildlife trade.

As CITES only regulates a fraction of international trade and movement of animals, the first step in understanding whether there could be a meaningful role for CITES in mitigating zoonotic spill over is to gain a stronger understanding of the relevance of zoonotic risk in the current CITES context. While some studies have looked at a subset of zoonotic diseases and their prevalence in CITES-listed taxa that are traded as live animals, no study has yet considered the potential zoonotic risk of trade in both live and raw commodities of CITES-listed species across all sources and purposes, or across a broad spectrum of pathogen types.

In this report, we systematically reviewed literature detailing known associations between animals and zoonotic diseases to collate a dataset of 1,608 unique taxa associated with 369 pathogens causing 275 diseases. We then investigated the prevalence in trade over a ten-year period of CITES-listed taxa that have been associated with at least one zoonotic disease in this dataset, looking at the commodities that are traded as well as the key trade routes. We particularly concentrated on trade in live animals and meat, as two of the commodities that have been identified as having particularly high zoonotic risk. We also focussed our efforts on investigating trade at the family level, in order to address the issue of species sampling bias and because species within the same family are likely to carry similar zoonotic diseases.

The key findings of our analysis were as follows:

(1) Of the 264 animal families that contain at least one CITES-listed species (hereafter referred to as CITES families), **117 families (44%) included at least one taxon associated with a zoonotic disease. Mammals** and **birds** were the two classes

containing the highest proportion of CITES families associated with at least one zoonotic disease, with over two thirds of families associated with one or more zoonotic diseases in both cases. Of the dataset's 25 zoonotic diseases considered by OIE to have the highest risk to human health, 23 were directly recorded in CITES-listed taxa, and all 25 were found in families that include at least one CITES-listed taxon. In total, 52 CITES families were associated with at least one of these high-risk zoonotic diseases.

(2) **Only around 16% of exporter- and re-exporter-reported[1] trade transactions in CITES-listed animal taxa** between 2009 and 2018 **involved a family that was associated with one or more zoonotic diseases**. While this proportion is relatively low, however, this still corresponds to a large number of shipments (0.8 million) over the ten-year period; and means that there is a **sizeable amount of CITES transactions that could potentially carry zoonotic risk**. For live animals, for example, the 300,000 transactions involving families associated with at least one zoonotic disease that occurred between 2009 and 2018 involved ~26.5 million individuals. This supports the findings of other studies that considered the number of transactions involving CITES-listed species with zoonotic potential to be substantial.

(3) **Wildlife taxa that can potentially carry zoonotic risk are generally more prevalent in trade in live, raw or semi-raw commodities that are also assumed to carry a higher risk;** however, the proportion of transactions associated with zoonotic risk is variable across different commodities (see case studies below)**.** Across all transactions involving trade in live, raw and semi-raw commodities, **birds and reptiles are the classes** in which most transactions occur involving taxa with a potential zoonotic risk. Looking at the trade at a finer scale, however, the commodities and families with the highest number of transactions with potential zoonotic risk were **live** parrots, falcons, and pythons; **skins** of alligators, crocodiles, pythons and bears; felid **trophies**; and **specimens** of cercopithecines (baboons, macaques, vervet monkeys and relatives).

(4) **For live animals**, approximately **25% of CITES (re-)exporter-reported trade transactions** between 2009 and 2018 **were in families associated with at least one zoonotic disease.** The vast majority (94%) of these transactions were associated with one or more high-risk zoonotic diseases as identified by OIE, with these transactions dominated by birds and reptiles. By quantity, **29% of the 90 million live individuals** (~26.5 million) traded over this period belonged to a family associated with at least one zoonotic disease, and 24% of individuals belonged to families that were associated with one or more high-risk zoonotic diseases. Seventy-three per cent of individuals traded in families associated with high-risk zoonotic disease were reptiles.
For meat, around **12% of (re-)exporter-reported transactions** over the ten-year period **were in families associated with at least one zoonotic disease**. Of these transactions, 86% involved trade in families associated with one or more of high-risk zoonotic diseases as identified by OIE, with **reptiles** (specifically *Crocodylus simensis* and *C. porosus*) as the dominant class traded. By quantity of meat traded, **23.5 million kg** (27% of all meat traded by weight over this period) was in taxa belonging to a family associated with at least one zoonotic disease, although only 9.5% was in families that were associated with high-risk zoonotic diseases.

[1] Hereafter collectively referred to as (re-)exporters.

Actions to achieve a better understanding of the zoonotic risk posed by wildlife trade, and to build a strong knowledge base to underpin recommendations aiming to reduce it, could include the following:

(1) The creation of a **central repository of disease-species associations covering the full range of zoonotic pathogens and their associated diseases.** New species/disease associations are being characterised all the time, and the dataset used in this analysis should not be assumed to be a comprehensive collection of all known associations. A centralised repository that is regularly updated would allow more sophisticated and complete analyses of disease risk from international wildlife trade in future, and may be essential if measures are considered necessary for particular species that are deemed to be at high risk of zoonotic disease spill over. Unlike current databases such as WAHIS-Wild, which contains information on outbreak events for a limited number of notifiable diseases, the suggested database could contain a searchable list of all known zoonotic disease associations to serve as a resource for enhancing knowledge on taxon-specific risk.

(2) Developing a **closer cooperative relationship between CITES and the international quartet of OIE, FAO, WHO, and UNEP** advancing a "One Health" approach (considering human, wildlife and livestock health holistically). This could help ensure that research needs specifically relating to health and wildlife trade are identified and prioritised. The establishment of a broader consortium to work together with these entities – similar to the one recommended by the recent IPBES workshop on Biodiversity and Pandemics – could also be beneficial.

(3) Using **CITES illegal trade reports** and other sources of seizure data to explore the prevalence of potential high-risk species and pathways in illegal trade. **Analyses of domestic trade and trade in non-CITES species**, while not the direct remit of CITES, are other fundamental aspects to be explored in order to fully understand the risks presented by global wildlife trade as a whole.

(4) Conducting further analyses targeting **pathogens causing diseases that have the highest likelihood of developing into an epidemic/pandemic**. This could include focusing on pathogens that have a high likelihood of spill over and developing human to human transmission. The collaboration highlighted in (2) above could help to facilitate the identification of those species-pathogen associations of most relevant in the CITES context.

(5) Further work to explore how **different ways of measuring zoonotic risk** impact the outcome of trade risk analyses**.** For example, future analyses could account for the diversity of zoonotic diseases associated with particular taxa, as well as disease severity in humans. These analyses could be further refined by considering whether the range of wild-sourced specimens overlaps with the known range of particular zoonotic pathogens.

(6) Assessing whether **risk mitigation measures for wild animals in trade**, such as hygiene and quarantine requirements across different commodity types, are appropriately implemented and are effective in reducing zoonotic risk. Future research could also consider **whether CITES requirements to ensure animal welfare during transport are aligned fully with practices to reduce the risk of zoonotic spill over.**

Contents

1| Introduction

Zoonoses – diseases that are transmissible from animals to humans through direct contact or through food, water, and the environment (WHO 2020c) – are widely recognised to be one of the greatest challenges to global health (Institute of Medicine 2011; Grace *et al.* 2012; United Nations Environment Programme 2020). Over 61% of infectious organisms known to be pathogenic to humans have a zoonotic origin, including roughly 80% of viruses, 50% of bacteria, 40% of fungi, 70% of protozoans and 95% of helminths (Taylor *et al.* 2001). Only around a third of zoonotic pathogens are thought to be transmissible between humans (Taylor *et al.* 2001); but even so, zoonoses as a whole have an enormous impact on the wellbeing and financial security of billions of people worldwide (Institute of Medicine 2011). A 2012 study, for example, estimated that 56 of the world's priority zoonoses (including many that cannot be, or are only rarely, transmitted from human to human)[2] were responsible for an estimated 2.5 billion cases of human illness annually, and for 2.7 million deaths per year (Grace *et al.* 2012).

An additional concern is that zoonoses have been linked disproportionately to the emergence of new diseases. Woolhouse and Gowtage-Sequeria (2005) found zoonotic pathogens to be almost twice as likely to be associated with emerging and re-emerging infectious diseases as non-zoonotic pathogens, and Jones *et al.* (2008) concluded that 60% of emerging infectious diseases between 1940 and 2004 were zoonoses (with 71% of these originating in wildlife rather than livestock species). HIV, West-Nile fever, Zika virus disease, Ebola virus disease, severe acute respiratory syndrome (SARS coronavirus), Middle East respiratory syndrome, Hendra virus infection, Highly Pathogenic Avian Influenza (HPAI) and Nipah virus are all examples of new diseases that have emerged over the last century with a zoonotic origin involving wildlife (United Nations Environment Programme 2020). Most recently, COVID-19 – a respiratory disease with a zoonotic origin (WHO 2020a) which, at the time of writing, had claimed more than two million lives in little over one year (WHO 2020b)– has shone an unprecedented spotlight on the effects of zoonotic spill over[3]. With some evidence indicating that the incidence of emerging infectious diseases is increasing over time (Jones *et al.* 2008), and as the ramifications of COVID-19 continue across the globe, calls to minimise the risk of zoonotic disease spill over have never been louder.

While many human activities are known to influence the risk of zoonotic spill over (Allen *et al.* 2017; Gibb *et al.* 2020), wildlife trade has been identified as one of the major potential pathways of zoonotic disease emergence, as well as an activity that plays a role in maintaining endemic zoonotic diseases (i.e. those that regularly spill over from animals to humans) in circulation (Karesh *et al.* 2005; Karesh *et al.* 2007; Pavlin *et al.* 2009; Smith *et al.* 2012; OIE 2020). The scale of the global wildlife trade is difficult to quantify, with the nature of transactions varying from informal and highly localised markets to well established international trade routes that cover both legal and illegal shipments. However, estimates that do exist point to extremely large numbers of species and individual animals involved; Karesh *et al.* (2005), for example, estimated that numbers of hunters/collectors, middle marketers and consumers resulted in "at least some multiple of 1 billion direct and indirect contacts among wildlife, humans, and domestic animals…annually". Travis *et al.* (2011) described wildlife trade as "[conceivably]… the biggest risk factor in the global spread of zoonotic and emerging infectious diseases" and noted that it was "unarguably among the top-ranking modes of transmission".

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[2] Defined by Grace *et al.* (2012) as diseases that appeared on more than one of the following: the World Health Organisation Global Burden of Disease, the World Animal Health Organisation list of notifiable zoonoses, zoonoses important to poor people identified by expert consultation (Perry *et al.* 2002), the Rosetta listing of infectious causes of death, and a systematic review of zoonoses commissioned by DFID, which identified 373 zoonoses as important.
[3] Defined here as the transmission of a pathogen from an animal to a human after Plowright *et al.* (2017).

One of the avenues through which it has been suggested that zoonotic risk could be integrated more closely into the management of international wildlife trade is the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). The aim of CITES is to ensure that international trade does not threaten species survival. The criteria for listing taxa in the CITES Appendices (outlined in Resolution 9.24 (Rev. CoP17) of the Convention) are therefore focused on the sustainability of trade and not on any potential impacts of such trade on human health; Article XIV.2 of the Convention additionally stipulates that provisions of the Convention shall not affect domestic measures or those derived from other international agreements that relate to, amongst other things, public health and veterinary issues. Importantly, the Convention does not regulate international trade in all species, but only those that are listed under its Appendices, which currently contain around 6000 animal taxa (CITES Secretariat 2020). There have been suggestions that CITES Parties might specifically mitigate the risk of zoonotic spill over resulting from or propagated by international trade in wildlife (Ashe & Scanlon 2020; Weissgold *et al.* 2020), although various counter-arguments have been published (Mongabay 2020; Weissgold *et al.* 2020), which view the Convention's focus on sustainability as one of its key strengths.

Important discussions about the options for minimising zoonotic disease risk from international wildlife trade are yet to take place at a multilateral level. However, the first step in deciding whether CITES might be an appropriate mechanism for interventions is to gain a stronger understanding of the relevance of zoonotic risk in the CITES context, by scrutinising recent trade patterns in CITES-listed species that have been found to host zoonotic pathogens. Some studies have started to consider these questions: Can *et al.* (2019) cross-compared trade in live individuals of CITES listed mammal, reptile, amphibian, and bird species with disease reports held in the OIE WAHIS-Wild database for the same species groups[4]. The authors considered trade for commercial and personal purposes only, and used a database containing details of host/disease associations of a limited list of diseases that member countries of OIE are encouraged to provide information on voluntarily. Borsky *et al.* (2020) investigated trade levels in live CITES-listed terrestrial species and the number of viruses associated with these species, based on a dataset created through a literature review by Johnson *et al.* (2020). Both studies agreed that the number of transactions involving CITES-listed species with zoonotic risk was substantial.

To our knowledge, no study has yet considered the potential zoonotic risk of trade in both live and raw[5] commodities of CITES-listed species across all sources and purposes. Neither has a study investigated zoonotic risk of CITES trade across a broad spectrum of pathogen types (viruses, bacteria, fungi, protozoans and parasitic worms (helminths)). In this report, we systematically reviewed literature detailing known associations between animals and zoonotic diseases to collate a dataset with which to explore potential zoonotic risk. We focus on investigating trade at the family level, since species within the same family are likely to carry similar zoonotic diseases (Davies & Pedersen 2008), but not all species are equally well studied in the context of zoonotic risk. Research effort has been shown to be a major predictor of detecting species-disease associations (Olival *et al.* 2017; Becker *et al.* 2020 and references therein; Johnson *et al.* 2020), so it is important that species are not discounted as a potential zoonotic risk due to lack of published evidence of direct disease associations; particularly if they are closely related to taxa for which risk has been documented (Becker *et al.* 2020).

Firstly, we provide an outline of trade across all raw commodities, sources and purposes in CITES animal families that were found to be associated with at least one zoonotic disease in

[4] Note however that this paper has been critiqued for suggesting that its results are indicative of all trade in wildlife rather than a particular subset of species (see Eskew *et al.* (2019) and the associated reply from Can *et al.*)

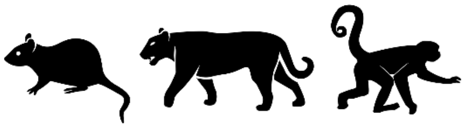
[5] Term codes for manufactured and processed products were excluded from the analysis. See Annex A for methods and commodities included.

the literature, including taxa associated with a subset of zoonotic diseases in our dataset that were considered to pose the highest risk to human health by the World Organisation for Animal Health (OIE).

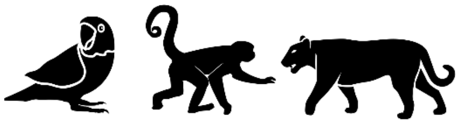
Secondly, we explore patterns of legal trade in two key commodities that are considered to be particularly high risk in terms of zoonotic spill over: live animals and meat. It should be noted that, to our knowledge, there have been no systematic reviews of the comparative zoonotic risk posed across different commonly traded wildlife commodities; for example, whether meat is generally a higher risk commodity than unprocessed skins. It is also often difficult to separate risks that are related purely to the commodity itself (i.e. is meat a commodity that intrinsically carries a high pathogen load?) from those related to their preparation (is meat a high risk commodity because its preparation involves butchering, which can increase the chances of pathogens entering the body as a result of injury?), as well as those that relate to the rearing and trading conditions of the animals. Animals that are captive-bred may carry an increased risk, for example, if they are being kept in unsanitary (Greatorex *et al.* 2016) or cramped conditions (Webster 2004; Woo *et al.* 2006). Likewise, disease risk is known to vary throughout the supply chain (e.g. Van Vliet *et al.* 2017; Huong *et al.* 2020), meaning that it is often impossible to provide a definitive risk rating for any particular species or commodity regardless of context. Nevertheless, there is a wealth of literature outlining examples of zoonotic spill over from live animals and meat, and of zoonotic pathogens that have been detected within such commodities (Bachand *et al.* 2012; Boseret *et al.* 2013; Kurpiers *et al.* 2015; Chaber & Cunningham 2016; Temmam *et al.* 2017).

2| Occurrence of zoonotic disease in CITES-listed taxa

38% of taxa associated with at least one zoonotic disease were CITES-listed



Rodents, carnivores and primates were associated with the largest number of zoonotic diseases



Parrots, primates and carnivores had the largest number of CITES-listed taxa that were directly associated with zoonotic diseases

Source: Literature review

In order to explore the potential health risk posed by the international trade in CITES-listed wildlife, it is important to first understand the zoonotic diseases likely to be associated with different species. To identify which animal taxa are associated with zoonotic diseases, and ultimately which taxa to include in our analysis of CITES trade data, we conducted a systematic, targeted search of peer reviewed literature. Through this we identified 22 source papers containing taxon/zoonotic disease associations, detailing 1608 unique taxa associated with 369 pathogens causing 275 diseases. Twenty-five of these diseases were classified as having the highest risk to human health by OIE; hereafter these 25 diseases are referred to as “high-risk zoonotic diseases”[6]. Complete methods on the systematic search are detailed in Annex A.

While the majority (80%) of taxa were reported at the species level in the source papers, some were reported at higher taxonomic levels, including genus, family, order, and class (Table 2.1). Of the 1608 unique taxa identified from the source papers, 611 (~38%) were either CITES-listed taxa (527, including higher level taxon listings such as Primates) or were higher level taxa that included both CITES-listed and non-CITES-listed taxa (84), hereafter collectively referred to as “CITES taxa” (Table 2.1). CITES taxa were associated with 193 pathogens known to cause 152 diseases. These accounted for 52% and 55% of the total number of pathogens and diseases identified in the source papers, respectively.

[6] Anthrax, Avian influenza, Botulism, Bovine tuberculosis/zoonotic tuberculosis, Brucellosis, Bunyamwera fever, Crimean-Congo haemorrhagic fever, Cystic echinococcosis, Dengue fever, Eastern equine encephalitis, Ebola virus disease (EVD), Japanese encephalitis, Leishmaniasis, Marburg virus disease, Monkeypox, Plague, Porcine cysticercosis, Rift Valley fever, Haemorrhagic Fever with Renal Syndrome, Salmonellosis, Severe acute respiratory syndrome (SARS), Tick-borne encephalitis, Venezuelan equine encephalitis, Western equine encephalitis, Zika virus

Table 2.1: Number of taxa reported in source papers (n=22) as associated with at least one zoonotic disease (and with at least one high-risk zoonotic disease), by the reported taxonomic level.

Taxonomic level	CITES taxa	Non-CITES taxa	Total taxa
Superclass	1 (0)	0 (0)	1 (0)
Class	1 (1)	0 (0)	1 (1)
Infraclass	1 (0)	0 (0)	1 (0)
Order	11 (10)	1 (1)	12 (11)
Suborder	2 (2)	0 (0)	2 (2)
Family	58 (44)	36 (19)	94 (63)
Genus	70 (47)	83 (51)	153 (98)
Species	435 (94)	856 (240)	1291 (333)
Subspecies	32 (10)	21 (7)	53 (17)
Total taxa	611 (208)	997 (318)	1608 (525)

From the source papers analysed, the orders Rodentia (rodents), Chiroptera (bats) and Carnivora (mammalian carnivores) contained the largest number of taxa associated with at least one zoonotic disease (together comprising 40% of all taxa included in the source papers; Table 2.2a). Rodentia and Carnivora were also the top orders by number of associated zoonotic diseases (141 and 88 diseases, respectively); they were followed by Primates with 83 associated diseases (see Annex B for complete list). When only considering orders that include CITES-listed taxa, Psittaciformes (parrots) had the highest number of taxa associated with zoonotic diseases (22% of the CITES taxa associated with zoonotic diseases), followed by Primates and Carnivora (Table 2.2b). While orders Rodentia and Chiroptera were associated with a high number of diseases in the source papers, these taxa are not well-represented in the CITES Appendices.

