Wildlife trade in Latin America: people, economy and conservation

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Abstract

Wildlife trade is among the main threats to biodiversity conservation and may pose a risk to human health because of the spread of zoonotic diseases. To avoid social, economic and environmental consequences of illegal trade, it is crucial to understand the factors influencing the wildlife market and the effectiveness of policies already in place. I aim to unveil the biological and socioeconomic factors driving wildlife trade, the health risks imposed by the activity, and the effectiveness of certified captive-breeding as a strategy to curb the illegal market in Latin America through a multidisciplinary approach. I assess socioeconomic correlates of the emerging international trade in wild cat species from Latin America using a dataset of >1,000 seized cats, showing that high levels of corruption and Chinese private investment and low income per capita were related to higher numbers of jaguar seizures. I assess the effectiveness of primate captive-breeding programmes as an intervention to curb wildlife trafficking. Illegal sources held >70% of the primate market share. Legal primates are more expensive, and the production is not sufficiently high to fulfil the demand. I assess the scale of the illegal trade and ownership of venomous snakes in Brazil. Venomous snake taxa responsible for higher numbers of snakebites were those most often kept as pets. I uncover how online wildlife pet traders and consumers responded to campaigns associating the origin of the COVID-19 pandemic. Of 20,000 posts on Facebook groups, only 0.44% mentioned COVID-19 and several stimulated the trade in wild species during lockdown. Despite the existence of international and national wildlife trade regulations, I conclude that illegal wildlife trade is still an issue that needs further addressing in Latin America. I identify knowledge gaps and candidate interventions to amend the current loopholes to reduce wildlife trafficking. My aspiration with this thesis is to provide useful information that can inform better strategies to tackle illegal wildlife trade in Latin America.

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Chapter 1. General Introduction

1.1 Global wildlife trade

Wildlife trade (the trade in wild species and their derivative products) affects one in every four extant vertebrate species on the planet (Scheffers et al. 2019), and the trade in some overlooked groups, such as invertebrates, plants, and fungi can be substantial, but is yet poorly documented (Fukushima et al. 2020). The monetary value generated globally by regulated (and therefore legal) wildlife trade was estimated at over US$323 billion in 2009, based on customs declarations on wildlife imports (Newton and Cantarello 2014), whereas more recently, Nijman (2021a) estimated it at over US$400 billion. The scale of illegal wildlife trade, on the other hand, remains difficult to measure due to several methodological hurdles, such as frequent lack of or difficulty in accessing confidential reports, low reliability of existing data, scarcity of prosecutions, and potential risks to researchers (Passas 2003). More arduous to calculate, estimates of the monetary value of the illegal wildlife trade vary considerably among assessments, ranging from US$4 to 23 billion annually (’t Sas Rolfes et al. 2019). Heads of organized groups and middlemen are among those who financially benefit the most from the trade, while harvesters, hunters, trappers and fishermen often receive a relatively low proportion of the chain revenue (Morcatty and Valsecchi 2015; Reeve 2002; Busilacchi et al. 2021).

Diverse motivations stand behind the demand for live wildlife, body parts and derivative products, which includes meat for consumption (El Bizri et al. 2020a), medicine (Cheung et al. 2021), spiritual and religious practices (Alves et al. 2012), decoration (Nijman and Lee 2016), pet ownership (Bush et al. 2014) and symbols of social status (Lee et al. 2020). Both transnational and domestic illegal wildlife trade pose substantial social, economic and

environmental impacts in several parts of the world (Morton et al. 2021; Chambers and Conway 1991). When unsustainable, both legal and illegal trade can be very harmful to the ecosystems. The impacts of illegal and unsustainable wildlife trade remain unassessed for most taxa, but recent estimations for birds, mammals and reptiles suggest that over 60% of the traded wild species experienced a decrease in abundance, and that over 16% may have faced local extinctions (Morton et al. 2021). Other indirect impacts, such as introduction of invasive species or pathogens in the wild increase the concerns regarding wildlife trade (Sutherland et al. 2009; Toomes et al. 2020; Diagne et al. 2021; Thumsová et al. 2021). The overall rate of wildlife trade has been increasing over years and reaching further regions of the globe due to improvements in goods transportation and facilitated international travel (Nijman 2010; Andersson et al. 2021), and its potential impact is even more worrying considering that trade usually happens in combination to other anthropogenic activities, such as land-clearing, and to climate change.

In order to avoid social, economic and environmental consequences of illegal trade and overexploitation of wildlife, a range of international regulation frameworks were developed and adopted over time, the most important being the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), enacted in 1975. There is a large and growing body of research examining wildlife exports and imports between countries reported to CITES to provide information on demand for wildlife, and evaluate possible risks of unsustainability. Using these data, some studies have given an overview of wildlife trade across the tree of life (Scheffers et al. 2019 for vertebrates; Fukushima et al. 2020 for invertebrates), while others discussed trade patterns and their implications for conservation of specific taxa (e.g., Fisher and Reeves

2005 for cetaceans, Carpenter et al. 2014 for amphibians, Hinsley et al. 2018 for orchids, Nijman 2019 for molluscs, and Hierink et al. 2020 for snakes) or specific uses (e.g., Bush et al. 2014 for pet trade). However, much is still unknown about how the illegal international trade may interact with, resemble or diverge from the legal trade chain for most species and in most countries worldwide (e.g., ‘t Sas-Rolfes et al. 2014).

Due to the increase in Internet access in the past decades, wildlife trade has been shifting from brick-and-mortar markets to virtual marketplaces (Siriwat et al. 2020; Lavorgna 2015). Online platforms, particularly social media, may facilitate the connection between sellers and buyers, decrease the cost of advertising, and provide an environment of apparent anonymity, especially when involving the trade in protected species. Advertisements selling live individuals and derivative products from wild species, such as ivory, primates and plants, have been detected online, including on well-known e-commerce platforms such as Amazon and eBay (Hinsley et al. 2015; Bergin et al. 2017; Yeo et al. 2017). In addition, online posts on social media displaying wild animals as pets have been shown to stimulate the desire of users to own wild species (Nekaris et al. 2013). Being such a recent activity, there is still a large knowledge gap on the role of the Internet on the wildlife trade for different demands, taxa and geographical regions, specifically regarding rare or niche-targeted taxa and megadiverse countries.