Table 2.2: Top ten taxonomic orders by number of taxa associated with zoonotic diseases reported in source papers by (a) all orders, and (b) orders that include CITES-listed taxa. The percentage of the total number of (a) taxa (n=1608) or (b) CITES-listed taxa (n=611) associated with at least one zoonotic disease is shown in parentheses. See Annex B for a list of diseases associated with each order based on the source papers, as well as the number of CITES-listed species per order.

(a) Order	No. of taxa
Rodentia (rodents)	279 (17%)
Chiroptera (bats)	201 (13%)
Carnivora (carnivores)	160 (10%)
Psittaciformes (parrots)	142 (9%)
Primates (primates)	124 (8%)
Passeriformes (songbirds)	114 (7%)
Artiodactyla (even-toed ungulates)	55 (3%)
Charadriiformes (waders/gulls)	50 (3%)
Falconiformes (falcons)	40 (2%)
Anseriformes (ducks)	31 (2%)

(b) Order	No. of CITES-listed taxa
Psittaciformes (parrots)	138 (23%)
Primates (primates)	124 (20%)
Carnivora (carnivores)	95 (16%)
Falconiformes (falcons)	40 (7%)
Artiodactyla (even-toed ungulates)	38 (6%)
Chiroptera (bats)	18 (3%)
Testudines (tortoises/turtles)	15 (2%)
Rodentia (rodents)	14 (2%)
Sauria (lizards)	13 (2%)
Strigiformes (owls)	13 (2%)

Of the 25 zoonotic diseases considered the highest risk to human health, 23 were directly recorded in CITES-listed taxa, although all 25 were found in families that include CITES-listed taxa. In total 52 CITES families were associated with at least one of these high-risk zoonotic diseases. See Annex C for a list of CITES-listed species directly associated with at least one zoonotic disease (and any high-risk diseases) according to the source papers. The taxa/zoonotic disease associations identified in the source papers were used to determine which animal families were included in the CITES trade data analysis. CITES families where the family or at least one taxon (e.g. species or genus) were found to be associated with a zoonotic disease (e.g. as a host or vector) in the source papers were hereafter collectively referred to as ‘families associated with at least one zoonotic disease’. Trade in all CITES-listed taxa within these families was included in the trade analysis, in an effort to address any sampling bias in the research community for identifying species with zoonotic risk (i.e. some species may not yet have been studied) and since species within the same family are likely to carry similar zoonotic diseases.

3| Analysis of CITES trade data and zoonotic diseases risk

The CITES Appendices currently include representatives from 324 families: 264 animal families and 60 plant families. Families vary in the number of species that are listed; in some cases, listings made at the higher taxonomic level[7] mean that all species comprising that family are included in the Appendices, however in other cases[8] only a small subset of species in a family are listed.

Of the 264 CITES animal families, 117 families (44%) included at least one taxon associated with a zoonotic disease (Figure 3.1). Mammals and birds are the two classes containing the highest proportion of families associated with at least one zoonotic disease, with over two thirds of families associated with one or more zoonotic disease in both cases (54 and 38 families respectively; Figure 3.2).

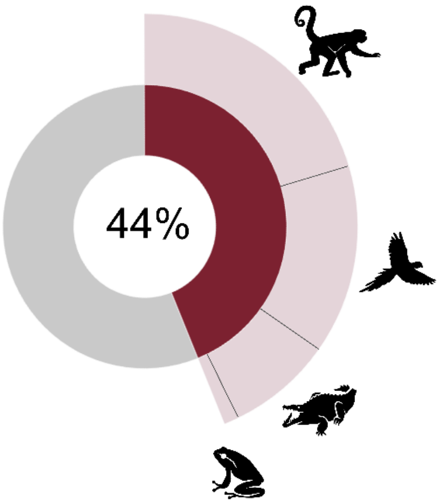


Figure 3.1: Proportion of CITES animal families (n=264) associated with at least one zoonotic disease (red). The outer ring shows the proportion of these families that belong to each taxonomic class.

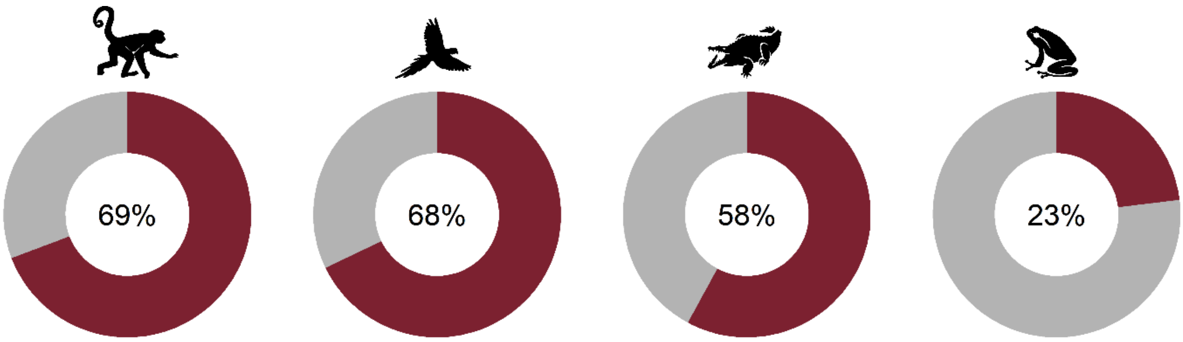
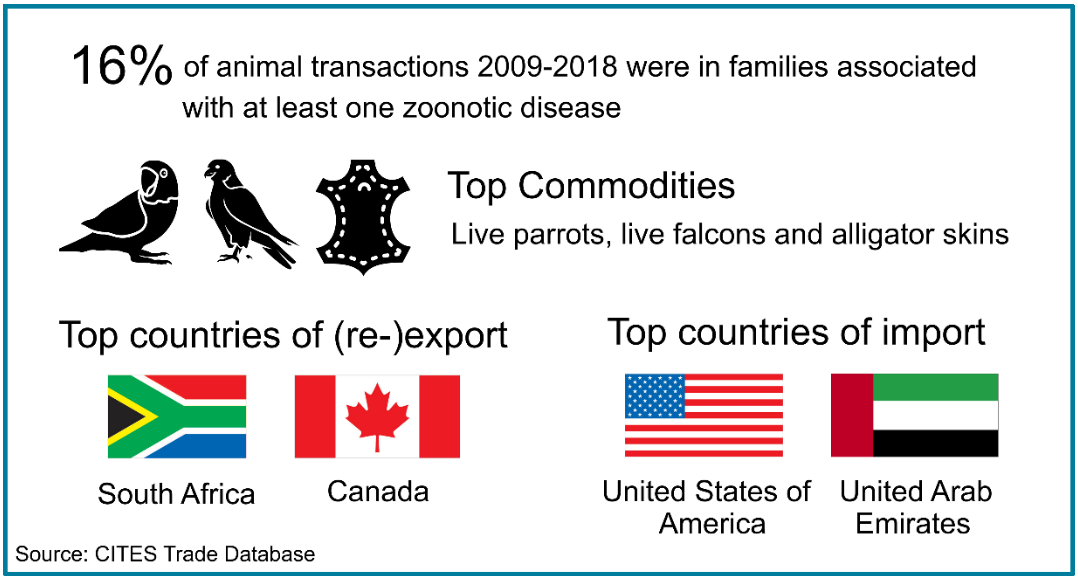


Figure 3.2: Proportion of CITES mammal (n=78), bird (n=56), reptile (n=38) and amphibian (n=13) families that included at least one taxon associated with a zoonotic disease.

[7] For example, all members of the family Pythonidae are listed in the Appendices under “Pythonidae spp.”, therefore all python species are fully represented in the Appendices.

[8] For example, all members of the fruit bat genus *Acerodon* and almost all *Pteropus* species (excluding *Pteropus brunneus*) (both family Pteropodidae) are listed in the Appendices, but other genera within Pteropodidae are not represented. Furthermore, in some cases only specific species of a given family may be listed in the Appendices (e.g. *Lama guanicoe* and *Vicugna vicugna* in the family Camelidae).

3.1 Global overview of transactions in CITES animal families associated with zoonotic diseases



The CITES Trade Database contains 5.1 million (re-)exporter[9]-reported animal transactions between 2009-2018. Of these, approximately 0.8 million (16%) involved families associated with at least one zoonotic disease. The relative proportion of CITES trade transactions in families associated with zoonotic diseases has remained fairly consistent over the past 10 years (range: 14%-18% of trade per year; Figure 3.3). When looking at trade in live, raw and semi-raw commodities only (see Annex A for definition and commodities included), around 40% of transactions were in families associated with zoonotic diseases (see Annex D for family trade summarised by number of items and weight).

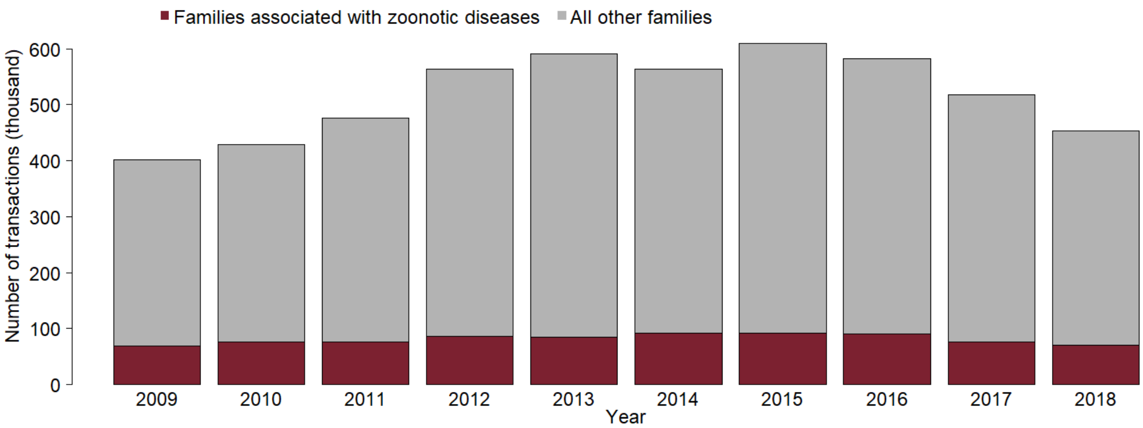


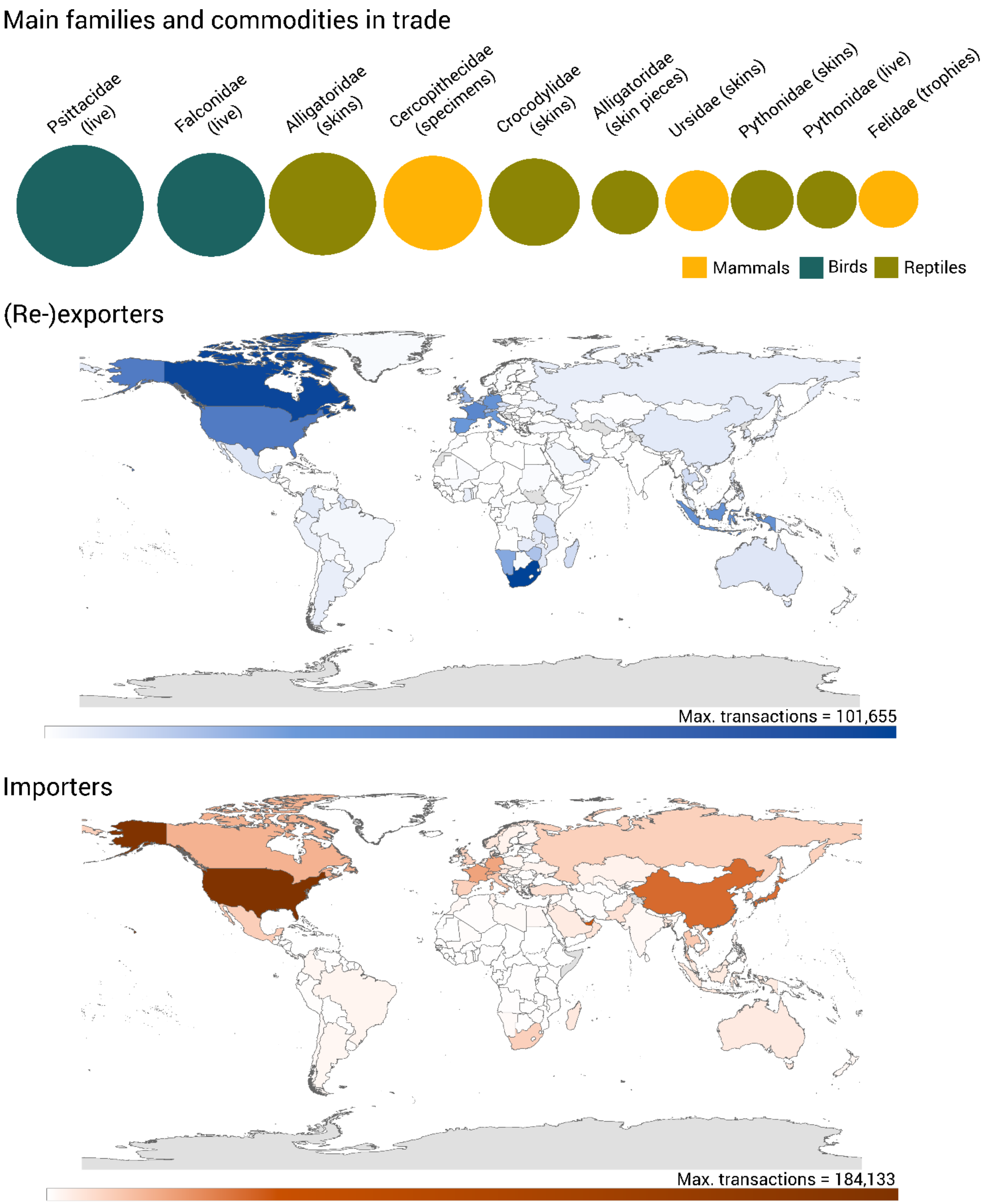
Figure 3.3: Number of (re-)exporter-reported CITES-listed animal transactions in all commodities over time.

Over the ten-year period, approximately 19% of (re-)exporter-reported transactions in families associated with zoonotic diseases were in live Psittacidae (~90,000 transactions) and Falconidae (~65,000 transactions). A further 17% of transactions (~140,000) were in reptile skins, particularly Alligatoridae skins (~63,000 transactions) (Figure 3.4). The largest (re-)exporters of families associated with at least one zoonotic disease by number of

[9] Exports (direct trade) and re-exports (indirect trade) are collectively referred to as (re-)exports.

transactions were South Africa (13%, primarily live birds and mammal trophies) and Canada (12%, primarily mammal skins). The largest countries of import by numbers of transactions were the United States of America[10] (23%, primarily live reptiles and mammal specimens and trophies), United Arab Emirates (6%, mainly live birds) and East Asia (China, Japan, and the Republic of Korea comprising 14%, reptile skins and live birds and reptiles) (Figure 3.4). It is important to note that the high levels of trade noted here do not necessarily indicate that there is a higher risk of disease in trade with these countries, as the relative level of risk from individual taxa or commodities (and any mitigation measures in place, such as animal health provisions, that could potentially lower risk) were not taken into account.

[10] Hereafter referred to as 'the United States'.



Data source: CITES Trade Database (https://trade.cites.org/). Base layers: United Nations Geospatial, 2020. The designations employed and the presentation of material on this map do not imply the expression of any opinion whatsoever on the part of the Secretariat of the United Nations concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries.

Figure 3.4: Number of (re-)exporter-reported CITES-listed animal transactions in live, raw or semi-raw commodities of families associated with at least one zoonotic disease by (a) main families and commodities, (b) (re-)exporter, and (c) importer, 2009-2018. Continuous scales indicate the relative levels of trade among exporters and among importers, and the maximum number of transactions per (re-)exporter/importer; grey shading indicates no data.

There were 225 zoonotic diseases associated with CITES-listed families traded as live, raw or semi-raw commodities 2009-2018. Leptospirosis and Chlamydiosis were found in the highest number of traded families (37 and 36 respectively), although care should be taken in interpreting this due to biases in researcher effort.

Whilst all 25 high-risk zoonotic diseases were associated with CITES families, only 22 of these diseases were associated with CITES families *in trade* as live, raw or semi-raw commodities 2009-2018. Of the ten most traded families associated with any zoonotic disease (based on the number of (re-)exporter-reported transactions), nine families were associated with at least one high-risk zoonotic disease, with Felidae associated with 13 (Table 3.1).

Table 3.1: Matrix showing the high-risk zoonotic diseases associated with each of the ten most-traded CITES families by number of (re-)exporter-reported transactions 2009-2018.

	Highly traded families									
High-risk zoonotic disease	Alligatoridae	Bovidae	Cercopithecidae	Crocodylidae	Falconidae	Felidae	Psittacidae	Pythonidae	Ursidae	Varanidae
Anthrax		■	■			■			■	
Avian influenza			■			■				
Botulism		■								
Bunyamwera fever										
Bovine tuberculosis/zoonotic tuberculosis		■	■			■			■	
Brucellosis		■				■			■	
Crimean-Congo haemorrhagic fever		■				■				
Cystic echinococcosis		■				■				
Dengue fever			■							
Eastern equine encephalitis			■							
Ebola virus disease (EVD)		■	■							
Haemorrhagic fever with renal syndrome										
Japanese encephalitis			■							
Leishmaniasis						■				
Marburg virus disease			■							
Monkeypox			■							
Plague						■			■	
Porcine cysticercosis									■	
Rift Valley fever		■				■				
Salmonellosis		■		■	■	■	■	■		■
Severe acute respiratory syndrome (SARS)						■				
Tick-borne encephalitis		■								
Venezuelan equine encephalitis						■				
Western equine encephalitis										
Zika virus		■	■			■				

3.1.1. Summary of commodities in trade in species associated with at least one zoonotic disease

From the source papers, 433 CITES-listed species were found directly associated with at least one zoonotic disease (e.g. as host or vector). Of these, 331 species were reported by (re-)exporters in transactions of live, raw, or semi-raw commodities 2009-2018 (15% of all CITES-listed species reported as traded in these commodities during this time) (Table 3.2), including some of the dominant species in trade by number of species commodity transactions (e.g. *Macaca fascicularis* (long-tailed macaque) scientific specimens and *Crocodylus niloticus* (Nile crocodile) skins). Within CITES families associated with zoonotic diseases, five of the top ten species by commodity transactions were directly associated with at least one zoonotic disease (Figure 3.5). It is important to note that the absence of a direct association between a species and zoonotic disease does not indicate that the species isn't a potential host or vector, just that it was not found following the literature search methodology detailed in Annex A (e.g. it may not have been studied, or published papers may not have been returned via the search parameters used).

Table 3.2: Overview of the number of species and (re-)exporter-reported live, raw and semi-raw trade transactions in CITES-listed species directly associated with at least one zoonotic disease 2009-2018. This excludes trade reported at higher taxonomic levels.

	Total in trade	Species directly associated with zoonotic diseases	
		Any zoonotic disease	High-risk zoonotic disease
CITES-listed species in trade	2182	333	95
Transactions	810,000	268,000	200,000

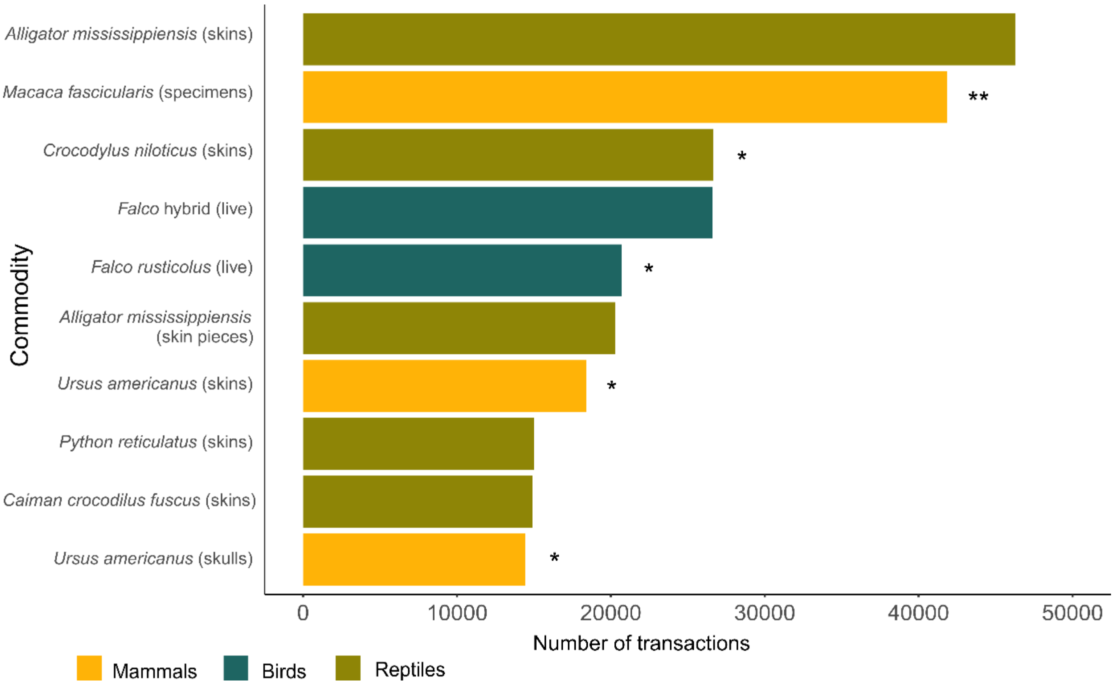


Figure 3.5: The top ten CITES-listed species commodities in trade from families associated with at least one zoonotic disease, based on the number of transactions in live, raw, and semi-raw commodities 2009-2018. Species directly associated with a zoonotic disease in the source literature are indicated with asterisks: * = associated with any zoonotic disease, ** = associated with at least one high-risk disease. Zoonotic associations for species hybrids were not included in the literature review.

Zoonotic disease risk from live animals and meat was considered and characterised in greater depth in the literature than for other commodities, and trade in live animals and meat comprised 38% of the (re-)exporter-reported transactions in 'live, raw, and semi-raw' commodities of families associated with zoonotic diseases. To allow comparable analysis by quantity as well as transaction, trade in live animals and meat will be considered in separate case studies.

3.2. Case study: Trade in CITES-listed live animals associated with zoonotic risk

Between 2009 and 2018, there were approximately 1.2 million (re-)exporter-reported live animal transactions and 90 million live animals in direct trade. Of these, 25% of transactions (~300,000 transactions) were in families associated with at least one zoonotic disease and involved ~26.5 million individuals (29% of all live individuals traded over this period). The majority of these families (94% of transactions and 79% individuals) were associated with one or more of the high-risk zoonotic diseases, either exclusively or in addition to lower-risk diseases: 22% of transactions (~274,000) and 24% of individuals (~21 million) were in families associated with high-risk zoonotic diseases.

Table 3.3 provides an overview of live trade in (a) all families associated with at least one zoonotic disease and (b) just the 52 families associated with the 25 high-risk zoonotic diseases. It summarises the main taxa, exporters, importers and sources by both (re-)exporter-reported transaction and quantity (direct trade by gross exports). This is followed by a more detailed analysis of trade in families associated with the high-risk zoonotic diseases.

Table 3.3: Overview of the highest taxa, exporters, importers and sources by the number of (re-)exporter reported transactions and quantity (direct trade by gross exports) of **live animals** in trade 2009-2018. Data are summarised for (a) all families associated with zoonotic diseases and (b) families associated with the high-risk zoonotic diseases.

	(a) All families associated with zoonotic diseases	(b) Families associated with high-risk zoonotic diseases
By transaction	**300,000 transactions** **25% of total transactions** **Main taxa**: Psittacidae (34%); Falconidae (22%) **Main (re-)exporters** South Africa (15%) Indonesia (9%) **Main importers** United Arab Emirates (15%) United States (12%) Japan (8%) **Sources** Captive-produced (77%); Wild-sourced (20%)	**274,000 transactions** **22% of total transactions** **Main taxa**: Psittacidae (33%); Falconidae (23%) **Main (re-)exporters** South Africa (13%) Indonesia (10%) **Main importers** United Arab Emirates (16%) United States (13%) **Sources** Captive-produced (76%) Wild-sourced (20%)
By quantity	**26.5 million animals** **29% of total quantity** **Main taxa**: Testudines (48%); Psittacidae (19%) **Main exporters** Peru (14%) China (12%) United States (11%) **Main importers** Hong Kong, SAR (16%) China (13%) United States (13%) **Sources** Captive-produced (59%); Wild-sourced (22%); Ranched (19%)	**21 million animals** **24% of total quantity** **Main taxa:** Psittacidae (23%); *Iguana iguana* (13%) **Main exporters** China (15%) El Salvador (13%) **Main importers** United States (17%) Hong Kong, SAR (9%) Italy (9%) **Sources** Captive-produced (64%) Wild-sourced (25%)

3.2.1 Summary of trade by transactions of live animals associated with high-risk zoonotic diseases

The CITES trade transactions in live animals belonging to families associated with the 25 high-risk zoonotic diseases were dominated by birds (56% of transactions) and reptiles (35%) (Figure 3.6). Mammals accounted for the majority of the remaining 9% of live transactions. Whilst, overall, the number of live reptile transactions was fairly similar between captive-produced (47% of reptiles) and wild-sourced (45% of reptiles), the majority of transactions of live birds and mammals were captive-produced (92% of bird transactions and 85% of mammals).

The main (re-)exporters of live taxa from families associated with high-risk zoonotic diseases, based on (re-)exporter-reported number of transactions, were South Africa (13%) and Indonesia (10%; Figure 3.7). The United Arab Emirates (16%) and the United States (13%) accounted for the majority of import transactions. The top ten trade routes based on these transactions included (re-)exports from Indonesia to the United States (mostly reptiles); from European nations to the United Arab Emirates (primarily falcons); from South Africa to Oman and Bangladesh (primarily parrots), from Madagascar to the United States (mostly reptiles); from the United States to Canada (primarily monkeys); and from Belgium to Japan (mostly owls and parrots) (Figure 3.8). It is important to note that the high levels of trade noted here do not necessarily indicate that there is a higher risk of disease in trade with these countries, as the relative level of risk from individual taxa (and any mitigation measures in place, such as animal health provisions, that could potentially lower risk) were not taken into account. The top families associated with high-risk zoonotic diseases based on the number of live animal transactions are summarised in Table 3.4 and include (a) Psittacidae, (b) Falconidae, (c) Pythonidae, and (d) Testudinidae.

Table 3.4: Overview of the top families associated with high-risk zoonotic diseases based on the number of (re-)exporter-reported **live animal transactions** in trade 2009-2018.

(a) Psittacidae (parrots)	
Total number of associated zoonotic diseases:	5 (Chlamydiosis; E. coli infection; Enterobacter infection; Salmonellosis; West Nile fever)
Number of associated high-risk diseases:	1 (Salmonellosis)
Quantity:	89,858 transactions; 33% of total live animal transactions from families associated with high-risk diseases zoonotic disease
Trade summary:	224 Psittacidae taxa were reported in trade; the top traded species was *Psittacus erithacus* (African grey parrot, 10,939 transactions), although no individual taxa accounted for more than ~12% of the total number of live Psittacidae transactions. South Africa was the primary (re-)exporter of this family (32,726 transactions), exporting a total of 161 taxa, including species of *Amazona* (Amazon parrots, 6,142 transactions) and *Ara* (macaws, 6,132 transactions) as well as 4,609 *P. erithacus* transactions. Japan, Oman, Pakistan and the United Arab Emirates were the top importers (5,301, 5,216, 5,205 and 5,045 transactions, respectively). Approximately 90% of Psittacidae transactions were captive-produced.

(b) Falconidae (falcons)	
Total number of associated zoonotic diseases:	3 (Chlamydiosis; Salmonellosis; Tularemia)
Number of associated high-risk diseases:	1 (Salmonellosis)
Quantity:	64,550 transactions; 24% of total live animal transactions from families associated with high-risk diseases zoonotic disease
Trade summary:	36 Falconidae taxa were reported in trade, largely *Falco* hybrid (26,598 transactions) and *F. rusticolus* (gyrfalcon, 20,710 transactions). The United Kingdom (15,656 transactions), United Arab Emirates (12,933) and Spain (12,299) were the main (re-)exporters; the United Arab Emirates was also the primary importer (37,828 transactions). Approximately 95% of Falconidae transactions were captive-produced.

(c) Pythonidae (pythons)	
Total number of associated zoonotic diseases:	4 (Chlamydiosis; *Mycobacterium genavense* infection; Salmonellosis; Strongyloidiasis)
Number of associated high-risk diseases:	1 (Salmonellosis)
Quantity:	19,911 transactions; 7% of total live animal transactions from families associated with high-risk diseases zoonotic disease
Trade summary:	38 Pythonidae taxa were reported in trade, with the highest being *Python regius* (ball python, 7,539 transactions) and *Morelia viridis* (green tree python, 1,691 transactions). The main (re-)exporters were Indonesia (8,395 transactions, primarily species of *Morelia* and *Python*) and the United States (4,523 transactions, primarily captive-produced *P. regius*); the United States was also the main importer of Pythonidae (6,259 transactions). Approximately 58% of live Pythonidae transactions were captive-produced (11,490 transactions), while 28% were wild-sourced (5,661 transactions).

(d) Testudinidae (tortoises)	
Total number of associated zoonotic diseases:	3 (Chlamydiosis; Leptospirosis; Salmonellosis)
Number of associated high-risk diseases:	1 (Salmonellosis)
Quantity:	15,860 transactions; 6% of total live animal transactions from families associated with high-risk diseases zoonotic disease
Trade summary:	44 Testudinidae taxa were reported in trade; approximately 34% of transactions were in species belonging to the genus *Testudo* (5,325 transactions), with the highest traded species being *Chelonoidis carbonarius* (red-footed tortoise, 2,062 transactions) and *Stigmochelys pardalis* (leopard tortoise, 1,986 transactions). The main (re-)exporters were Germany (1,448 transactions, primarily species of captive-produced *Testudo*) and Uzbekistan (1,314 transactions, almost all wild-sourced and ranched *Testudo horsfieldii* (Horsfield's tortoise)). The main importers were the United States (3,017 transactions), Hong Kong, SAR (2,113 transactions) and Japan (2,017 transactions). Approximately 70% of live Testudinidae transactions were captive-produced.

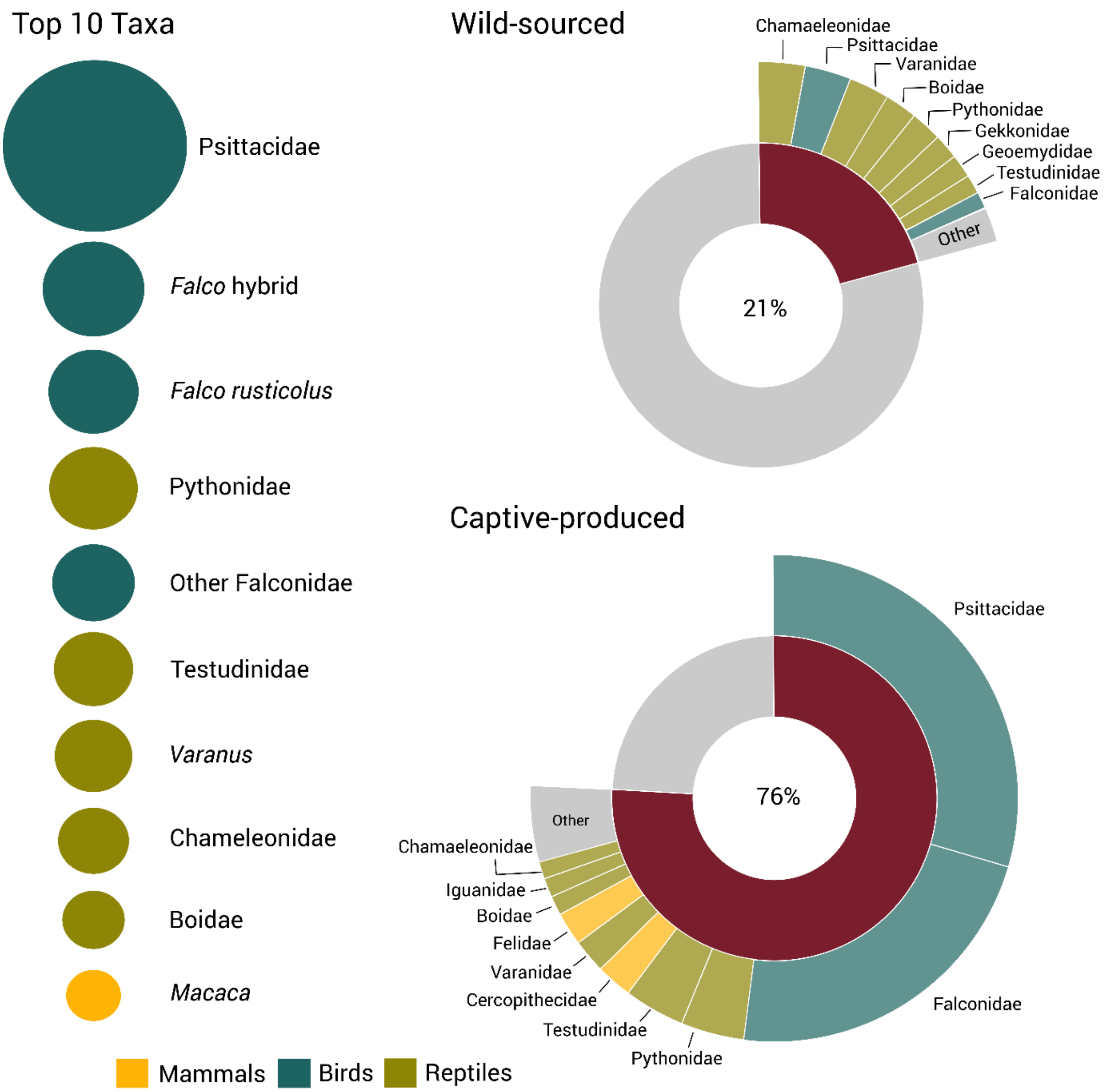
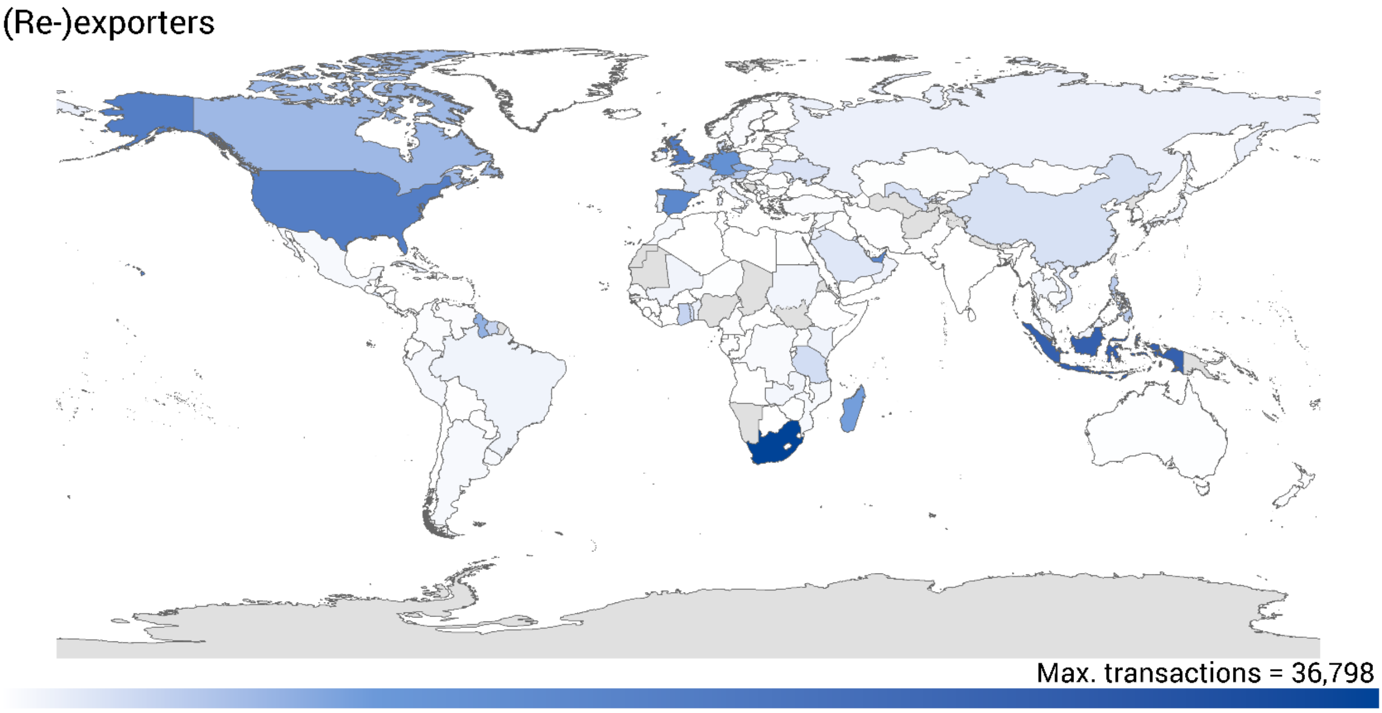
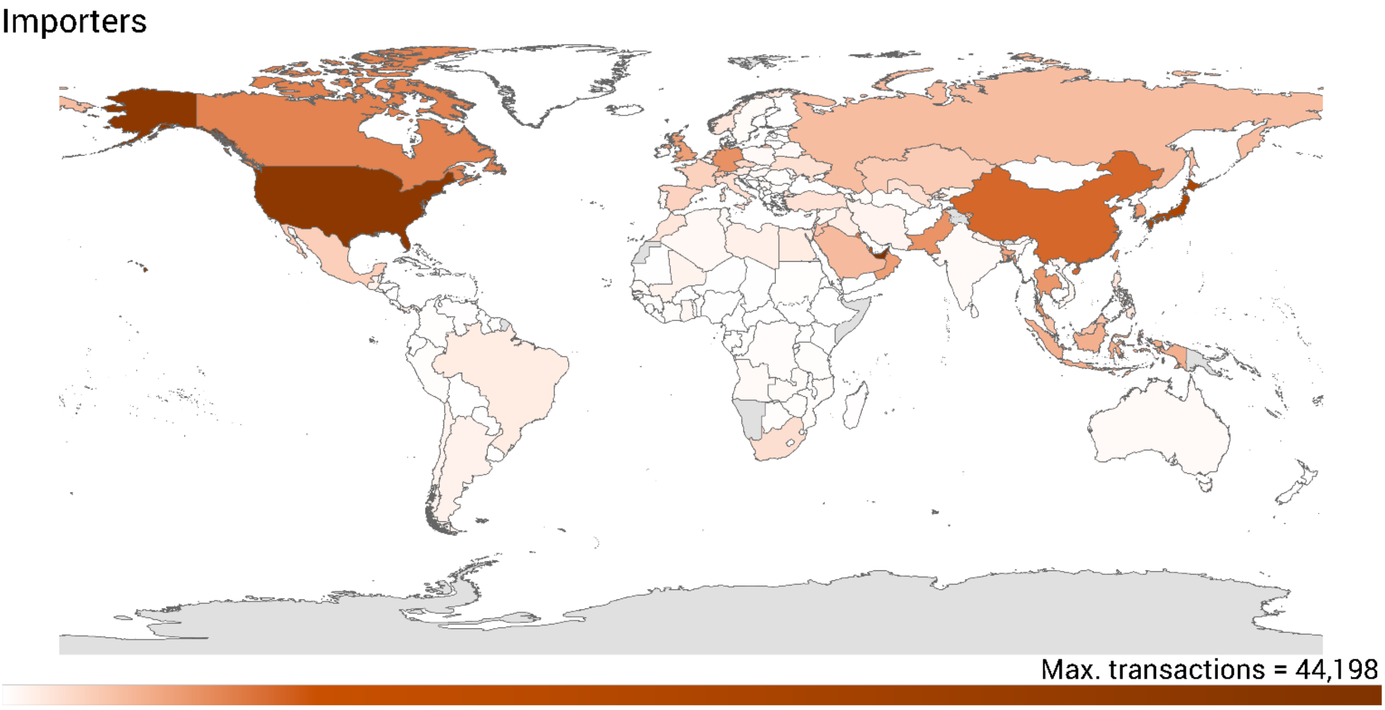