1.2 Wildlife trade in Latin America

Studies assessing international trade frequently highlight Latin America as an important source of wildlife products to other continents, in both regulated and illegal trade (Scheffers et al. 2019; Esmail et al. 2020; Olsen et al. 2021). Globally, Latin America appears among the top 5% of regions with the largest

number of traded species per territory for birds and amphibians and among the top 25% for mammals and reptiles (Scheffers et al. 2019). Political and socioeconomic instability commonly found in Latin American countries have been pointed out as factors that aggravates the establishment of illegal markets (Esmail et al. 2020). Considerable part of the literature reporting on the wildlife trade in the region, however, is not currently published in scientific articles, but available in difficult-to-access conference abstracts or regional governmental reports (Roldán-Clarà et al. 2014). To develop effective measures and tackle the impacts of wildlife trade in Latin America, there is a clear need for further studies on trade in the region to unveil the most traded taxa, identify the main actors and types of market (physical or online market) involved, and assess the drivers of trade, especially for the illegal or non-regulated trade.

Large amounts of legal exports from Latin America have been recorded over time. For example, in the decade between 2005 and 2014, skins of spectacled caiman (*Caiman crocodilus*), bodies of brown sea cucumber (*Isostichopus fuscus*), live orchids (Orchidaceae) and live side-necked turtles (Podocnemididae) amounted the majority of what was legally exported from Amazonian countries of Latin America, with a considerable fraction of these products being sourced from wild populations (Sinovas et al. 2017) (Figure 1.1).

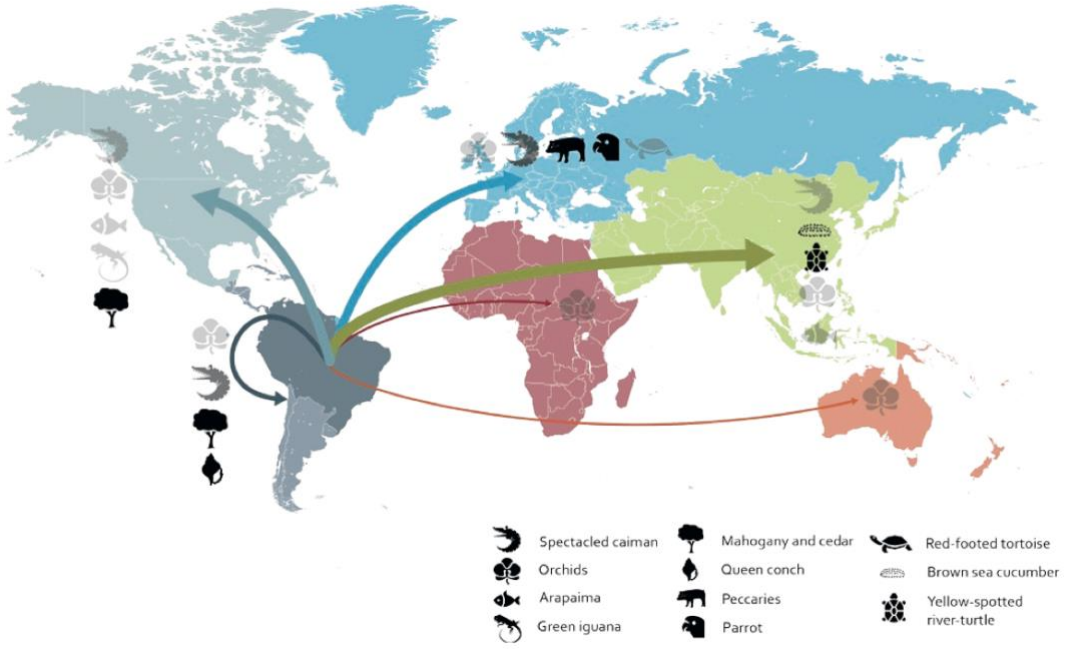

Figure 1.1 Main groups legally exported from Amazonian countries of Latin America between 2005 and 2014. The groups are ordered according to their trade volumes; arrow width denotes the relative trade volume, and the symbols are shaded according to the source (black: >75% wild, dark grey: 75-25% wild, and light grey: <25% wild). Figure extracted from Sinovas et al. (2017).

The best coverage in terms of market sampling in Latin America probably refers to regional wild meat trade and urban consumption in the Amazon, especially in the Peruvian, Brazilian and Colombian Amazon (van Vliet et al. 2014; Mayor et al. 2019; El Bizri et al. 2020a,b; D'Cruze 2021), which often includes a mix of legal and illegal trade, depending on the taxa or region considered. In addition, parts of wild animals can be found in trade as components of jewellery and souvenirs (Redford and Robinson 1991). Notably, nocturnal monkeys (*Aotus* spp.) are illegally traded domestically and across borders for use in biomedical research in Peru, Colombia and Brazil (Maldonado et al. 2009). Other reports also suggest that cubs of Andean bears,

birds, reptiles and primates are traded as pets (González 2003; Shanee 2012; Quevans et al. 2013; Figueroa 2014; Shanee et al. 2017), most of them more likely related to domestic (in-country) markets (Pires 2014; Leberatto et al. 2016).

Birds, particularly parrots, are the taxa with the most comprehensive number of studies in different Latin American countries (González 2003; Herrera and Hennessey 2007; Gastañaga et al. 2011; Regueira and Bernard 2012; Nóbrega Alves et al. 2012; Pires et al. 2012; Tella and Hiraldo 2014; Sánchez-Mercado et al. 2020). In Venezuela alone, it is estimated that 18,334 parrots are extracted yearly from the wild to supply the pet market (Sánchez-Mercado et al. 2020). In Bolivia, where 94% of parrots traded are believed to be sourced from the wild, most of the individuals supply the domestic market, while the more expensive species, including threatened ones, are illegally trafficked to Peru and some European countries (Herrera and Hennessey 2007). In Mexico, Tella and Hiraldo (2014) reported that the quantities and prices of traded parrots depend on the perceived attractiveness towards the species, and that the most expensive ones, such as amazons and macaws, are heavily smuggled to the USA. As a consequence of illegal poaching, parrot populations are declining considerably, which makes parrots the most threatened bird group in the Neotropics (Pires 2012).

Multiple reports on seizures of jaguar (*Panthera onca*) body parts across different Latin American countries indicated a potential wave of illegal trade in the species, raising concerns internationally (Fraser 2018; Lemieux and Bruschi 2019; Nuñez and Aliaga-Rosell 2017; Reuter et al. 2018; Verheij 2019). Reports on illegal trade in jaguar body parts, especially from Bolivia and Suriname, suggested that people living in Asian countries, particularly in China, may be the

main consumers, with jaguar parts possibly acting as a substitute for tiger body parts (Villalva and Moracho 2019; Nuñez and Aliaga-Rosell 2017; Verheij 2019). While trade in tiger and lion parts has been widely reported in Asian countries (e.g., Wong 2015; Williams et al. 2017), the emerging trade in jaguars has been only recently addressed in Bolivia, Guatemala, and Belize (Arias et al. 2020a; Arias et al. 2020b; Polisar et al. in review). In contrast to data on parrots, there is still a need for a large-scale assessment of the trade in jaguar in all Latin American countries. There is also a need for understanding the possible drivers related to this market, and the role that legal trade may pose in driving more illegal trade in the species.

Apart from wild meat and parrots, very few studies were dedicated to a systematic sampling of wildlife markets, although many mention an existence of a trade. Even less studied are the drivers and correlates of wildlife trafficking in Latin America, for both domestic and international markets, which considerably hinders the development of appropriate legislation and public policies to avoid population reductions and extinctions of target species in the region. In this thesis, I will focus on Latin America – particularly Brazil – as my study area and use strategically-selected taxa as models to study the wildlife trade from the perspective of (i) socioeconomic drivers of trade, (ii) public human health related to trade and ownership of wild animals and (iii) legal frameworks related to wildlife trafficking in terms of crime in the region (Figure 1.2). In the following sections of the Chapter 1, I will present a summary of the state-of-the art of socioeconomic factors, public health issues and policies related to wildlife trade and contextualize the research gaps in the topics that this thesis aims to fill.

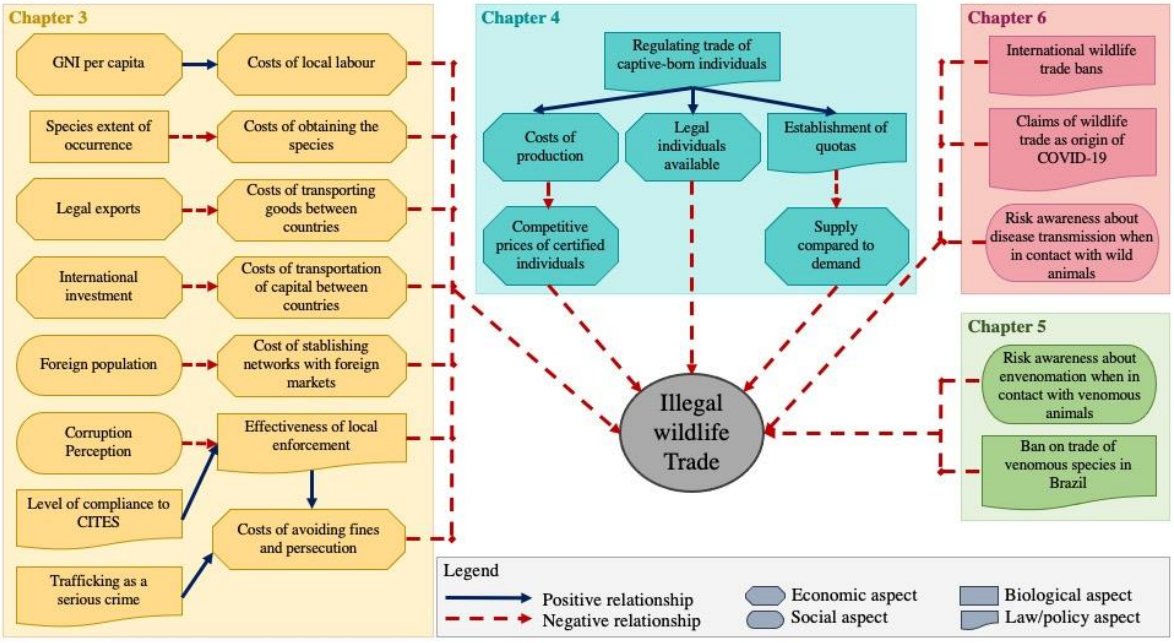

Figure 1.2 Chain of expected effects of the studied factors on the level of wildlife trade according to literature, organized per thesis chapter.

1.3 The role of socioeconomic factors in wildlife trade

The most commonly employed strategy to tackle illegal wildlife trade involves reforming legal and regulatory systems, law enforcement and surveillance (White 2013; UNODC 2020). However, regulatory and prohibitive strategies alone are often insufficient to curb illegal wildlife trade (Kideghesho 2016; Challender and MacMillan 2014; Biggs et al. 2017; Cooney et al. 2017). This is because several socioeconomic factors may facilitate the establishment and persistence of an illegal chain; consequently, to develop more effective interventions, wildlife trade should be assessed under a market perspective (Challender and MacMillan 2014; Challender et al. 2015).

The cost of obtaining wild animals from their source areas, for example, influences the establishment of the supply chain and prices paid along it (Wyatt 2009). Local people are typically responsible for sourcing wildlife or derivative products, and their labor costs depend on how easy it is to access wildlife, how

much they could earn in alternative economic activities and the risk of being caught by local law enforcement (Barret et al. 2011; Biggs et al. 2017; Cooney et al. 2017). High levels of corruption and lack of governance reduce the chances of people involved in the illegal trade to be caught and, more decisively, persecuted. Consequently, impunity usually discourages people to conserve wildlife, does not dissuade stakeholders in taking part in illegal activity and often undermines trust in governmental and judicial institutions (Challender and MacMillan 2014; Silva and Bernard 2015; Wyatt et al. 2018). In addition, if penalties from environmental crimes are lenient or the occurrence of bribes along the chain is ubiquitous (and consequently low-price), the costs of evading sentences are lower. This impunity, when associated with high poverty rates and lack of public policies to ensure access to basic services, may drive people to involve in poaching and illegal wildlife trade in all steps of the chain, i.e., collection, transportation, and commercialization (Twinamatsiko et al. 2014; Challender and MacMillan 2014; Harrison et al. 2015).

In addition, setting up networks for transporting illegal products is usually difficult. Because covert trade networks must be concealed, stakeholders cannot count on a legal system to resolve contractual disputes. Therefore, trust becomes a key factor in reducing transaction costs and results in the majority of supply-chain transactions being done among ethnically homogeneous groups, in effect “trusting their own” (Raab and Milward 2003); this is how diasporas may facilitate the establishment of illegal chains (Skinner 2017; Hughes et al. 2020).

Bottlenecks in the supply chain occur when products are moved up and capital is moved down to the different intermediaries involved (Raab and Milward 2003). Because of that, the presence of networks and flows of legal

goods and capital between the consumer and the supplying regions can also help reduce costs of illegal trafficking and should be considered when assessing illegal markets. Illegal networks may find opportunities to exploit synergies with established, legal networks at the same time that a strong flow of legal goods and capital can mask illegal flow and lower the cost of hiding trade (Raab and Milward 2003; Wyatt 2009). While the existence of legal transactions and exports of any product may ease the establishment or mask the illegal chain, the existence of legal chains trading high-demanded wildlife deserves careful consideration. Protected wildlife is sometimes traded illegally alongside legal trade, making use of established, legal networks of wildlife products, often counting on lack of surveillance, misidentification or through use of false licenses (Bulte and Damania 2005; Lyons and Natusch 2011; Musing et al. 2015; Wyatt et al. 2018). Therefore, the comparison between legal trade - including origin and destination and the type of item and quantity of what is traded - is key to understand whether illegal trade was established in the back of legal trade, whether the regulations in place related to legal trade are being effective, and what amendments along legal chains and frameworks could be undertaken to prevent this to happen (Tittensor et al. 2020).