Figure 3.6: Summary of trade by **number of (re-)exporter-reported transactions** in live individuals from families associated with high-risk zoonotic diseases by top 10, wild-sourced taxa, and captive-produced taxa (all families accounting for >1% of trade by source are shown) 2009-2018. The proportion of transactions that were wild-sourced (21%) or captive-produced (76%) are indicated in red.

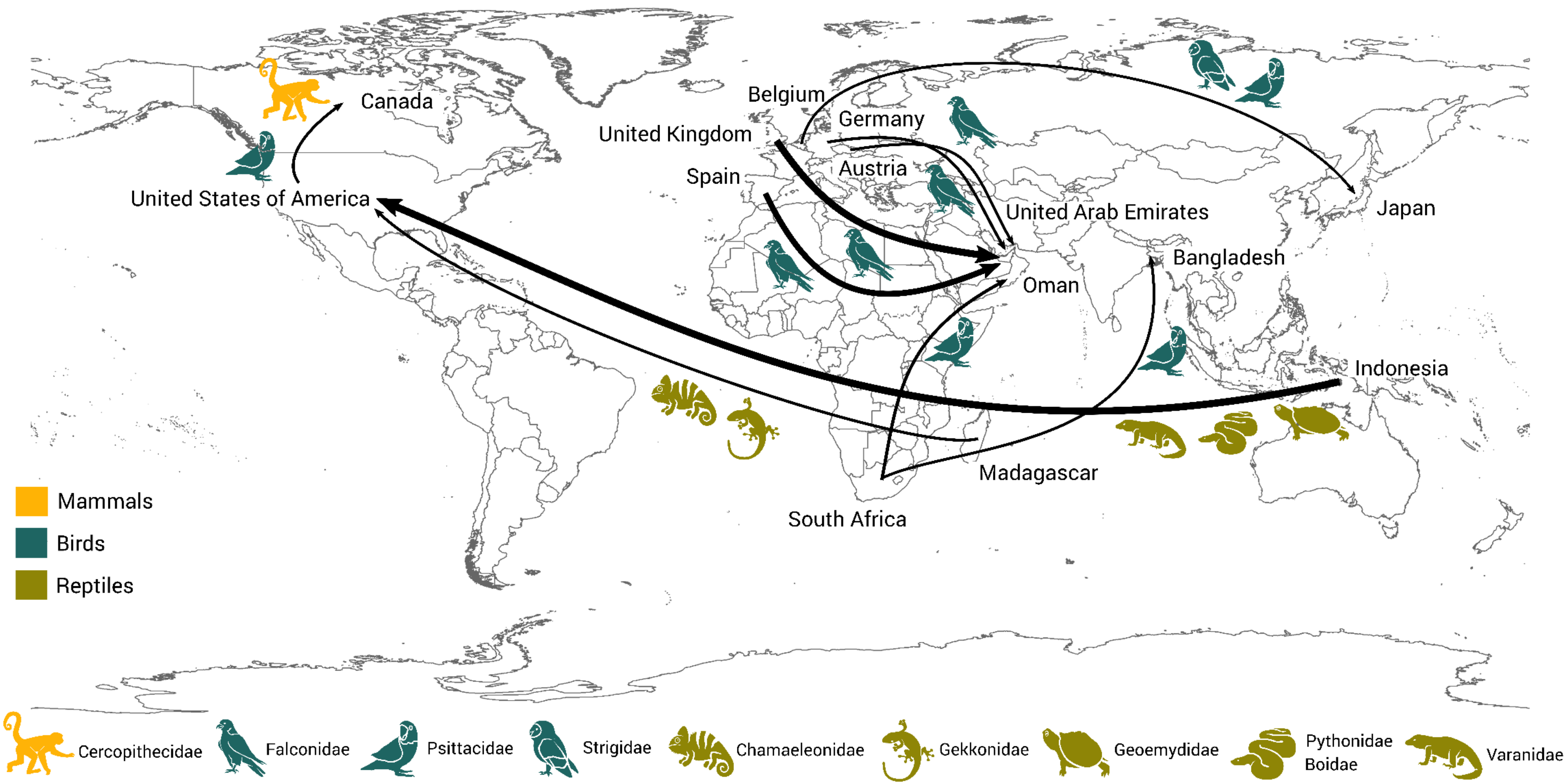




Data source: CITES Trade Database (https://trade.cites.org/). Base layers: United Nations Geospatial, 2020. The designations employed and the presentation of material on this map do not imply the expression of any opinion whatsoever on the part of the Secretariat of the United Nations concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries.

Figure 3.7: Main (re-)exporters and importers by **number of (re-)exporter-reported transactions in live animals** (all sources) from families associated with high-risk zoonotic diseases 2009-2018. Continuous scales indicate the relative levels of trade among exporters and among importers, and the maximum number of transactions per (re-)exporter/importer; grey shading indicates no data.

Zoonotic potential of international trade in CITES-listed species



Data source: CITES Trade Database (https://trade.cites.org/). Base layers: United Nations Geospatial, 2020. The designations employed and the presentation of material on this map do not imply the expression of any opinion whatsoever on the part of the Secretariat of the United Nations concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries.

Figure 3.8: Top ten trade routes by **number of (re-)exporter-reported transactions in live animals** (all sources) from families associated with high-risk zoonotic diseases 2009-2018; trade routes visualised account for 23% of this trade. Icons indicate the main taxa traded along each route.

3.2.2. Summary of trade by quantity of live animals associated with high-risk zoonotic diseases

Whilst the greatest number of live trade transactions were in birds, reptiles accounted for the highest *quantities* of live animals in families associated with the high-risk zoonotic diseases (73%). Over half of reptiles traded were captive-produced (58% of live reptiles), with 28% from wild sources and 14% from ranched. The majority of the remaining trade was in birds (24% of the total quantity), primarily from captive-produced sources (Figure 3.9).

The main exporters of live taxa from families associated high-risk zoonotic diseases, based on the quantity of animals in direct trade, were China (15%) and El Salvador (13%) (Figure 3.10). The United States (17%), Hong Kong, SAR (9%) and Italy (9%) were the top importers. While the main taxa traded along top trade routes by transaction involved mostly birds and reptiles, the main taxa in top trade routes by quantity almost exclusively involved reptiles. The top ten trade routes based on quantity included exports from China to Italy and Germany (mainly turtles); from El Salvador to the United States, Mexico, and Hong Kong, SAR (primarily iguanas and tortoises); from Togo to the United States (mostly reptiles); from Uruguay to Mexico (exclusively parrots); from Indonesia to China (mostly reptiles); from the United States to Portugal (mainly pond turtles); and from Viet Nam to China (mainly crocodiles and other reptiles) (Figure 3.11). It is important to note that the high levels of trade noted here do not necessarily indicate that there is a higher risk of disease in trade with these countries, as the relative level of risk from individual taxa (and any mitigation measures in place, such as animal health provisions, that could potentially lower risk) were not taken into account. The top families associated with high-risk zoonotic diseases based on the quantity of live animals in trade are summarised in Table 3.5 and include (a) Psittacidae, (b) Testudinidae, (c) Iguanidae, and (d) Geoemydidae.

Table 3.5: Overview of the top families associated with high-risk zoonotic diseases based on the **quantity of live animals** in trade 2009-2018.

(a) Psittacidae (parrots)	
Total number of associated zoonotic diseases	5 (Chlamydiosis; E. coli infection; Enterobacter infection; Salmonellosis; West Nile fever)
Number of associated high-risk diseases	1 (Salmonellosis)
Quantity	4.9 million individuals; 23% of total trade in live animals from families associated with high-risk diseases zoonotic disease
Trade summary	234 Psittacidae taxa were reported in trade; the top traded taxa were *Agapornis fischeri* (Fischer's lovebird, 0.96 million individuals) and *Psittacus erithacus* (African grey parrot, 0.69 million individuals). South Africa was the primary exporter of this family (2.2 million individuals, ~44% of the total number of Psittacidae in direct trade). Mexico and Indonesia were the top importers (0.77 million and 0.5 million individuals, respectively). Approximately 80% of Psittacidae trade was in captive-produced individuals, with almost all of the remaining 20% wild-sourced.

(b) Testudinidae (tortoises)	
Total number of associated zoonotic diseases	3 (Chlamydiosis; Leptospirosis; Salmonellosis)
Number of associated high-risk diseases	1 (Salmonellosis)
Quantity	3 million individuals, 14% of total trade in live animals from families associated with high-risk diseases zoonotic disease
Trade summary	46 Testudinidae taxa were reported in trade, with over half the total quantity accounted for by *Testudo horsfieldii* (Horsfield's tortoise, 1 million individuals) and *Stigmochelys pardalis* (leopard tortoise, 0.55 million individuals). The main exporters were Uzbekistan (0.94 million individuals, all *T. horsfieldii,* primarily from wild and ranched sources) and Zambia (0.33 million, primarily captive-produced *S. paradalis*). Hong Kong, SAR and the United States were the top importers (0.97 million and 0.4 million individuals respectively). Approximately 64% of Testudinidae trade was in captive-produced individuals, with 22% wild-sourced and 13% ranched.

(c) Iguanidae (iguanas)	
Total number of associated zoonotic diseases	8 (Chlamydiosis; Dermatophytosis; Leptospirosis; *Mesocestoides* infection; Pentastomiasis; *Plesiomonas* infection; Salmonellosis; Yersiniosis)
Number of associated high-risk diseases	1 (Salmonellosis)
Quantity	2.7 million individuals, 13% of total trade in live animals from families associated with high-risk diseases zoonotic disease
Trade summary	Whilst there were 22 Iguanidae taxa reported in trade, almost all were in one species: *Iguana iguana* (green iguana, >99%). *I. iguana* were primary exported by El Salvador (2.5 million individuals) and imported by the United States (1 million individuals), Mexico (0.61 million individuals) and Hong Kong, SAR (0.36 million individuals). Trade was almost entirely captive-produced (97%).

(d) Geoemydidae (pond/river and wood turtles)	
Total number of associated zoonotic diseases:	2 (Leptospirosis; Salmonellosis)
Number of associated high-risk diseases:	1 (Salmonellosis)
Quantity:	2.6 million individuals, 12% of total trade in live animals from families associated with high-risk diseases zoonotic disease
Trade summary	44 Geoemydidae taxa were reported in trade; the top traded taxa were *Mauremys reevesii* (Reeves' pond turtle, 1.2 million individuals) and *M. sinensis* (Chinese stripe-necked turtle, 0.97 million individuals). China was the main exporter (2 million individuals, almost entirely *M. reevesii and M. sinensis*, primarily captive-produced). Italy and Germany were the main importers (0.83 million and 0.65 million individuals, respectively). Approximately 65% of Geoemydidae in trade were captive-produced, with 33% wild-sourced.

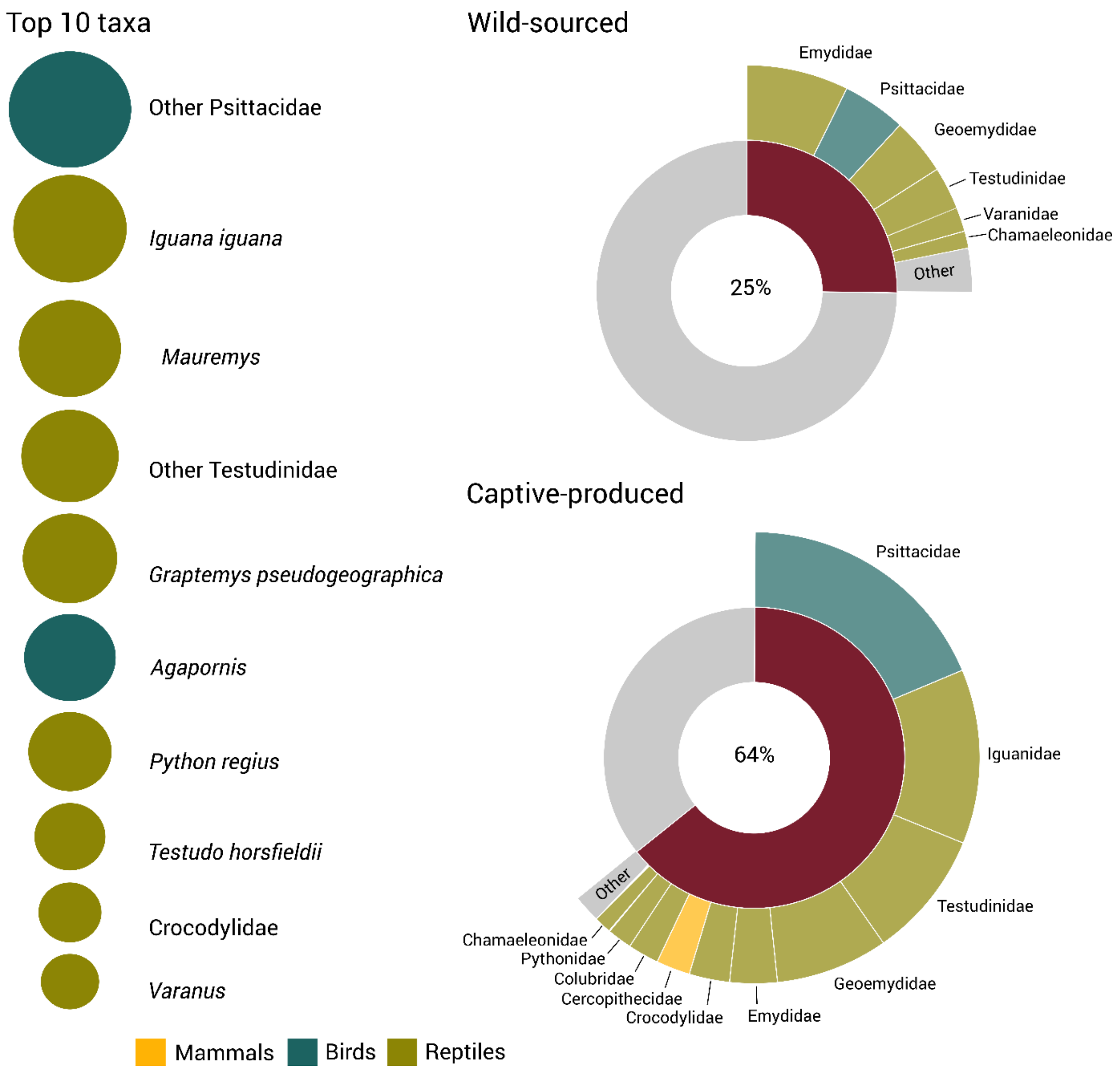
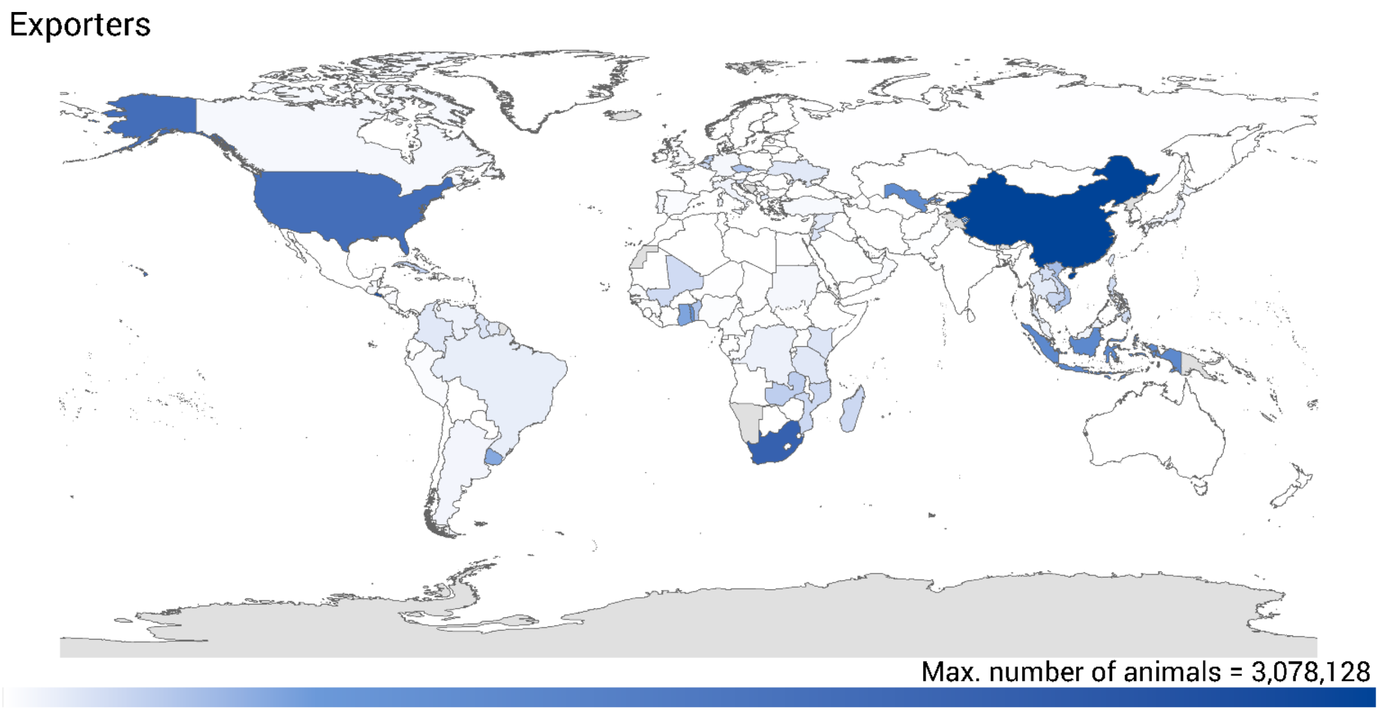
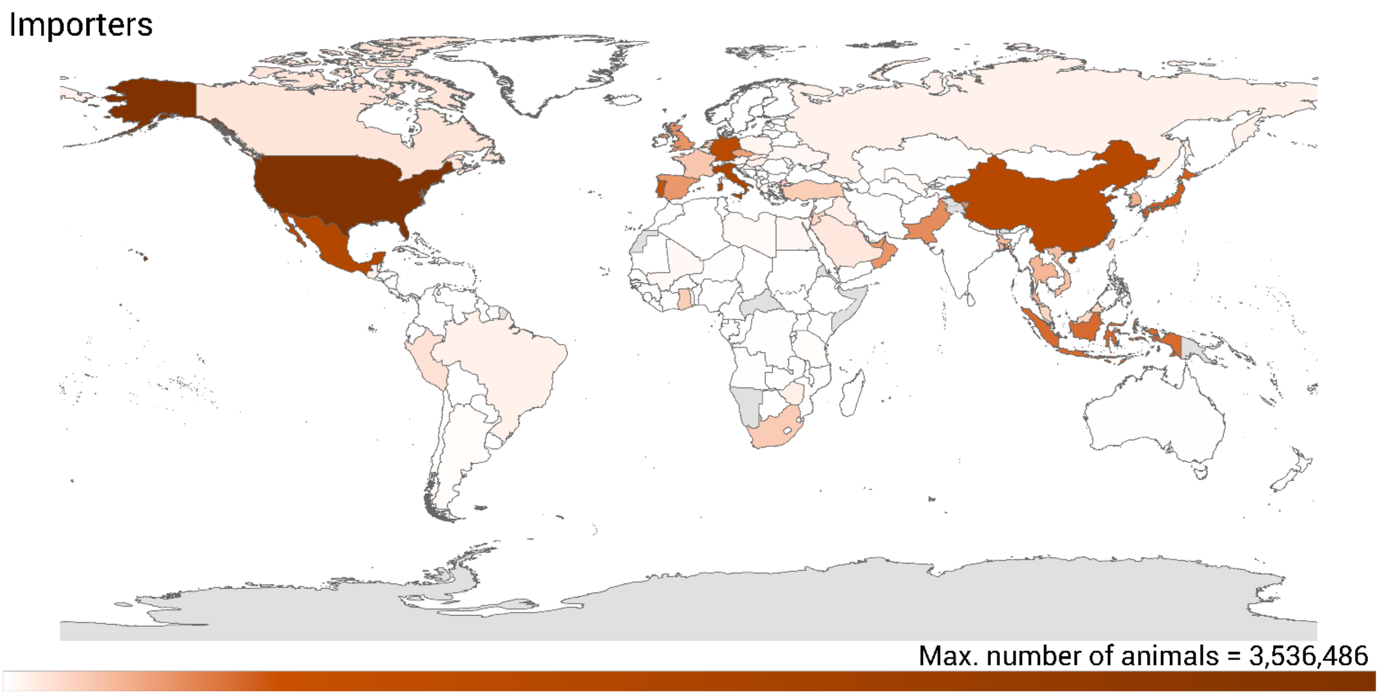