The establishment of a certified trade is in fact among the most prominent market strategies suggested to reduce the illegal market for wild species (Hutton and Webb 2003; Archawaranon 2005; Robinson et al. 2015). This market strategy has been adopted to meet the demand for bear bile (Foley et al. 2011), tiger bones (Kirkpatrick and Emerton 2010) and black rhino horns (Brown and Layton 2001), porcupine meat (Brooks et al. 2010), pet reptiles (Nijman and Shepherd 2009), butterflies for collection and decoration (Gordon and Ayiemba 2003) and several other taxa (Tensen 2016) in an effort to

conserve these species. From a market perspective, however, substituting illegal products by genuinely, legally sourced products is only effective when the legal product can compete with the illegal product in terms of quality and/or cost (Damania and Bulte 2007; Bulte and Damania 2005; Challender et al. 2015). The production costs of legal and illegal markets differ substantially, especially where surveillance is not effective, as previously mentioned. For legal breeders, the cost of building and running animal enclosures, paying taxes and meeting the quotas established by legislation play an important role in setting the levels of production and the prices applied to the wildlife products. Conversely, in the illegal chain, there may be a lower cost associated with structure, since it often involves underpaid hunters or middle-man that capture the specimens in the wild, or illegal breeding facilities that do not have to comply with animal welfare or paying taxes. Insufficient price controls of legal sources could lead to excessively high prices and result in consumers relying more often on cheaper illegal sources to satisfy their demand (Challender et al. 2015). If the captive-bred and wild-caught animals are identical in all aspects but price, the cheapest product is more likely to be purchased (Bulte and Damania 2005; Kirkpatrick and Emerton 2010). Although this market strategy has been constantly suggested - and in some cases put into practice - to avoid the effects of overexploitation of wild populations, scientific assessments of real-life operating legal wildlife markets to confirm their effectiveness in curbing illegal wildlife trade are still scarce.

For several wildlife trade chains, existing studies provide a fair estimate of the amount of specimens illegally traded (e.g., Nijman 2010; Ferreira et al. 2012; Scheffers et al. 2019; Fukushima et al. 2019; Andersson et al. 2021) and, on a few occasions, assess some correlates of supply of or demand for wildlife

(e.g., Brashares et al. 2011, MacMillan and Nguyen 2014; El Bizri et al. 2020a; Chaves et al. 2020; Busilacchi et al. 2021). Considering that wildlife markets are complex and there is no “one-size-fits-all” approach that could be applied to all contexts, there is a clear need for further assessments of how socioeconomic factors interact and drive the establishment and persistence of current wildlife trade chains to develop context-appropriate programmes to tackle illegal wildlife trade, in particular for less-studied but most trade-imperiled taxa and geographical areas.

1.4 The health risks associated with wildlife trade

The impacts that wildlife trade can cause the environment and human society goes beyond animal population reduction due to overexploitation. Wildlife trade may facilitate the emergence of infectious diseases that can pose serious health risks to humans (Morens et al. 2020; Borsky et al. 2020). Around two-thirds of emerging infectious diseases affecting humans are zoonoses, i.e., the disease has originated from animals and recently crossed the species barrier to infect humans (Jones et al. 2008; Smith et al. 2014); of these, 72% originated in wildlife (Jones et al. 2008). In addition to causing around one billion cases of illnesses and millions of human deaths every year (Karesh et al. 2012), zoonotic diseases also generate serious social and economic impacts to human societies.

Transmission of pathogens between wildlife and humans often occurs due to direct contact with infected animals, dead or alive, or with their body fluids. In this context, wildlife consumption has been suggested as the cause for the emergence of several diseases, such as HIV and Ebola (Karesh et al. 2005). Although more studies on the role of wildlife trade in potentializing the emergence of diseases need to be carried out, examples such as the 2003

Monkeypox outbreak in the USA show how unsafe the import of live individuals with improper sanitary control can be in spreading hazardous pathogens (Reed et al. 2004). Wildlife markets usually put stressed and often immunosuppressed wild and domestic species in close proximity, and hunters, middlemen, and consumers often have close contact among them and with the traded animals, providing optimal conditions for spillover and cross-species transmission of pathogens. In addition, the poor hygiene conditions often observed in the commercialization of wildlife in markets – especially when they are illegal – can be a crucial potentiator of pathogen transmission (Cantlay et al. 2017; Borsky et al. 2020; Bezerra et al. 2021).

Animal-human transmission has also been suggested in all three deadly outbreaks of beta-coronaviruses, including SARS-CoV, MERS-CoV and the recent SARS CoV-2. These viruses were responsible for outbreaks of severe acute respiratory syndrome (SARS) in 2002, Middle East respiratory syndrome (MERS) in 2012 and COVID-19 in 2019 (Ye et al. 2020). Natural infection by SARS-CoV was identified in wild-caught masked palm civets (*Paguma larvata*) for sale in wildlife markets but was not present in farmed civets (Guan et al. 2003). Further, it was found that 40% (n = 8) of wild-animal traders and 20% (n = 3) of workers who slaughtered animals showed presence of anti-bodies to SARS-CoV, while only 5% (n = 1) of vegetable traders and none of the human controls (n = 60) were seropositive (Guan et al. 2003). It has been suggested that the highly pathogenic SARS-CoV and MERS-CoV have not adapted sufficiently to humans to exclude the need for animal reservoirs to maintain and propagate themselves (Ye et al. 2020). Additionally, phylogenetic differences between human and animal S–CoV viruses indicate that, in this case, transmission from humans to animals is highly unlikely (Guan et al. 2003). The

potential for infection was emphasized because in many live-animal markets, animals such as poultry, fish, reptiles, and mammals are slaughtered on the spot, and either legally or illegally traded as medicines, meat and pets (Webster 2004).

Recently, the COVID-19 pandemic has brought back to the spotlight the concern of wildlife markets as a major health challenge for humanity. Although not yet confirmed, it was initially reported that the intermediate animal hosts of SARS-CoV-2, the virus responsible for the COVID-19 pandemic, were among the wildlife species sold and killed in a live-animal market in Wuhan, where many of the initial COVID-19 cases were associated (Ye et al. 2020). As a response, China issued a nationwide ban on terrestrial wild animal consumption and trade, including captive-bred exotic species (Wang et al. 2020). At the same time several petitions and campaigns emerged to discourage the purchase of wildlife products and to demand governments to ban wildlife trade in several countries (e.g. Anonymous 2020a,b).

Being a pathway to new diseases is not the only way that wildlife trade can pose risks to human health. The trade in aggressive or venomous species, for example, exposes owners, sellers, customs officials, and others involved in transport and maintenance of wild species to potentially serious accidents, including envenomation or poisoning (Hierink et al. 2020). Venom/poison composition of different species, i.e., snakes, scorpions, spiders, amphibians, can vary widely and cause health complications, varying from pain and local tissue damage to largely systemically destructive effects on haematological or neurological tissues (Gutiérrez et al. 2017). Snakebite envenoming, for instance, is a serious public health issue worldwide, with 1.8 to 2.5 million envenoming cases estimated to occur annually (Chippaux 1998; Kasturiratne et

al. 2008). Although snakebites more often affect dwellers of rural areas, especially agricultural workers, cases of snake bites by pet specimens are persistently reported worldwide, and many may go unreported (Schaper et al. 2009; Warrell 2009; Valenta et al. 2014; Hierink et al. 2020).

Despite recent progress, there is a clear need for deeper assessments of health risks posed by wildlife trade to improve policies, sanitary measures and public awareness. In the post-COVID-19 era, further studies on identification of possible pathogens harboured by species exploited for trade, evaluating the chances of spillover and detecting whether traders and consumers are changing their behaviour as a response to worldwide trade bans and campaigns are crucial to inform further policies or educational strategies to avoid the emergence of new diseases (Bueno et al. 2016). Similarly, the assessment of the extension of the market that potentially targets venomous or poisonous species (i.e., taxa traded, quantities and geographical regions) is critical to evaluate the risks involved in owning these taxa and develop regulations and educational measures aimed at reducing the risk of accidents throughout the trade chain.

1.5 Policies and legislation related to wildlife markets

The most common policies and legal instruments developed to prevent unsustainable exploitation are based on outright bans and trade certification (Dutton et al. 2013). Internationally, the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), enacted in 1975, was a landmark for regulating and controlling international wildlife trade. CITES defines the mechanisms to regulate the trade, including permits and licensing for wild-caught or captive-bred wildlife, and currently includes 183 signatory countries, called CITES Parties (UNEP-WCMC 2019). Parties are responsible

for amending their national legislation to ensure the prohibition of possession, transportation, and trade of wild specimens without proof of legal acquisition, confiscation of illegally traded specimens, punishment of frauds and non-compliance, controlling of borders, and stimulation and regulation of breeding operations when suitable for the listed species (Reeve 2002). Although this important international policy instrument aided to reduce considerably the exploitation of species in the wild in the past decades, notably for the pelt and skin trade (Antunes et al. 2016), several challenges regarding regulation of international wildlife trade still persist. The perception regarding the burden of crimes against wildlife depends on the countries or contexts (‘t Sas-Rolfes et al. 2019), and consequently the severity of penalties varies largely. For example, in Latin America, 14 countries (i.e., Argentina, Bolivia, Colombia, French Guiana, Guatemala, Guyana, Honduras, Mexico, Panama, Paraguay, Peru, Suriname, United States, and Venezuela) consider wildlife trade as serious crime in its current legislation, i.e., 3 to 10 years of imprisonment as a punishment (Kretser et al. 2022). In 5 other countries, however, i.e., Belize, Brazil, Costa Rica, Ecuador, and Nicaragua, the most common penalties applied to perpetrators involved in wildlife trade are administrative penalties, or at most 2 years of imprisonment, the latter being quite rare (Kretser et al. 2022).

In addition, countries have struggled with amending their legislative framework to meet the CITES recommendations (‘t Sas-Rolfes et al. 2019; Challender et al. 2015), in part because wildlife crimes are often not priorities for criminal justice, especially in developing countries. Lenient penalties and legislation loopholes along with lack of resources and capacities (e.g., officers being poorly trained to identify wildlife products) often constrain considerably the effectiveness of law enforcement in curbing illegal wildlife trade.

Bans, on the other hand, may only work when in combination with additional measures of demand reduction, complete substitution by similar products or total adherence from the stakeholders involved in the existing chain. The ban alone can potentially exacerbate the threat posed by trade, once in locations where prohibitions are implemented, clandestine markets often expand to supply the demand. In these contexts, illegal wildlife trade prevails and monitoring becomes nearly impossible (Harrison et al. 2016). Very often, criminals already involved in other illicit activities become responsible for the supply of a recently criminalized product when the demand still persists (Dutton et al. 2013). Similarities between the structure of illegal wildlife trade and drug trafficking show that both markets may interact with each other (South and Wyatt 2011). An overlap between wildlife trade and drug trafficking has been reported based on a few but high-profile reports of animals imported legally to the USA stuffed with drug-filled condoms (Cook et al. 1994). Other studies also reported an increased participation of drug cartels in wildlife trade (UNODC 2002), and a three-fold raise in the number of fishing vessels engaged in drug shipment worldwide between 2010 and 2017 (Belhabib et al. 2020).

The participation of organized crime in wildlife trade is still debatable. The often-required skills to access wildlife, sophisticated methods to conceal live animals or derivative products along a trade chain and personal or institutional collaborations to travel long distances and often cross international borders can be seen as an opportunity for the establishment of involvement with an organized network (Schloenhardt and Ege 2020). Many authors reported the involvement of organized mafias and other crime syndicates in China, Japan, Italy, and Russia in wildlife trade (e.g., Challender and MacMillan 2014; Bergenas and Knight 2015; van Uhm 2016), while others did not find any

evidence to support that claim (Pires and Clark 2011; Reuter and O'Regan 2017). Although Latin America presents an extensive and active network of organised crime (Bagley 2010), assessments of the structural organization of the illegal parrot trade, one of the most prominent known trade in the region, concluded that it is largely opportunistic (Pires and Clark 2011; Pires et al. 2016). A recent systematic review of academic literature and government reports also showed that criminals persecuted for being involved in illegal wildlife trade work independently; however, this study also pointed out the role that some legitimate businesses may play in the illegal trade (Reuter and O'Regan 2017). Worldwide, legitimate business is often found to participate in the transportation of animals and derivative products and in laundering by forging documents to facilitate illegal animals or derivative products to enter in the legal chain (van Uhm 2016; Schloenhardt and Ege 2020). Even zoos may sometimes fail to comply with international regulations and therefore, consent to wildlife trade at some extent (Nijman 2021b). Organized crime is often driven to places that offer a combination of high-profits and low-risks of prosecution, such as most countries of Latin America (Dalberg 2012). Therefore, further studies on the typology and structure of the illegal wildlife trade are still required, especially taking into account the local level of enforcement and corruption, the level of penalties applied to environmental crimes, the possibility of existence of organized crime networks, and possible interactions among legal and illegal wildlife market chains.