Figure 3.9: Summary of trade by **quantity of live individuals** (direct by gross exports) from families associated with high-risk zoonotic diseases by top 10 taxa, wild-sourced taxa, and captive-produced taxa (all families accounting for >1% of trade by source are shown) 2009-2018. The proportion of transactions that were wild-sourced (21%) or captive-produced (76%) are indicated in red.





Data source: CITES Trade Database (https://trade.cites.org/). Base layers: United Nations Geospatial, 2020. The designations employed and the presentation of material on this map do not imply the expression of any opinion whatsoever on the part of the Secretariat of the United Nations concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries.

Figure 3.10: Main exporters and importers by **quantity of live individuals** (direct by gross exports; all sources) from families associated with high-risk zoonotic diseases 2009-2018. Continuous scales indicate the relative levels of trade among exporters and among importers, and the maximum number of animals per (re-)exporter/importer; grey shading indicates no data.

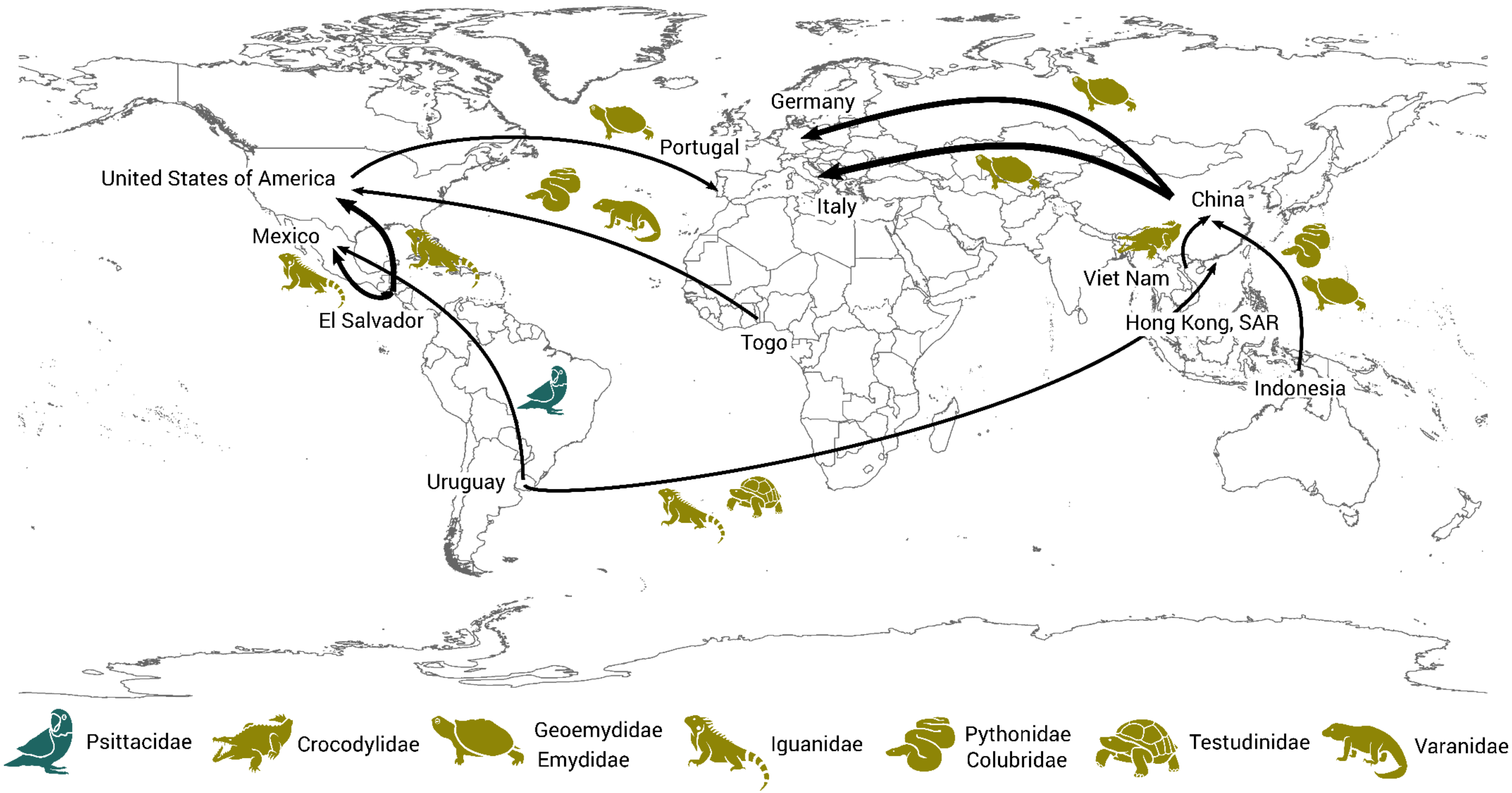


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Figure 3.11: Top ten trade routes by **quantity of live individuals** (direct by gross exports; all sources) from families associated with high-risk zoonotic diseases 2009-2018; trade routes visualised account for 31% of this trade. Icons indicate the main taxa traded along each route.

3.2.3. Summary of species in live trade associated with at least one zoonotic disease

Whilst 1369 species (66% of all CITES-listed animal species traded as live 2009-2018) were in families associated with a zoonotic disease, 295 of these species were reported to be directly associated with at least one zoonotic disease in the source papers (14% of all CITES-listed species reported in live trade during this time) (Table 3.6). The CITES-listed species directly associated with a zoonotic disease include some of the dominant species in live trade by both number of transactions (e.g. *Falco rusticolus* (gyrfalcon) and *Psittacus erithacus* (African grey parrot)) and quantity (e.g. *Iguana iguana* (green iguana) and *Python regius* (ball python)). Within CITES families associated with zoonotic diseases, nine of the top ten species by transactions and five of the top ten species by number of individuals were directly associated with at least one zoonotic disease (Figure 3.12). It is important to note that the direct associations between species and zoonotic diseases referenced here result from the literature search (see Annex A for methodology), and that the absence of any direct association with a species does not indicate that it isn't a potential host or vector (e.g. the association could be absent due to gaps in research effort).

Table 3.6: Overview of the number of species, transactions or quantity of live trade in CITES-listed species directly associated with at least one zoonotic disease 2009-2018. This excludes trade reported at higher taxonomic levels.

	Total in live trade	Species directly associated with zoonotic diseases	
		Any zoonotic disease	High risk zoonotic disease
CITES-listed species in live trade	2086	295	80
Live animal transactions	306,000	131,000	43,000
Quantity of live animals	26 million	6.5 million	6 million

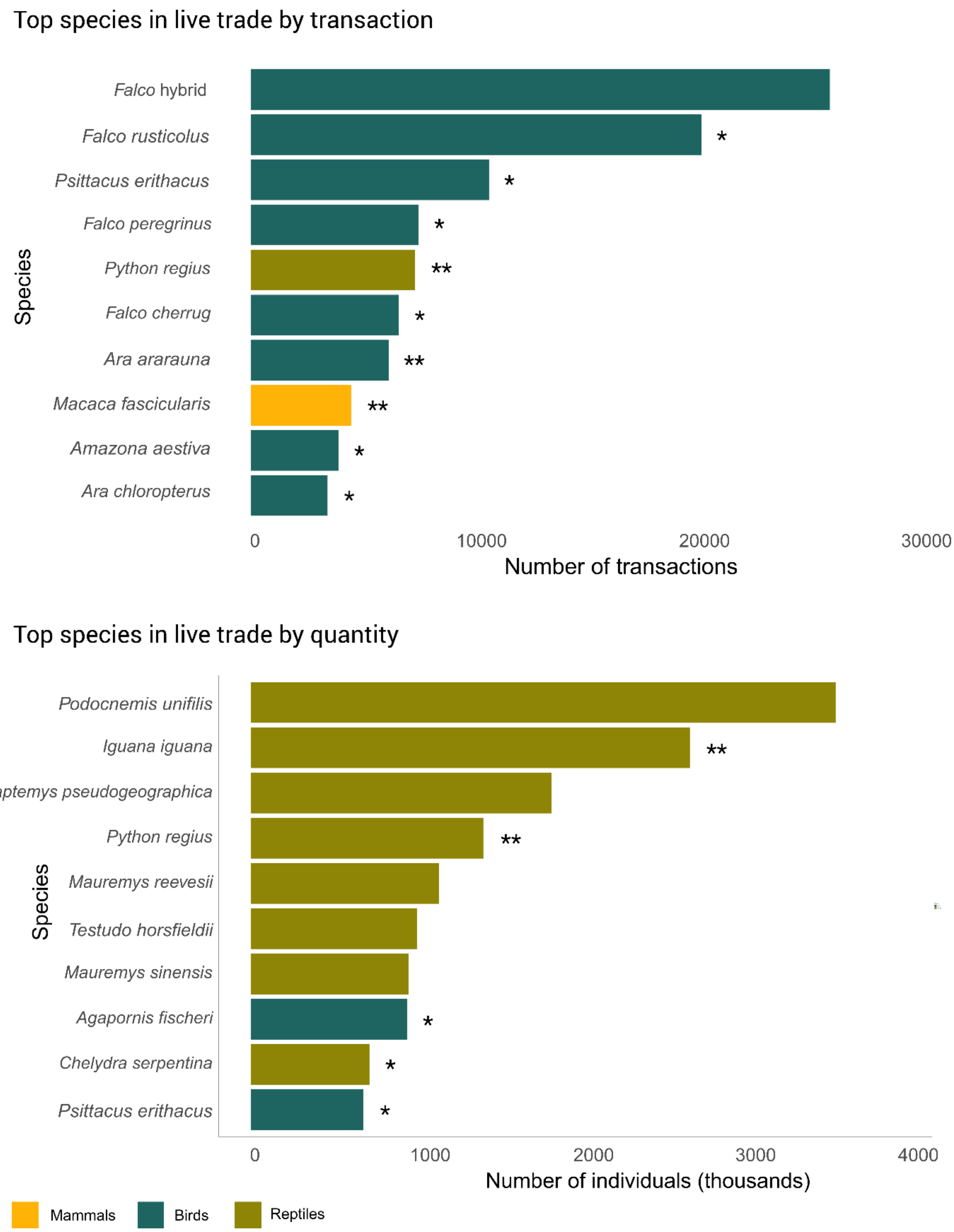


Figure 3.12: The top ten CITES-listed species from families associated with at least one zoonotic disease, based on the number of transactions and the quantity of live trade 2009-2018. Species directly associated with a zoonotic disease in the source literature are indicated with asterisks: * = associated with any zoonotic disease, ** = associated with at least one high-risk disease. Zoonotic associations for species hybrids were not included in the literature review.

3.3. Case study: Trade in meat of CITES-listed species associated with zoonotic risk

Between 2009 and 2018, there were approximately 23,000 (re-)exporter-reported transactions in meat (reported by weight) and 88 million kg meat in direct trade. Of these, 12% of transactions (~2800 transactions) were in families associated with at least one zoonotic disease and involved ~23 million kg (27% of all meat traded by weight over this period). Whilst the majority of these transactions (86%) were in families also associated with one or more of the high-risk zoonotic diseases, this percentage was much lower when looking at meat by weight (36%): 10% of transactions (2400) and 9.5% of meat by weight (~8.4 million kg) were in families associated with high-risk zoonotic diseases.

Trade in meat (by weight) was reported for 52 CITES-listed species belonging to families associated with at least one zoonotic disease 2009-2018[11]. Of these species, 29 (56%) were found in the source papers to be directly associated with one or more zoonotic diseases (10 of which included at least one high-risk zoonotic disease). This includes some of the dominant species traded as meat by both number of transactions and quantity including *Crocodylus niloticus* (Nile crocodile), *C. porosus* (saltwater crocodile), *Balaenoptera acutorostrata* (minke whale), as well as species associated with high risk diseases including *Python bivittatus* (Burmese python).

Table 3.7 provides an overview of trade in meat for (a) all families associated with at least one zoonotic disease and (b) just the 52 families associated with the 25 high-risk zoonotic diseases. It summarises the main taxa, exporters, importers and sources by both (re-)exporter-reported transaction and quantity (direct trade by gross exports). This is followed by a more detailed analysis of trade in families associated with the high-risk zoonotic diseases.

[11] It is important to note that the absence of a direct association between a species and zoonotic disease does not indicate that the species isn't a potential host or vector, just that it was not found following the literature search methodology detailed in Annex A (e.g. it may not have been studied, or published papers may not have been returned via the search parameters used).

Table 3.7: Overview of the highest taxa, exporters, importers and sources by the number of (re-)exporter-reported transactions and quantity (direct trade by gross exports) of **meat (kg)** in trade 2009-2018. Data are summarised for (a) all families associated with zoonotic diseases and (b) families associated with the high-risk zoonotic diseases.

	(a) All families associated with zoonotic diseases	(b) Families associated with high-risk zoonotic diseases
By transaction	**2806 transactions** 12% of total transactions **Main taxa**: *Crocodylus siamensis* (35%); *C. porosus* (13%) **Main (re-)exporters** Thailand (33%) Indonesia (18%) **Main importers** Hong Kong, SAR (42%) China (11%) Denmark (11%) **Sources** Captive-produced (54%); Wild-sourced (42%)	**2400 transactions** 10% of total transactions **Main taxa**: *Crocodylus siamensis* (40%); *C. porosus* (16%) **Main (re-)exporters** Thailand (38%) Indonesia (21%) **Main importers** Hong Kong, SAR (49%) China (13%) **Sources** Captive-produced (63%) Wild-sourced (31%)
By quantity (kg)	**23.5 million kg** 27% of total quantity **Main taxa**: *Balaenoptera physalus* (43%); Crocodylidae (26%) **Main exporters** Iceland (44%) Introduction from the Sea (17%) **Main importers** Japan (65%) Hong Kong, SAR (22%) **Sources** Wild-sourced (56%) Captive-produced (22%)	**8.4 million kg** 9.5% of total quantity **Main taxa:** *Crocodylus siamensis* (36%); *C. porosus* (32%) **Main exporters** Thailand (35%) South Africa (16%) **Main importers** Hong Kong SAR (62%) Belgium (12%) **Sources** Captive-produced (63%) Wild-sourced (26%)

3.3.1 Summary of trade by transactions of meat associated with high-risk zoonotic diseases

The CITES trade transactions in meat from animals belonging to families associated with the 25 high-risk zoonotic diseases were dominated by reptiles (~88% of transactions), with mammals accounting for the remaining 12% (Figure 3.13). Approximately 71% of reptile transactions were captive-produced, with most of the remaining transactions from wild sources. In contract the mammal transactions were almost exclusively wild-sourced (97%) and predominantly from wild-sourced *Ursus amercicanus* (brown bear) (79%).