1.6 Thesis structure, aims and objectives

1.6.1 Aims and objectives

Through a multidisciplinary approach, the overall aim of this PhD thesis is to assess the scale, correlates and implications of the trade of flagship taxa in

Latin America. For this purpose, I unveil biological and socioeconomic factors driving this wildlife trade, the health risks imposed by the activity, and the effectiveness of certified captive-breeding as a strategy to curb the illegal market in Latin America.

1.6.2 Outline of the thesis

This thesis is divided into seven chapters. In **Chapter 1**, I present the general introduction and in **Chapter 2**, I present the general methods, with details of the study area and the source of data used in the data chapters. Apart from Chapter 4, all data chapters have already at least part of the content published in scientific journals (i.e., Chapter 3, 5 and 6), and the published version of these publications are included at the end of the thesis.

The objective of **Chapter 3** was to assess socioeconomic correlates of the emerging international trade in native wild cat species from Latin American countries to other countries worldwide. In this chapter, I compiled a dataset of >1000 seized wild cats to present the first large-scale, multicountry assessment of the illegal trade in jaguars to fulfil a current international demand for the likely hotspots of trade and support feasible interventions.

In the next three chapters (Chapter 4, 5 and 6) I focussed on the domestic wildlife market in Brazil, as this country covers ~50% of the South American landmass, encompasses 60% of Amazonia, is the largest economy in the region, and borders almost all other South American countries. All these characteristics put the country in a strategic position in terms of policies, economy, and biodiversity to suffer the most from the consequences, but also to help to curb wildlife trade in Latin America.

The objective of **Chapter 4** was to assess effectiveness of captive-breeding programmes as an intervention to curb wildlife trafficking in Brazil.

Using a market perspective and primates as model taxa, I monitored online trade (social media and E-commerce platforms), visited an open fair, and sampled certified primate breeders throughout the Brazilian territory to estimate the volume, composition, and economic factors of the trade in primates, including unit and revenue market share and price comparisons between certified breeders and illegal sources. I also identified candidate interventions to amend the current flaws in the current market in order to make it effective to reduce primate trafficking.

The objective of **Chapter 5** was to assess the scale of the illegal trade and ownership of venomous snakes in Brazil and evaluate the potential risk to human health posed by snakebites. In this chapter, I examined social media posts trading or portraying native and exotic venomous species as pets and obtained data from official seizures to estimate the volume and composition of the trade in venomous snakes. I also compiled a large-scale dataset of occurrence of snakebites throughout the country to compare the geographical locations and the taxa involved in snakebites and pet trade, and evaluate the availability of antivenom to these species, therefore estimating the the potential risk of human envenomation posed by the illegal ownership and trade of venomous snakes in the country.

The objective of **Chapter 6** was to uncover how the traders and custumers involved in the wildlife pet trade in Brazil responded to campaigns associating the origin of the COVID-19 pandemic with wildlife markets in China and advocating wildlife trade bans worldwide. In this chapter, I analyzed the content of ~20,000 posts on 41 Facebook™ groups devoted to wild pet trade in Brazil, and for comparison, in Indonesia, another megadiverse country but geographically closer to the epicentre of the pandemic. I assessed when and

how the COVID-19 pandemic was incorporated into the discourse within wildlife trade communities, and whether it had an effect in discouraging the trade in wild pets.

The data chapters are organized based on the approach adopted to address the questions. Figure 1.3 is presented at the beginning of each chapter and the internal circle points out the topics that addressed in that particular chapter (e.g., here it points out the 'socioeconomic and policy factors behind the trade').

Figure 1.3 Simplified diagram signalling the main topics related to my multidiciplinary approach addressed in each of the thesis' data chapters.

In the last chapter of the thesis, **Chapter 7**, I summarise the main results and contributions of this thesis, emphasizing the novel aspects of this work and how it fills knowledge gaps existent in the wider context of wildlife trade research. I also highlight opportunities for future research on this topic. Figure 1.2 provides the hypothesized effect of the social, economic, biological and policy factors assessed in this thesis on illegal wildlife trade, and Table 1.1 provides a breakdown of chapters with details on the factors assessed, taxa, geographical scope, type and source of data used and type of market addressed.

Table 1.1 An overview of the chapters presented in this thesis, including the theoretical factors studied, taxa used as a model, geographical coverage, and type and sources of data and market addressed.

Chapter	Theoretical approach/ factor	Taxa	Geographical scope	Type and source of data	Type of market
3	Economic (international investment, legal exports, GNI[a] per capita); Social (corruption perception index, populational aspects); Policies/Legislation (serious crime, CITES[a] signatories, CITES compliance)	Main focus jaguar (*Panthera onca*); Puma (*Puma concolor*) and ocelot (*Leopardus pardalis*) also included	Latin America[b] ~20 countries	Seizures (News reports, official reports available online); Legal exports (CITES database)	International and domestic, focus on international
4	Economic (market forces, market share) Policies (effects of regulating trade of captive-bred individuals)	Primates	Brazil	Trade advertisement (Facebook™ - manual search and E-commerce – automated search); Legal trade (certified breeders)	Domestic
5	Public health (risk of envenomation); Legislation (bans).	Venomous snakes	Brazil	Trade advertisement (Facebook™ and YouTube™ - manual search); Seizures (IBAMA[a] database); Seizures (News reports); Envenomation reports (Notifiable Diseases Information System platform – SINAM)	Domestic
6	Public health (risk of diseases transmission – covid-19 context); Effects of bans or campaigns discouraging wildlife trade (Behaviour change and stakeholder's awareness)	All traded groups, mainly mammals, birds and reptiles	Brazil, and for comparison, Indonesia	Facebook™ (manual search)	Domestic

[a] GNI = Gross National Income; CITES = Convention on International Trade in Endangered Species of Wild Fauna and Flora; IBAMA = Brazilian Institute of the Environment and Renewable Natural Resources

[b] Latin America = includes all Latin American countries plus the non-Latin Guyana, Suriname and Belize.

Chapter 2. General Methods

2.1 Introduction

There are several nuances in the study of wildlife markets that often make them very complex to assess. The scale of the trade in wild specimens or their derivative products can vary substantially, from domestic markets, more or less close to the species distribution range, to international markets, where the items may cross borders and oceans to reach the consumers (Phelps et al. 2016; McEvoy et al. 2019). In addition, a substantial fraction of the trade is also considered illegal under international or domestic regulations. Therefore, to record trade instances systematically, especially from illegal trade, is still challenging, both due to the secrecy of the activity and the risks it may pose to the researchers (Passas 2003; Phelps et al. 2016).

As an alternative, seizure incidents have been consistently used as a proxy for the illegal wildlife trade (Tittensor et al. 2020; Symes et al. 2018). It is commonly acknowledged that the seizures only represent a fraction of the actual illegal trade and are dependent on the local level of law enforcement; however, this minimum estimate that seizures provide is necessary and helpful for decision-making (Tittensor et al. 2020).