The main (re-)exporters of meat from families associated with high-risk zoonotic diseases, based on (re-)exporter-reported number of transactions, were Thailand (38%) and Indonesia (21%; Figure 3.14). Hong Kong, SAR (49%) and China (13%) accounted for the majority of import transactions. The top trade routes based on these transactions included (re-)exports from Thailand to Hong Kong, SAR (all *Crocodylus siamensis* (Siamese crocodile)), and from Indonesia to Hong Kong, SAR (all reptiles, primarily *Crocodylus porosus* (saltwater crocodile) and the snakes *Pytas mucosus* (common ratsnake) and *Cerverus rynchops* (dog-faced water snake)) and China (9%) (primarily snakes *P. mucosus* and *C. rynchops* (dog-faced water snake)) (Figure 3.15). It is important to note that the high levels of trade noted here do not necessarily indicate that there is a higher risk of disease in trade with these countries, as the relative level of risk from individual taxa (and any mitigation measures in place, such as animal health provisions, that could potentially lower risk) were not taken into account.

Almost two thirds (64%) of trade transactions in meat from families associated with at least one high-risk zoonotic disease were from the family **Crocodylidae** (crocodiles) (~1500 transactions). Seven crocodile species were reported as traded for meat, all in the genus *Crocodylus;* this was dominated by trade in *Crocodylus siamensis* (Siamese crocodile) (63% of total) and *C. porosus* (saltwater crocodile) (24%), primarily from captive sources (93%). The largest exporter of crocodile meat 2009-2018 was Thailand (59%) and Hong Kong, SAR was the largest importer (61%). This family was associated with 10 zoonotic diseases and one high-risk zoonotic disease (Salmonellosis, which was reported in the literature at the family level).

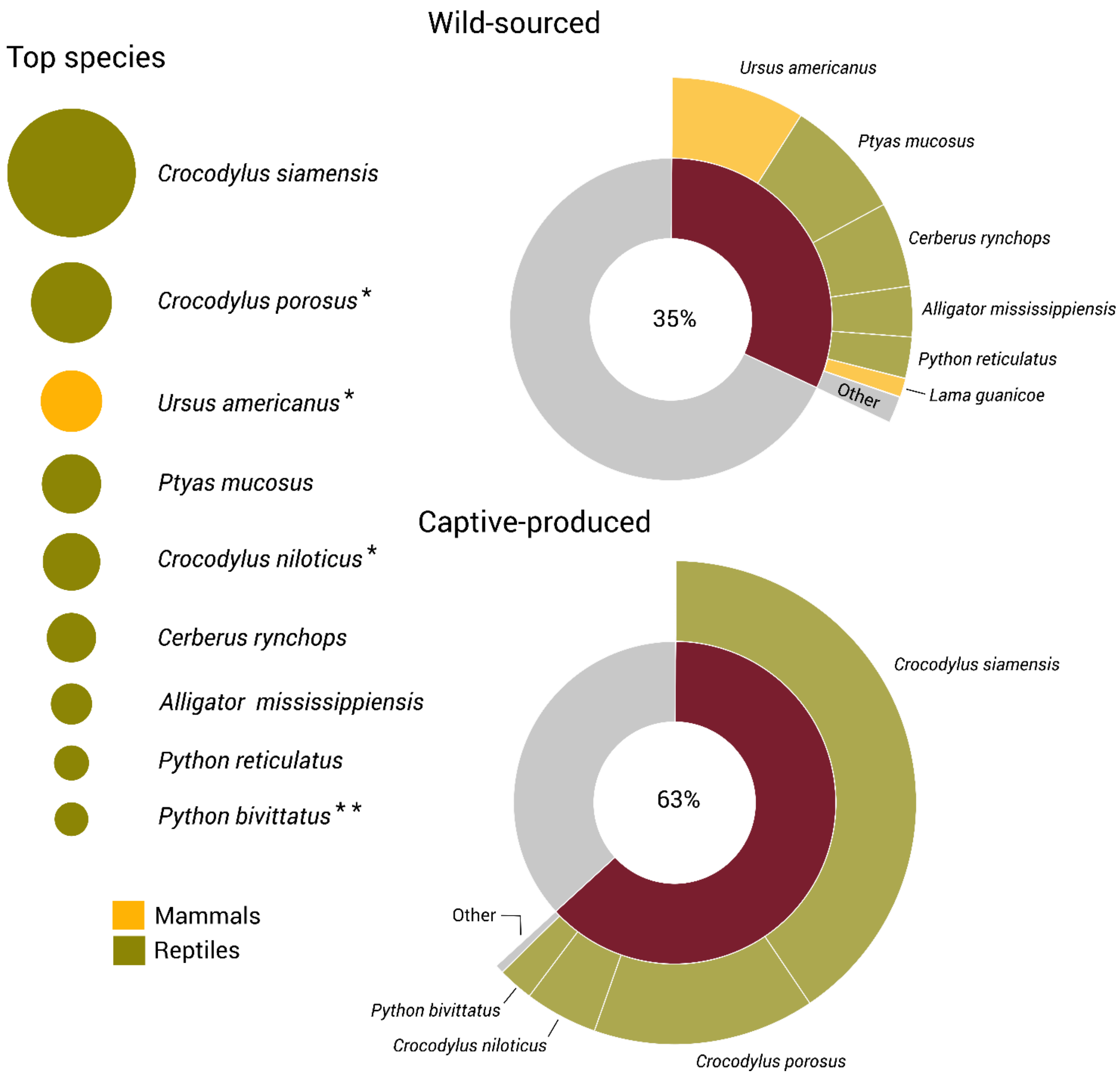
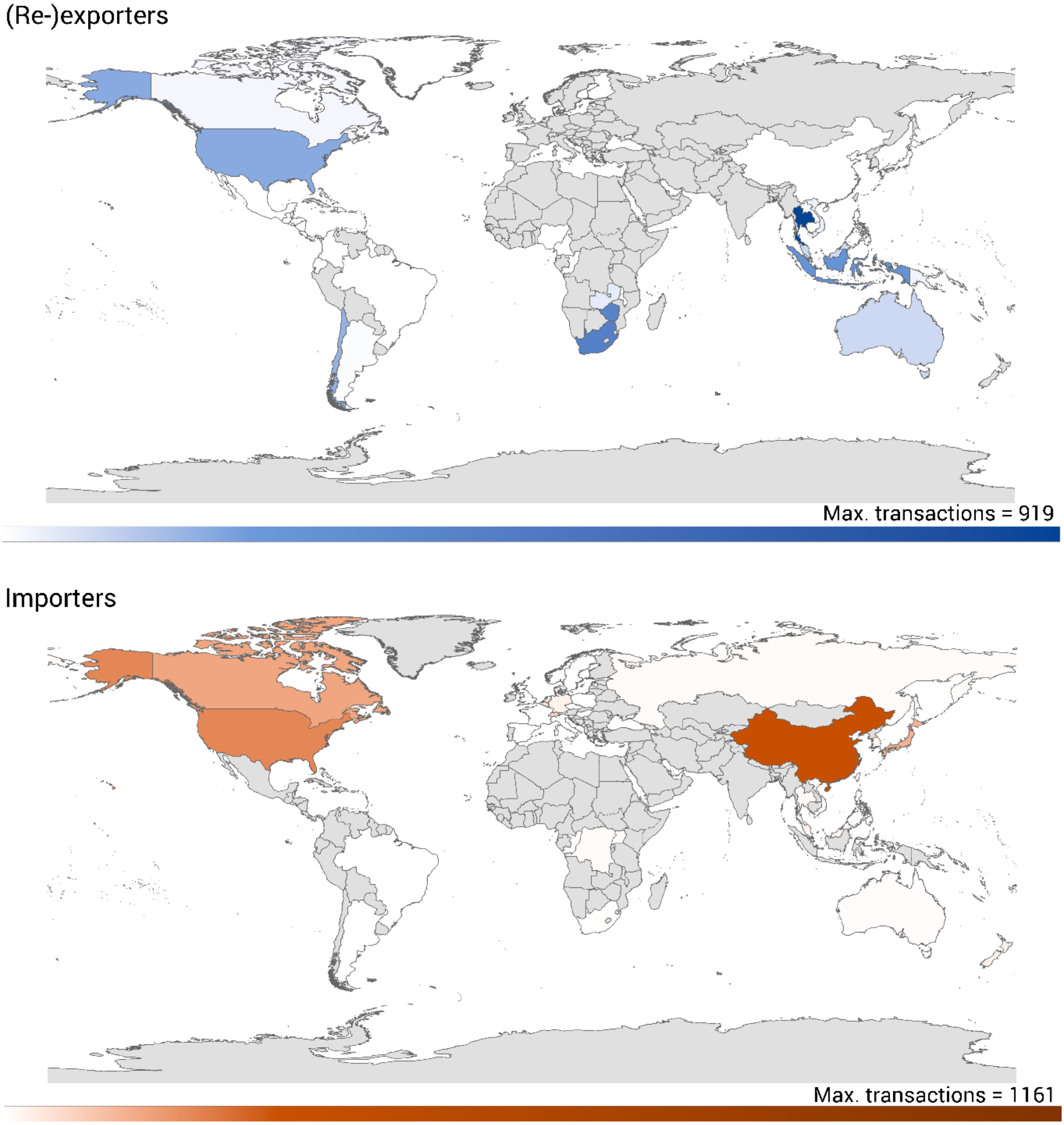
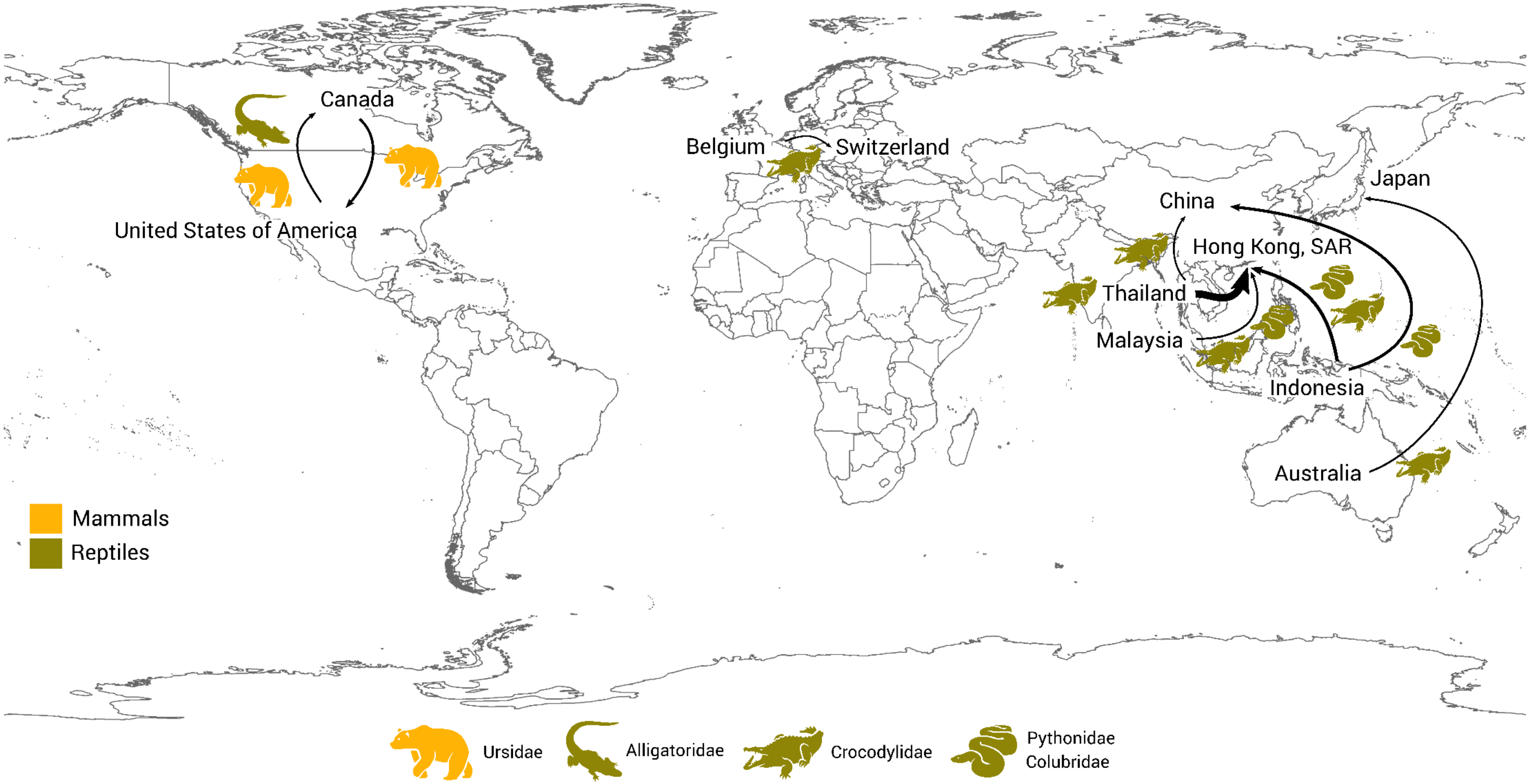


Figure 3.13: Summary of trade by **number of (re-)exporter-reported transactions** in meat from families associated with high-risk zoonotic diseases by top taxa, wild-sourced taxa, and captive-produced taxa (all species accounting for >1% of trade by source are shown) 2009-2018. Top species in trade that were directly associated with a zoonotic disease in the source literature are indicated with asterisks: * = associated with any zoonotic disease, ** = associated with at least one high-risk disease. The proportion of transactions that were wild-sourced (35%) or captive-produced (63%) are indicated in red.



Data source: CITES Trade Database (https://trade.cites.org/). Base layers: United Nations Geospatial, 2020. The designations employed and the presentation of material on this map do not imply the expression of any opinion whatsoever on the part of the Secretariat of the United Nations concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries.

Figure 3.14: Main (re-)exporters and importers by **number of (re-)exporter-reported transactions in meat** (all sources) from families associated with high-risk zoonotic diseases 2009-2018. Continuous scales indicate the relative levels of trade among exporters and among importers, and the maximum number of transactions per (re-)exporter/importer; grey shading indicates no data.



Data source: CITES Trade Database (https://trade.cites.org/). Base layers: United Nations Geospatial, 2020. The designations employed and the presentation of material on this map do not imply the expression of any opinion whatsoever on the part of the Secretariat of the United Nations concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries.

Figure 3.15: Top trade routes by **number of (re-)exporter-reported transactions in meat** (all sources) from families associated with high-risk zoonotic diseases 2009-2018; trade routes visualised account for 75% of this trade. Icons indicate the main taxa traded along each route.

3.3.2 Summary of trade by quantity of meat (by weight) associated with high-risk zoonotic diseases

Trade in meat (by weight) from CITES-listed animals belonging to families associated with the 25 high-risk zoonotic diseases were dominated by reptiles (~93% of the weight), with mammals accounting for almost all of the remaining 7% (Figure 3.16). Approximately 68% of reptile meat was captive-produced, with most of the remaining reptile meat from wild sources. In contrast, almost all mammal meat was from wild sources (>99%) and predominantly from wild-sourced *Lama guanicoe* (guanaco) (87%).

The main exporters of meat (by weight) from families associated high-risk zoonotic diseases, based on the quantity of animals in direct trade, were Thailand (35%) and South Africa (16%) (Figure 3.17). Hong Kong, SAR (63%), Belgium (12%) and China (8%) were the top importers. The top trade routes based on quantity included exports from Thailand, South Africa, and the United States to Hong Kong, SAR (mainly crocodiles) and Zimbabwe to Belgium (all *Crocodylus niloticus* (Nile crocodile)) (Figure 3.18). It is important to note that the high levels of trade noted here do not necessarily indicate that there is a higher risk of disease in trade with these countries, as the relative level of risk from individual taxa (and any mitigation measures in place, such as animal health provisions, that could potentially lower risk) were not taken into account.

As for meat transactions, the family **Crocodylidae** (crocodiles) was the dominant family associated with at least one high-risk zoonotic disease traded as meat (by weight), accounting for 73% of trade in meat (by weight) (~6 million kg). This trade was dominated by trade in *Crocodylus siamensis* (Siamese crocodile) (49% of total) and *C. niloticus* (Nile crocodile) (44%), primarily from captive sources (85%). The largest exporter of crocodile meat (by weight) 2009-2018 was Thailand (48%) and Hong Kong, SAR was the largest importer (67%). This family was associated with 10 zoonotic diseases and 1 high-risk zoonotic disease (Salmonellosis, which was reported in the literature at the family level).