Different from the illegal trade, the legal trade has been systematically tracked at an international level, using the global database on exports of wildlife individuals or derivative products, the CITES database. CITES database has been used for decades as a source of information to understand the extent and motivations behind the legal international wildlife market (Bruckner 2001; Nijman and Shepherd 2010; Williams et al. 2021).

With the recent increase in access to the internet, and the consequent popularization of E-commerce and social media platforms, sellers have been provided with an unprecedented connection to potential consumers and

expanded markets (Siriwat and Nijman 2020); but the role of dark web marketplaces is still negligible (Harrison et al. 2016). The rate of internet access, also known as internet penetration rate, increased by 2,600% worldwide between 2000 and 2021, and it is estimated that an average of 66% of the world population has current access to the internet; in Latin America, access rates are higher than the global average (76%) (Miniwatts Marketing Group 2021). Worldwide, people spend on average 6h56min daily on the internet, 2h30min of those on social media; many Latin American countries figure above the worldwide average (Hootsuite 2021). Consequently, the online market for wildlife specimens and derivative products, including protected species, is incresingly attracting the attention of researchers and authorities. Methodological advances in the field of online wildlife trade are still required. Recent studies started to define frameworks on monitoring and quantifying online wildlife trade (e.g., Stringham et al. 2020), and to develop machine learning techniques to authomatize the mining, filtering, and identifying steps of the data collection in digital platforms (Kulkarni and Di Minin 2021). Advances has also been advocated in the jurisdictional realm, given the borderless nature of cyberspace where online wildlife transactions can traverse multiple territories and hinder law enforcement (Lavorgna et al. 2020).

In this chapter, I present the geographical scope considered in this thesis and different sources of information and general methods that have been used to collect data for the data chapters. I was responsible for the conceptualization, data collection, data analysis and writing of all chapters, but I collaborated with my supervisors Professor Vincent Nijman, Professor Anna Nekaris, Dr Magdalena Svensson and strategic partners throughout the process.

2.2 Study area and taxa studied

The Neotropical region, from Mexico to southern South America, is singled out as the world's most biodiverse region of the planet, being home to more than twice as many species of vascular plants and of various animal taxa when compared to the similarly sized Afrotropical Region (Raven et al. 2020).

The Neotropics encompass countries geographically located in the North, Central and South American regions, and it is often referred as Latin America in the scientific literature. Latin America *sensu stricto* includes the countries historically under the Hispanic and Iberian colonial empires or the ones in which laguages derived from Latin - in this case, Spanish, Portuguese and French - are primarily spoken. In this thesis, I will refer to Latin America in a broader sense, including the South American countries of Guyana and Suriname and the Central American country of Belize, where English and Dutch are the primarily languages spoken. In Chapter 3, I assess the aspects of international wildlife trade in jaguars in 21 countries of Latin America (Mexico southward, excluding Caribbean Islands): Argentina, Belize, Bolivia, Brazil, Chile, Colombia, Costa Rica, Ecuador, French Guiana, Guatemala, Guyana, Honduras, Mexico, Nicaragua, Panama, Paraguay, Peru, Suriname, Uruguay, and Venezuela (Figure 2.2).

Figure 2.2 Map of assessed countries in Latin America.

The assessed countries vary considerably according to the socioeconomic variables that are expected to affect wildlife trade, as well as in the extent of occurrence of wild cats (Table 2.1). Jaguar (body mass ~130 kg) is one the most iconic species in Latin America, being a flagship species that has united different countries to work together in an effort to save the species from the extinction after local extictions happened in the USA, El Salvador and Uruguay (de la Torre et al. 2018). With the urgency to understand the apparent new surge in trade in the species (Fraser 2018; Nuñez and Aliaga-Rosell 2017; Verheij 2019), I focus on jaguars along with the two most widespread wild cats, puma (*Puma concolor*) (~80 kg) and ocelot (*Leopardus pardalis*) (~20 kg), to assess the international illegal trade in Latin America was exclusive to jaguar or

extended to other cats. I obtained data on the extent of occurrence for each species in each country from the IUCN Red List (IUCN 2019) and on the Chinese population in Latin American countries from the Central Intelligence Agency (2016), and on the corruption perception index from Transparency International (2018). I extracted the GNI per capita for each country from World Development Indicators (World Bank 2019) and Chinese foreign private investment and exports to China from the World Trade Organization (WTO 2019).

Table 2.1 Data on the socioeconomic factors considered in this thesis, level of compliance of national legislation to CITES requirements, and extent of occurrence of wild cats in Latin American countries. CPI = Corruption Perception Index; GNI = Gross National Income; CITES= National legislation compliance to CITES recomendations; Chinese inv. = Chinese private investiment; EOO = Species Extent of Occurrence.

Country	CPI	GNI per capita (US$)	CITES[a]	Exports to China (millions US$)	Chinese inv. (millions US$)	Resident Chinese population	EOO (1000 km^2) jaguar	puma	ocelot
Argentina	35.7	19,011	Full	4,641.3	3,990	120,000	44.1	2,428.0	180.0
Belize	38.1	7,828	None	0	0	1,930	22.0	23.0	23.0
Bolivia	33.1	6,401	Full	435.7	748	30,000	732.4	1,098.6	978.6
Brazil	39.7	14,823	Full	39,410	7,236	400,000	4,603.7	8,515.8	8,279.4
Chile	69.4	22,122	Full	17,568.3	770	10,000	0.0	378.1	0.0
Colombia	36.5	12,879	Full	1,797	200	25,000	854.2	1,138.9	1,010.1
Costa Rica	55.5	14,682	Full	0	470	45,000	34.1	51.1	51.1
Ecuador	32.7	10,536	Partial	716.3	2,157	30,000	94.5	283.6	283.6
El Salvador	36.9	6,999	Full	0	0	500	0.0	21.0	0.0
Guatemala	29.2	7,235	Full	0	700	1,000	49.5	108.9	108.9
Guyana	31.8	7,054	Full	0	375	2,919	215.0	215.0	215.0
Honduras	28.8	4,279	Full	0	350	530	44.8	112.1	112.1
Mexico	31.0	19,990	Full						
Nicaragua	27.0	4,788	Full	0	530	12,000	65.2	130.4	130.4
Panama	37.2	20,728	Full	0	503	135,000	37.7	37.7	75.4
Paraguay	26.9	11,071	Full	26.33	0	40,000	203.4	406.8	406.8
Peru	36.7	12,093	Full	9,169.7	3,346	1,100,000	642.6	1,285.2	1,285.2
Suriname	39.1	14,414	Partial	0	0	7,885	163.8	163.8	163.8
Uruguay	71.8	19,945	Full	1,145.7	0	226	0.0	22.0	0.0
Venezuela	18.2	17,703	Full	0	2,713	420,000	608.0	912.1	912.1
Total	-	-	-	74,910.3	24,088	2,381,990	-	-	-

[a] Fully compliant refers to Category 1 of Resolution Conf. 8.4 (Rev. CoP15), while partially compliant refers to Category 2, none refers to Category 3.