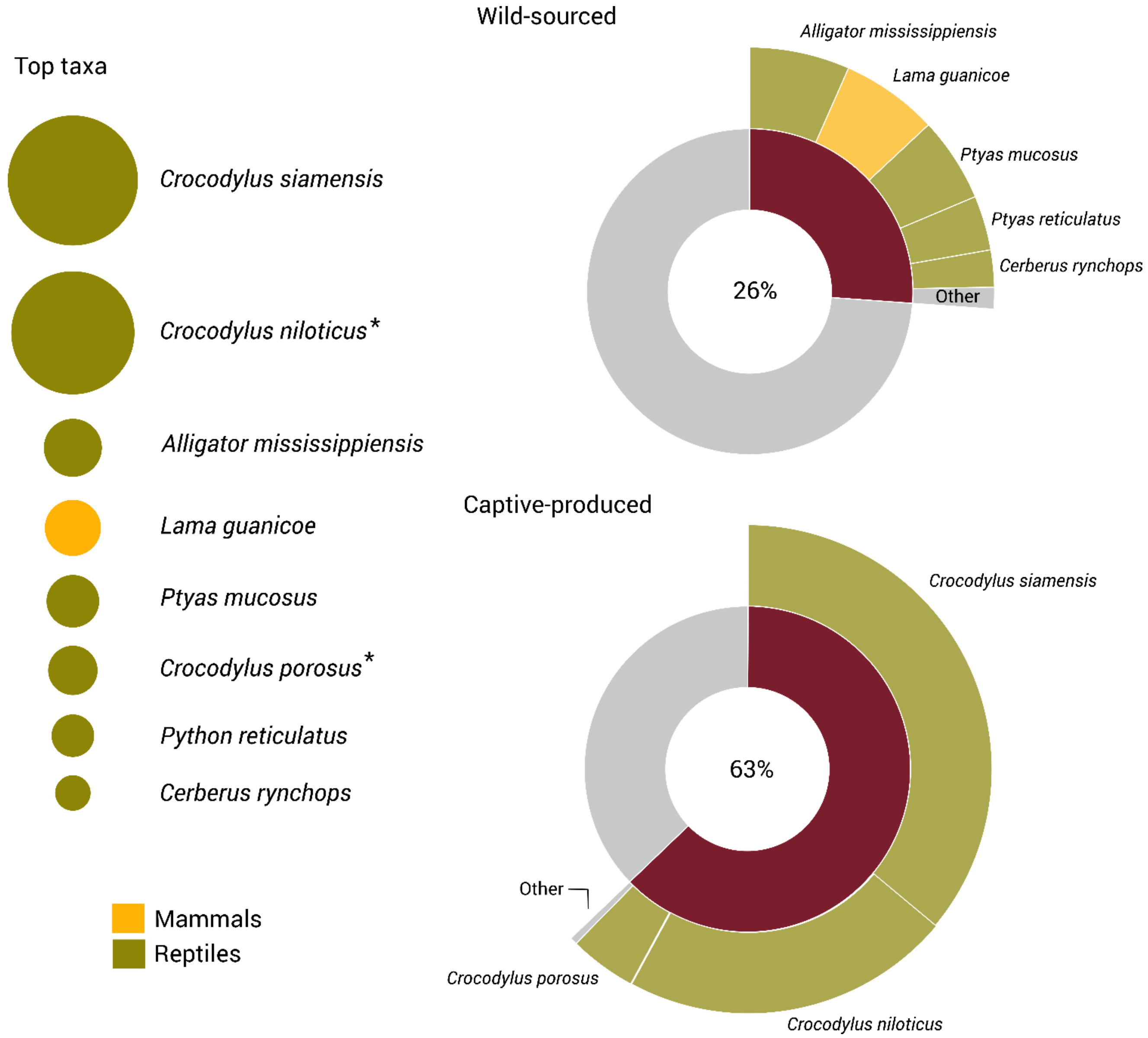
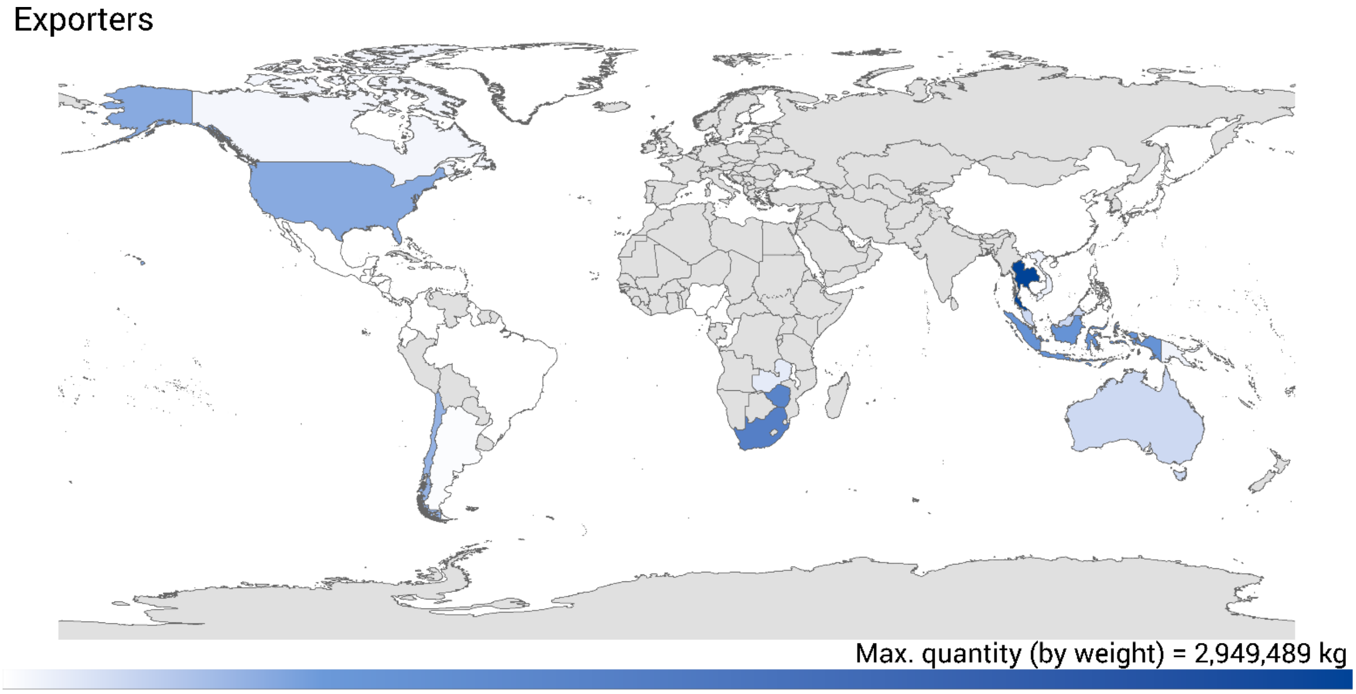
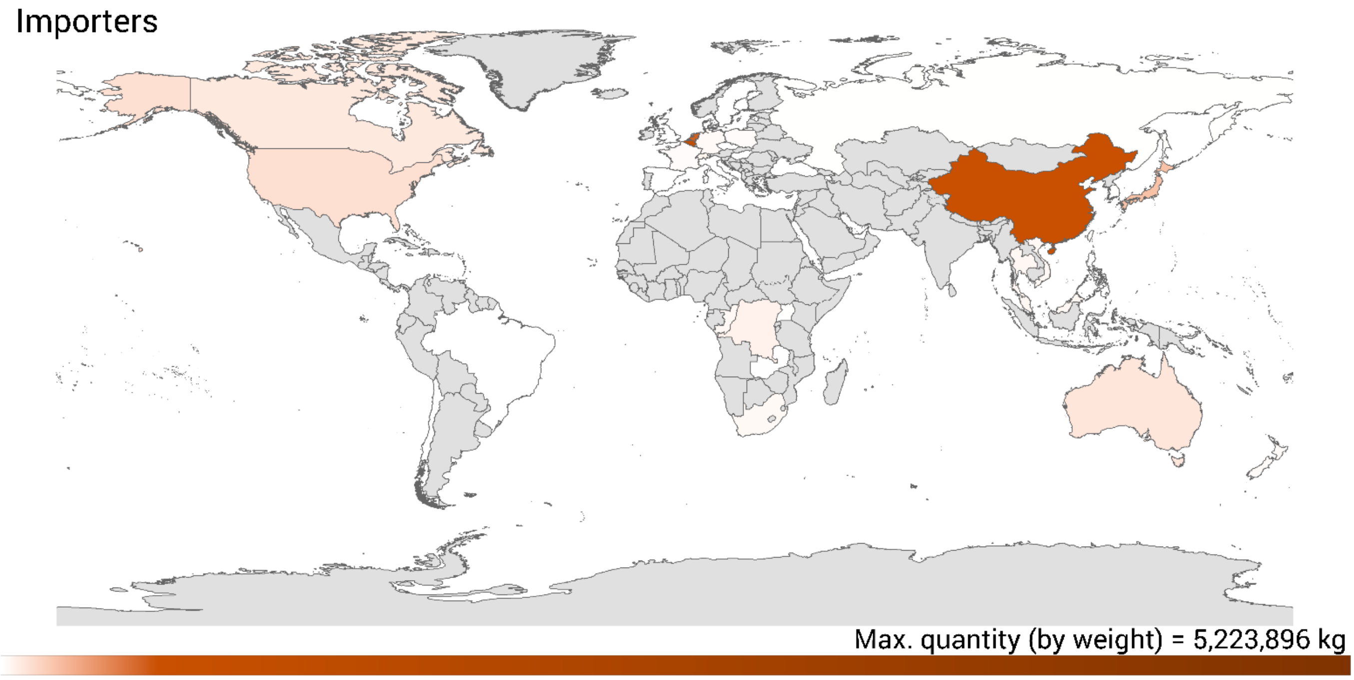


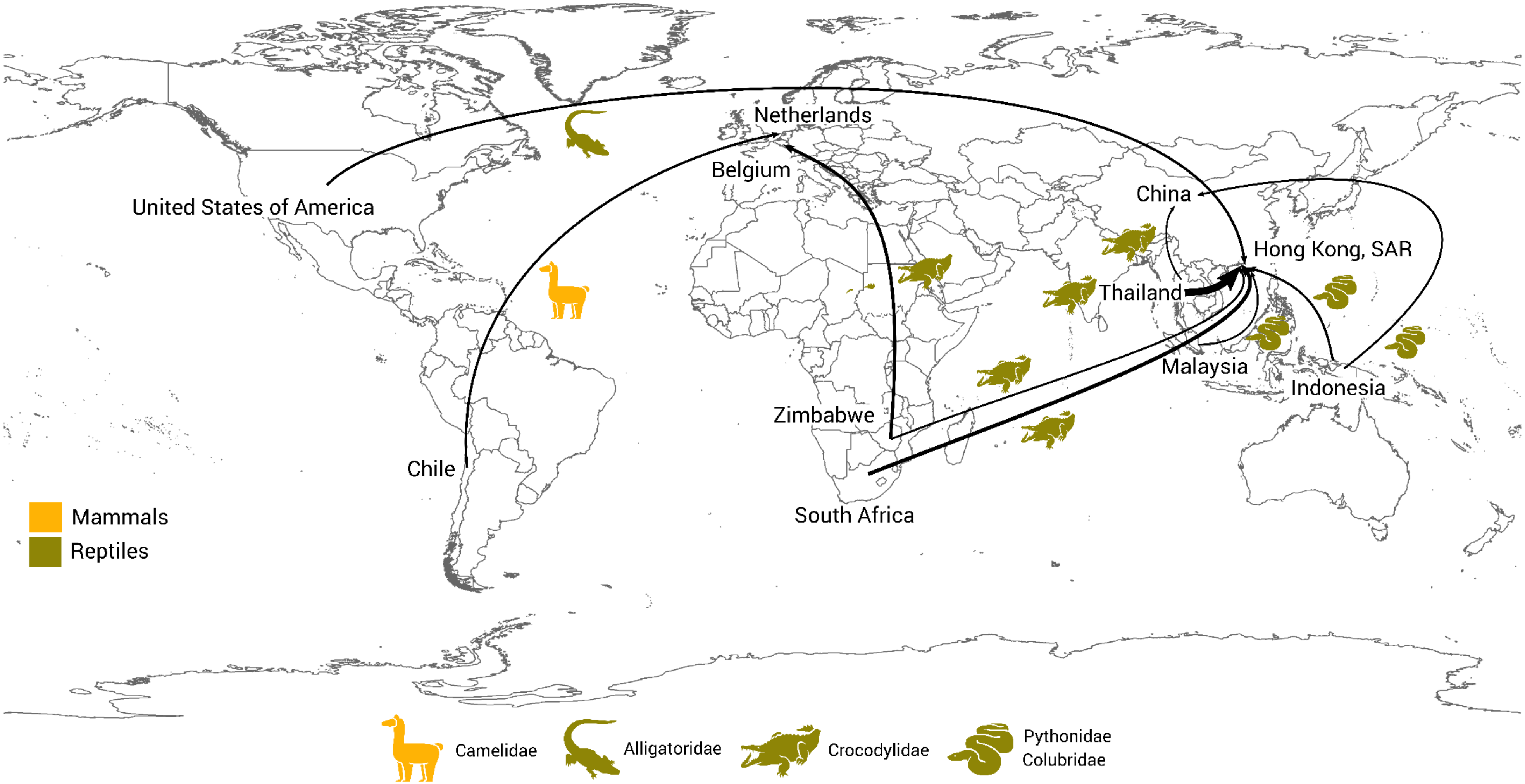
Figure 3.16: Summary of trade by **quantity of meat in kilogrammes** (direct by gross exports) from families associated with high-risk zoonotic diseases by top 10 taxa, wild-sourced taxa, and captive-produced taxa (all species accounting for >1% of trade by source are shown) 2009-2018. Top species in trade that were directly associated with a zoonotic disease in the source literature are indicated by an asterisk: * = associated with any zoonotic disease. The proportion of transactions that were wild-sourced (26%) or captive-produced (63%) are indicated in red.





Data source: CITES Trade Database (https://trade.cites.org/). Base layers: United Nations Geospatial, 2020. The designations employed and the presentation of material on this map do not imply the expression of any opinion whatsoever on the part of the Secretariat of the United Nations concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries.

Figure 3.17: Main exporters and importers by **quantity of meat in kilogrammes** (direct by gross exports; all sources) from families associated with high-risk zoonotic diseases 2009-2018. Continuous scales indicate the relative levels of trade among exporters and among importers, and the maximum quantity in kilogrammes per (re-)exporter/importer; grey shading indicates no data.



Data source: CITES Trade Database (https://trade.cites.org/). Base layers: United Nations Geospatial, 2020. The designations employed and the presentation of material on this map do not imply the expression of any opinion whatsoever on the part of the Secretariat of the United Nations concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries.

Figure 3.18: Top ten trade routes by **quantity of meat in kilogrammes** (direct by gross exports; all sources) from families associated with high-risk zoonotic diseases 2009-2018; trade routes visualised account for 85% of this trade. Icons indicate the main taxa traded along each route.

4| Discussion

What proportion of trade is in families and commodities that have been linked to zoonotic risk?

Our analysis found that, **while a relatively large proportion of animal families with at least one species listed in the CITES Appendices have been associated with a zoonotic disease (44%), only around 16% of trade transactions in CITES-listed animal taxa between 2009 and 2018 involved these groups**. While this proportion is relatively low, however, this still corresponds to a large number of shipments (0.8 million) over the ten-year period; and means that there is a **sizeable amount of CITES transactions that could potentially carry zoonotic risk**. It should be remembered that one shipment can contain multiple items, so the number of animals and derivatives in trade is much higher than 0.8 million. For live animals, for example, the 300,000 transactions involving families associated with at least one zoonotic disease that occurred between 2009 and 2018 involved ~26.5 million individuals.

The proportion of transactions involving families associated with a zoonotic disease increased to 40% when looking at trade in live, raw and semi-raw commodities only, indicating that **taxa that can potentially carry zoonotic risk are more prevalent in trade in commodities that are also assumed in this analysis to carry a higher risk**. However, the percentage across each of these commodities is variable. For live animals only, around 25% of transactions over the ten-year period were in families associated with at least one zoonotic disease, and 94% of these transactions involved families associated with one or more of the 25 high-risk zoonotic diseases as identified by OIE. In contrast only around 12% of transactions in meat over the ten-year period (~2800 transactions) were in families associated with at least one zoonotic disease. The volume of meat traded across a single transaction can, however, be very large; the 2800 transactions recorded over the period involved **~23 million kg of meat** being traded.

It should be noted that the general understanding of how the processing of wildlife products affects spill over risk is relatively poor, and there have been very few studies that track how risk is amplified or diminished throughout the supply chain (though see Huong *et al.* 2020). The decision to focus on raw and semi-raw commodities in the trade analysis was based on the general assumption that risk tends to decrease once commodities have undergone cooking, tanning or other chemical treatments (e.g. Van Vliet *et al.* 2017), but a better understanding of the relative risk posed by commodities at different stages of processing would allow a more nuanced analysis to be made.

What are the main CITES-listed taxa in trade that carry potential zoonotic risk?

While our literature review found that **mammals** and **birds** were the two classes containing the **highest proportion of families associated with zoonotic diseases**, **birds** and **reptiles** are the groups in which **most CITES transactions in potentially risky taxa actually occurred** across live, raw and semi-raw commodities**.** This might in part be because the orders Rodentia and Chiroptera (two of the mammal taxa that are associated with a high number of diseases in the source papers) are not well represented in the CITES Appendices; however further research would be required to confirm that this is the case. If zoonotic risk across live, raw and semi-raw commodities is to be measured purely by the number of transactions in families that have been associated with at least one zoonotic disease, then live parrots, falcons, and pythons; skins of alligators, crocodiles, pythons and bears; felid trophies; and cercopithecine (baboons, macaques, vervet monkeys and relatives) specimens may be important candidates on which to focus interventions overall. Our study does not consider whether actions that can mitigate risks, such as hygiene measures during processing and quarantine measures during transport, are applied to trade in these commodities; an important avenue for further research may therefore include identifying the availability of best practice guidelines for lowering zoonotic risk involved in trade in these groups, and assessing whether they are being fully implemented.

Within live animal trade, parrots, falcons, pythons, tortoises, iguanas, and pond/river and wood turtles may merit further consideration as priority groups on which to target interventions or further research, based on either the high number of transactions involving these species or the high number of individuals in trade. **Potential priority groups and species in the context of meat trade** based on high levels of transactions/quantities in families that have been associated with at least one zoonotic disease **include crocodiles, alligators, colubrids, pythons, camelids and bears.**

It is important to note, however, that species traded at low levels (e.g. as live or meat) may still pose a zoonotic risk, and these species would not have been highlighted by our approach. There are many ways of measuring the zoonotic risk posed by animal groups other than the one used in this study, which is principally based on trade volumes and considered disease risk at the family level. Future studies might wish, for example, to take account of the number of different zoonotic pathogens a species or higher taxon is known to be associated with[12], as well as the severity of disease caused by zoonotic pathogens, and evaluate whether this affects the priority species identified. Incorporating the diversity of pathogens a species is known to carry (i.e. applying a positive weighting to species that are known to host a high number of zoonotic diseases) into an analysis, for example, is likely to 'boost' groups such as primates up the risk rankings (but see caveats below about sampling effort). Further research could also focus specifically on diseases that have the highest chance of developing into future epidemics or pandemics; for example, by considering the probability of spill over, as well as the likelihood of developing human to human transmission after a spill over event occurs.

What are the important caveats associated with our analyses?

CITES trade data, as well as data linking particular species or higher taxa to particular diseases, are inherently complex and have known associated caveats. When placing our findings into context, we particularly highlight the following:

(1) Sampling and reporting bias are important to consider for both species and pathogens

A lack of reported zoonotic diseases for particular families could be the result of a lack of sampling or reporting rather than an actual absence. Within host animal species, there are known biases in the types of species that have been most intensively sampled; within mammals, for example, members of the orders Cingulata (armadillos), Pilosa (anteaters and sloths), Didelphimorphia (opossums), Eulipotyphla and Soricomorpha (insectivores) are considered to have been poorly sampled in comparison to other taxa (Han *et al.* 2016; Olival *et al.* 2017). Certain bird groups, reptiles, amphibians and other groups such as invertebrates have received less research attention still (Townsend Peterson *et al.* 2014; Gilbert *et al.* 2019; Carlson *et al.* 2020; Mendoza-Roldan *et al.* 2020).

As well as biases in *what* has been sampled, there are also biases in *where* samples have been taken, and which countries are able to monitor – and are therefore most

[12] The unweighted approach used in our analysis means that we have not made any assumptions about risk levels based on the number of diseases associated with particular families; trade in a family that has a low number of diseases associated with it was treated in the same way as a family that has a high number of diseases associated with it.

likely to report – spill over events (Hopkins & Nunn 2007; Han *et al.* 2016; Jorge & Poulin 2018; Can *et al.* 2019). Can *et al.* (2019) for example noted most zoonotic disease reports in the OIE-managed WAHIS-Wild database were made by countries in the European Union, Canada and the United Kingdom. Han *et al.* (2016) noted that many apparent zoonotic hotspots in higher latitudes also overlap with centres of high human population density (including Europe and Southeast Asia), which suggested to the authors an important role of reporting or study bias. Resources dedicated to disease related research are also generally higher in the northern hemisphere (Han *et al.* 2016).

Finally, the study and identification of pathogens themselves is also subject to biases in reporting (Pedersen *et al.* 2005; Hopkins & Nunn 2007); for example, in non-human primates, bacteria and fungi have previously been found to have been under-sampled relative to other infectious agents (Hopkins & Nunn 2007).

(2) This study only considers known zoonotic diseases that have already spilled over

The diseases included in this study are limited to those identified through the literature review that were confirmed to be zoonotic by OIE. They therefore do not reflect patterns of trade in taxa that may be considered higher risk in terms new disease emergence, and no inferences regarding the likelihood of emergence of new zoonoses can be made on the basis of these analyses. Finding "Disease X" (i.e. that which will cause the next major global pandemic) is inherently challenging, and just because a certain type of pathogen spills over more frequently does not mean that it has a higher chance of becoming the disease responsible for a pandemic. A review of human pathogens by Taylor *et al.* (2001) found that helminths (parasitic worms) actually make up the highest proportion of known zoonotic pathogens (32%) (i.e. those that have already spilled over), followed closely by bacteria (31%), then viruses and prions (19%), fungi (13%), and protozoa (5%). Most *emerging* pathogens, however, are thought to be bacteria (54.3%), followed by viruses or prions (25%), protozoa (11%), and fungi (6%) with helminths accounting for the lowest proportion (3%) (Jones *et al.* 2008)[13]. How common a pathogen type is in existing zoonoses is therefore not a good indicator of what may be most likely to become a new zoonotic disease, although the reasons behind this are not fully understood.

(3) Zoonotic spill over has not been confirmed in all species/disease associations included in our dataset

Some zoonotic diseases (e.g. salmonellosis and chlamydiosis) have a broad range of hosts. While they may have been detected in CITES-listed species, however, that species may not have been implicated in any known spill over event. While closely related species are thought to be more likely to share pathogens (Davies & Pedersen 2008), it should also be remembered that transactions highlighted here as involving taxa within a family that has been associated with zoonotic disease do not necessarily mean that the *species* involved has been associated with a zoonotic disease in particular.

In addition, the prevalence and distribution of zoonotic diseases are known to be constrained by factors other than the availability of their definitive host; for example, diseases that are transmitted via insects (such as leishmaniasis or yellow fever) are constrained by the distribution of their vectors (phlebotomine sandflies and *Aedes*

[13] Note that Taylor *et al.* (2001) found a slightly different order, with viruses or prions representing 44% of emerging pathogens, followed by bacteria (30%), protozoa (11%), fungi (9%) and helminths (6%). The difference was noted by Jones *et al.* (2008) to stem from their consideration of each individual drug-resistant microbial strain as a separate pathogen in their database.

aegypti mosquitoes, respectively). The geographic ranges of diseases and of host species may therefore not completely overlap, and host species may have portions of their range where they do not encounter particular zoonotic pathogens. This nuance is not accounted for in this study, which assumes that an individual of a particular species can be the source of zoonotic spill over regardless of whether it was harvested in or exported from an area where the zoonotic disease is known to exist.

(4) This study does not take into account variations in risk caused by differing conditions in rearing, housing, or the preparation and transport of wildlife products

In general, the probability of zoonotic spill over is thought to increase (a) in situations where the animal or commodity in question is shedding large amounts of a particular pathogen (see Kimman *et al.* 2013), (b) in situations where animals are kept in close proximity to one another and there is a rapid turnover of individuals (see Webster 2004; Woo *et al.* 2006; Enserink 2020), and (c) where hygiene measures to prevent disease transmission (such as the wearing of gloves, for example) are inadequate (Greatorex *et al.* 2016). The supply chain may also bring together species that would not ordinarily co-exist, creating opportunities for spill over that might not be present in the wild (Wang & Eaton 2007).

Although CITES trade data can provide some basic information pertaining to the source of traded animals or animal products (whether it was wild-sourced or captive-bred, for example), they do not provide information on the health of the animal nor an indication of whether the product was produced and transported under circumstances that are designed to lower the probability of zoonotic spill over (for example through following the standards for trade recommended by OIE in the Terrestrial Animal Health Code[14]).

Some trade terms included in our analyses of raw and semi-raw products can also obscure whether the commodity involved in a particular transaction has undergone a degree of processing that might significantly impact its zoonotic risk (e.g. both cooked and raw meat are traded under the same term, “MEA”). It is therefore important to remember that there is no “one size fits all” zoonotic risk measurement for a particular product; instead this can vary widely depending on the conditions in place throughout the supply chain.

(5) This study focusses only on a subset of all global wildlife trade - legal, international trade in CITES-listed species

Our analyses do not consider domestic or illegal trade in CITES-listed taxa, so it is important to remember that the results provided here do not reflect the total scale of trade in these species that may be occurring overall. Similarly, our analyses do not consider any trade (international, domestic, legal or illegal) in species not included in the CITES Appendices – they therefore provide a limited snapshot of the potential spill over global wildlife trade has as a whole.

Where should future research be focused, and how can we ensure that decisions based on the zoonotic risk posed by CITES-listed species are informed by the best data?

- With some minor exceptions, CITES regulates international trade at the species level. A major barrier to species-specific trade analysis in the context of zoonotic diseases, however, is the large amount of disease associations that are reported at a higher

[14] https://www.oie.int/standard-setting/terrestrial-code/

taxonomic level; this creates a trade-off between how specific an analysis can be versus how comprehensive an analysis can be. The creation and maintenance of a **central repository of disease/species associations covering the full range of zoonotic pathogens and their associated diseases** (rather than just viruses, for example) could be a valuable step towards allowing more sophisticated analyses in future, and may be essential if Parties decide to adopt an approach where stricter measures are in place for particular species that are deemed to be high risk. Such a database could draw on data held within the WAHIS and WAHIS-Wild databases maintained by OIE as a starting point, as well on peer reviewed literature and expert input. Priority focus could potentially be given to those CITES species known to be in trade and to families with documented zoonotic disease associations where there are currently species-specific gaps.

- Linked to the above, a **closer cooperative relationship between CITES and the international quartet of OIE, FAO, WHO, and UNEP** advancing a "One Health" approach (considering human, wildlife and livestock health holistically) could help ensure that research needs specifically relating to health and wildlife trade could be identified and prioritised. CITES already has a close working arrangement with UNEP, a Memorandum of Understanding with FAO[15] and a cooperation agreement in place with OIE[16], but fostering more direct collaboration with these institutions (and WHO) in relation to zoonotic diseases would be beneficial. The IPBES[17] Workshop on Biodiversity and Pandemics held in July 2020 also highlighted the need for increased cooperation, suggesting a partnership between CITES, WHO, OIE, the CBD, the International Air Transport Association, the United Nations Conference on Trade and Development, and the IUCN Survival Commission Wildlife Health Specialist Group (IPBES 2020).

- This study focussed only on legal, international trade in CITES-listed species. Smuggled animals and illicitly traded animal products, however, may pose a higher zoonotic risk than legally traded products, as they are more likely to be stored in cramped or poor conditions (Rosen & Smith 2010; ROUTES 2020) that can increase possibility of exposure to pathogens and suppress an animal's immune response. Smugglers may also seek to evade animal health provisions such as quarantine to which legal trade is subject. A key priority for future analytical work is the analysis of **CITES illegal trade reports** and other sources of seizure data to explore the prevalence of potential high-risk species and pathways. Access to CITES illegal trade reports was requested by the UK CITES Authorities for use in this study, but this was not provided. Analyses of **domestic** trade and trade in **non-CITES species** were also beyond the scope of this report, but these are other fundamental aspects to be explored in order to more fully understand the risks presented by global wildlife trade as a whole.

- Future analyses may wish to explore the impacts on the outcome of CITES trade data analyses by **weighting disease associations by a variety of risk measurements**; for example, by taking into account the diversity of zoonotic diseases associated with particular taxa, whether the range of wild-sourced specimens overlaps with the known range of particular zoonotic pathogens, and disease severity in humans. The large number of zoonotic pathogens and diseases associated with CITES-listed species, however, means that it is likely that there will be significant data gaps involved in undertaking analyses of this type.

[15] https://cites.org/sites/default/files/eng/disc/sec/FAO-CITES-e.pdf
[16] https://www.oie.int/fileadmin/Home/eng/About_us/docs/pdf/accords/Accord_CITES_OIE_novembre_2015.pdf
[17] Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services

- Following on from the above, future analyses may wish to concentrate on the prevalence of those **diseases that have the highest likelihood of developing into an epidemic** after spill over has occurred. This could include weighting diseases by the likelihood of spill over and whether human to human transmission has been recorded.

- While there is an existing CITES Resolution on transport of live specimens (Resolution Conf. 10.21 (Rev. CoP16)), and Articles III-IV the Convention text mandate that export permits should only be granted when the Party is “satisfied that any living specimen will be so prepared and shipped as to minimize the risk of injury, damage to health or cruel treatment”, there may be more work needed to align CITES controls and permitting processes with animal health controls, and ultimately to align animal health controls with mitigating disease risk. Future research could consider **whether CITES processes and practices to ensure animal welfare during transport are aligned fully with practices needed to reduce the risk of zoonotic spill over and review the implementation of existing guidance across Parties**.

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Annex A: Methods

Literature review

A systematic search of the peer reviewed literature was conducted in Web of Science to identify peer-reviewed papers that contained datasets listing multiple taxa and their associated zoonoses. Four search strings in English were used to identify relevant literature published in any year. The first general search string for “wildlife AND trade AND (zoonoses OR zoonosis OR zoonotic)” largely returned literature on mammals, so three more specific search strings were used to target papers on birds, reptiles, and amphibians in order to broaden the taxonomic focus of the search:

Search string 1: wildlife AND trade AND (zoonoses OR zoonosis OR zoonotic)
Search string 2: bird* AND (zoonoses OR zoonosis OR zoonotic)
Search string 3: reptile* AND (zoonoses OR zoonosis OR zoonotic)
Search string 4: amphibian* AND (zoonoses OR zoonosis OR zoonotic)

These four search strings returned a total of 884 papers; of these, all papers returned by search string 1, and the first 30 unique papers (after ranking by relevance) returned by search strings 2-4 (totalling 208 papers) were then assessed and the final papers selected based on the following:

1. Publications were peer-reviewed meta-analysis, review, or primary research papers focussing on multiple taxa associated with one or more zoonotic pathogens
2. Taxon-disease pairings were available in data tables or supplementary information

Following this selection process, 15 papers were ultimately selected, including two papers that were returned by more than one search string (Table A1). A further seven papers cited in the references of these selected papers were also examined and included. See Table A2 for complete list of selected papers.

Table A1: Summary of papers returned in Web of Science for each search string, and the number of papers ultimately selected. The number of unique papers (i.e. papers identified in addition to those identified/selected in the preceding strings) is shown in parentheses.

Search string	Number of papers returned	Number of papers selected
1. wildlife AND trade AND (zoonoses OR zoonosis OR zoonotic)	118	4 (4)
2. bird* AND (zoonoses OR zoonosis OR zoonotic)	500 (494)	2 (2)
3. reptile* AND (zoonoses OR zoonosis OR zoonotic)	261 (233)	8 (6)
4. amphibian* AND (zoonoses OR zoonosis OR zoonotic)	112 (39)	3 (3)
Additional papers		7
Total unique papers	**884**	**22**

Table A2: List of selected papers (referred to as 'source papers').

Reference
Bekker, J.L., Hoffman, L.C., and Jooste, P.J. 2012. Wildlife-associated zoonotic diseases in some southern African countries in relation to game meat safety: A review. *Onderstepoort Journal of Veterinary Research,* 79(1): 1-12.
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Chhabra, M.B., and Muraleedharan, K. 2016. Parasitic zoonoses and role of wildlife: an overview. *Veterinary Research International*, 4(1):1-11.
Chomel, B.B. 2015. Diseases transmitted by less common house pets. *Microbiology spectrum*, 3(6): IOL5-0012-2015.
Ebani, V.V. 2017. Domestic reptiles as source of zoonotic bacteria: a mini review. *Asian Pacific Journal of Tropical Medicine*, 10(8): 723-728.
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Oda, F.H., Borteiro, C., da Graca, R.J., Tavares, L.E.R., Crampet, A., Guerra, V., Lima, F.S., Bellay, S., Karling, L.C., Castro, O., Takemoto, R.M., and Pavanelli, G.C. 2016. Parasitism by larval tapeworms genus Spirometra in South American amphibians and reptiles: new records from Brazil and Uruguay, and a review of current knowledge in the region. *Acta Tropica*, 164: 150-164.
Olival, K.J., Hosseini, P.R., Zambrana-Torrelio, C., Ross, N., Bogich, T.L., & Daszak, P. 2017. Host and viral traits predict zoonotic spill over from mammals. Nature, 546(7660): 646-650.
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Pedersen, K., Lassen-Nielsen, A.-M., Nordentoft, S., and Hammer, A.S. 2009. Serovars of Salmonella from captive reptiles. *Zoonoses and Public Health*, 56: 238-242.
Perez-Flores, J., Charruau, P., Cedeno-Vazquez, R., and Atilano, D. 2017. Evidence for wild crocodiles as a risk for human leptospirosis, Mexico. *EcoHealth*, 14: 58-68.
Reaser, J.K., Clark Jr., E.E., and Meyers, N.M. 2008. All creatures great and minute: a public policy primer for companion animal zoonoses. *Zoonoses and Public Health*, 55: 385-401.
Ribas, A., and Poonlaphdecha, S. 2017. Wild-caught and farm-reared amphibians are important reservoirs of *Salmonella*, a study in north-east Thailand. *Zoonoses and Public Health*, 64: 106-110.
Smith, K.M., Machalaba, C.M., Jones, H., Caceres, P., Popovic, M., Olival, K.J., Jebara, K.B., and Karesh, W.B. 2017. Wildlife hosts for OIE-listed diseases: considerations regarding global wildlife trade and host-pathogen relationships. *Veterinary Medicine and Science*, 3: 71-81.
Souza, M.L., Coelho, M.L., Silva, A.O., Azuaga, L.B.S., Coutinho-Netto, C.R.M, Galhardo, J.A., Leal, C.R.B., Ramos, C.A.N. 2020. Salmonella spp. infection in Psittacidae at a wildlife rehabilitation center in the state of Mato Grosso do Sul, Brazil. *Journal of Wildlife Diseases*, 56(2): 288-293.
Waltzek, T.B., Cortes-Hinojosa, G., Wellehan Jr., J.F.X., and Gray, G.C. 2012. Marine mammal zoonoses: a review of disease manifestations. *Zoonoses and Public Health*, 59: 521-535.

Data tables on taxa and their associated pathogens were extracted as reported from these 22 selected papers (either from the main paper or from supplementary information) and combined, resulting in 5787 rows of data, each indicating a taxon-disease pairing. From this, 142 rows of data were excluded because the taxon was unidentified (10 rows), was domestic cat, dog or cattle (132 rows), or was associated with an ectoparasite or non-zoonotic disease according to OIE (585 rows corresponding to 113 pathogens and 106 diseases). The remaining 5060 rows of data were supplemented with the following, based on information available in the paper: whether the pathogen was stated to be zoonotic; source of taxon samples (wild- or captive-sourced); and description of commodity sampled (e.g. live, bodies, meat, etc.). Higher taxonomy was added to all taxa to enable cross-comparison at the same taxonomic level: CITES-listed taxa were mapped to CITES taxonomy using Species+, all other taxa were mapped to IUCN or Catalogue of Life taxonomy. A further three rows (corresponding to three taxa) were removed because they could not be mapped to higher taxonomy, resulting in a total 5057 rows of data comprising 3904 unique taxon/pathogen pairings. Of the 5057 individual rows of data extracted from the literature, 96% were at the family level or lower (i.e. only 4% were published at a higher level such as order).

Of the 275 zoonotic diseases identified by the literature review, 25 were classified as having the highest risk to human health through expert consultation with OIE: Anthrax, Avian influenza, Botulism, Bovine tuberculosis/zoonotic tuberculosis, Brucellosis, Bunyamwera fever, Crimean-Congo haemorrhagic fever, Cystic echinococcosis, Dengue fever, Eastern equine encephalitis, Ebola virus disease (EVD), Japanese encephalitis, Leishmaniasis, Marburg virus disease, Monkeypox, Plague, Porcine cysticercosis, Rift Valley fever, Haemorrhagic Fever with Renal Syndrome, Salmonellosis, Severe acute respiratory syndrome (SARS), Tick-borne encephalitis, Venezuelan equine encephalitis, Western equine encephalitis, Zika virus.

Trade analysis

Both direct and indirect trade in current CITES-listed animal taxa was downloaded at the shipment-by-shipment level from the CITES Trade Database on 10 November 2020. Trade data terms and units were standardised and term codes relating to live, raw or semi-raw commodities[18] were included in the analysis; manufactured/processed products were excluded. Sources, as defined in CITES Resolution 12.3 (Rev. CoP18) on *Permits and Certificates*, were grouped for analysis as follows: wild-sourced trade ('W', 'U', and no source specified), captive-produced trade ('C', 'D', and 'F'), ranched ('R'), and other ('X', 'I', 'O')[19]. All CITES purpose codes were included.

The taxa/zoonotic disease associations identified in the source papers were used to determine the CITES-listed animal families included in the trade data analysis. Trade in all CITES-listed taxa within these families was included in the trade analysis (Section 3); since species within the same family (i.e. those that are more closely-related) are likely to carry similar zoonotic diseases (Davies and Pedersen, 2008), this precautionary approach was taken in an effort to address varying research effort, which has been shown to be a major predictor in detecting taxa/disease associations (Johnson *et al.* 2020). It is important to note that the absence of a direct association between a species and zoonotic disease does not indicate that the species is not a potential host or vector, just that it was not found following

[18] Terms included: baleen, bodies, bones, bone pieces, calipee, carapaces, caviar, claws, cultures, derivatives, ears, eggs, eggs (live), eggshell, extract, feathers, fingerlings, fins, feet, gall bladders, gall, genitalia, gill plates, hair, heads, horns, horn pieces, horn scraps, frog legs, live, meat, medicine, musk, oil, plates, powder, pupae, quills, raw corals, rostrum, scales, scraps, shells, sides, skeletons, skin pieces, skins, skulls, soup, specimens, swim bladders, tails, teeth, cultures, trophies, trunk, tusks, unspecified, venom

[19] See https://cites.org/sites/default/files/notif/E-Notif-2019-072-A1.pdf for details of specific source codes.

the literature search methodology (e.g. it may not have been studied or published papers may not have been returned via the search parameters used).

Summary statistics on the number of families are based on direct and indirect trade data reported by either importers or exporters. The number of trade transactions are also based on both direct and indirect trade, but unless otherwise noted are exporter-reported only to prevent double counting. Taking a precautionary approach, quantities of trade were converted to gross exports[20] and based on direct trade only.

While the quantity of animals (and their parts and derivatives) in trade can influence potential disease risk, the number of transactions (i.e. shipments) in trade can also provide an indication of the amount of contact between traded animals and humans. The overview trade analysis uses the number of transactions to examine trade in all live, raw, and semi-raw commodities together, and to avoid combining incompatible trade terms and units which are needed when analysing the volume of trade by quantity (e.g. trade in whole animals versus their parts and derivatives, units reported by number versus weight). Trade terms in the overview analysis were not weighted based on potential zoonotic risk, as there is no established quantifiable approach to systematically compare these commodities, and many term codes are too broad to differentiate between varying levels of risk across commodities (e.g. ‘skins’ includes both raw and processed/tanned skins). Two case studies examine trade in specific commodities (live animals and meat), and each case study presents trade data based on the number of transactions as well as the quantity. Attention should be given to which metric each analysis is using, bearing in mind that a single shipment can contain multiple items.

[20] Gross exports; quantities reported by the exporter and importer were compared based on data aggregated by taxon, term, unit, importer, exporter, source and year and the larger quantity was used in the analyses.