In Chapter 4, 5 and 6, I assess aspects of domestic trade of snakes, primates, and other taxa, and for that purpose I defined Brazil as my focal study area. Brazil is the most megadiverse country worldwide and a global priority territory for biodiversity conservation (Mittermeier et al. 1997; Brooks et al. 2006). Brazil combines a high biodiversity with low levels of law enforcement, and as a consequence it has been suggested as a potential source of illegal fauna for domestic and international markets (RENCTAS 2001; Phelps et al. 2010; Silva and Bernard 2015).

Few decades ago, the Brazilian government estimated that 12 million specimens were annually removed from the wild to supply the demands of use and trade for diverse purposes (RENCTAS 2001). Most studies on wildlife trade in Brazil assessed seizure reports of trade in animal taxa (excluding fish) in order to understand the coverage of wildlife trade; most of the reports were on birds being traded (Alves et al. 2013). Seized in thousands annually, songbirds and members of the family Psittacidae are the main seized bird species in the Northeast Brazil (Pagano et al. 2009; Oliveira et al. 2020) and Southern Brazil (Ferreira and Glock 2004), while Muscovy duck (*Cairina moschata*), given its use as food, figured together with songbirds as the main seized birds in the Brazilian Amazon (Nascimento et al. 2015). As a consequence of studies demonstrating the relevance of illegal bird trade and breeding in Brazil, in 2011, the Brazilian government launched the System for Control and Monitoring of Amateur Bird Breeding Activity (in Portuguese: Sistema de Controle e Monitoramento da Atividade de Criação Amadora de Pássaros - SisPass). The system is part of an initiative to avoid breeding protected species and stimulate bird ownership from certified sources only. However, no similar effort has been made yet for other taxa.

Primary data on animal trade incidents through market sampling is still far from adequate to be used as evidence for improving of public policies on wildlife trade in the country. In addition to birds (Regueira and Bernard 2012; Faria et al. 2015), wild meat markets were sampled in the Amazon region, estimating 385 tonnes of wild meat traded yearly in the border cities of Peru, Brazil, and Colombia tri-frontier, in the far West Amazon (van Vliet et al. 2018), and 5,9 tonnes yearly traded in a town in the far East Amazon (Baia-Junior et al. 2010). An assessment of animals traded for medicinal use recorded 68 animal species in five cities of Northeast Brazil, mainly mammals (20 species), reptiles (17 species), and birds (12 species) (Ferreira et al. 2012).

Considering the online trade, to the best of my knowledge, only one study recorded incidents of online trade involving wild species in Brazil. Magalhães and São-Pedro (2012) reported 49 non-native species of amphibians and reptiles on sale by Brazilian profiles on Orkut™, an outdated social media that was shut down in 2014. In the remaining studies, trade has been assessed only indirectly through interviews with hunters or consumers/owners of wildlife in some parts of the country (e.g., Alves et al. 2019; El Bizri et al. 2020; Chaves et al. 2020; Mota et al. 2020).

Given that some estimate was already available for birds in Latin America as well better informed intervetions are in place, I decided to focus this thesis on other taxa that are also highly traded but yet poorly scientifically assessed in Brazil. These taxa were selected based on their potential to be used as models for answering important questions regarding wildlife trade and support the improvement and development of public policies in Brazil; i.e., primates were used as models to assess whether a certified wildlife market would prevent illegal trade to occur in the country (Chapter 4), and venomous

snakes were chosen to assess the risk posed to public health through envenomation by venomous specimens illegally raised by pet hobbyists (Chapter 5). Chapter 6 is not taxa-specific and considers all taxa traded on Facebook™ during the surveyed period. Because of the surge of online market in the recent years and its potential to expand the trade network, I give special attention to the online wildlife trade in this thesis.

2.3 Materials and Methods

2.3.1 Official source of legal exports: CITES database

CITES manages a comprehensive database of legal imports and exports of wild species worldwide. The database holds over 20 million records reported over the last 44 years. CITES is also responsible for the production and update of the list of species with international trade regulated or restricted. Species are listed in three Appendices according to the degree of protection they need based on the level of threat trade may pose to them. All import, export, re-export and introduction of CITES-listed species must be authorized through a licensing system.

The records in the database can be reported by the importing country or/and the exporting country; information available are the countries of origin, of import and of export, source (i.e., wild-sourced or captive-bred), product type (e.g., live individuals or derivative products), purpose (e.g., private ownership, trophies or commercial), units of measure. For Chapter 3, I downloaded all records (imports and exports) from the CITES database involving live individuals of jaguars or jaguar derivative products with origin in one of the species' range countries (i.e., traded for zoo keeping, commercial, personal and breeding purposes), excluding exports in specimens for scientific or medical purposes and re-exports. When the same transaction was reported by both

importer and exporter countries, I only considered one of the records in order to avoid double counting. I estimated the whole organism equivalents based using a conservative approach, adapted from Harfoot et al. (2018).

2.3.2 Online reports as a source of seizure incidents

In the absence of a comprehensive international database on illegal trade instances or seizures involving wildlife items in Latin American countries, I recorded seizures from accredited news reports, technical reports and official records publicly available online (Chapter 3 and 5). Despite the limitations due to the inherently incompletude of data, news and technical reports of seizure incidents have been successfully used to assess hidden markets of wildlife (e.g., Ni et al. 2018; Siriwat and Nijman 2018a). They can be an important source for a diagnosis of trade rates and patterns, especially considering the high risk and difficulty of conducting market surveys and interviews with traffickers.

I compiled news reports involving the confiscation of parts of jaguars and other wild cats in Latin America (Chapter 3), of venomous snake being illegally bred as pets in Brazil (Chapter 5). News reports were considered when detailed information on the seizure event was provided, such as locality and date of the incident, and precise identification of the seized specimens, number of items seized, and when the agency responsible for the seizure contributed to the content of the news report. In the case of wild cats, when the number of individuals was not specifically mentioned, I conservatively estimated whole organism equivalents considering the minimum number of individuals required to obtain the number of reported body parts – i.e., 4 canines, 1 skull, 1 skin, or any amount of meat was considered as 1 independent individual (adapted from Harfoot et al. 2018). Only incidents clearly related to trade (Chapter 3) and pet

ownership (Chapter 5) were considered. The reports collated for this thesis is now part of The World Wildlife Seizures (World WISE) database, a developing initiative led by the United Nations Office on Drugs and Crime to assemble the instances of seizures worldwide.

I used as search terms ‘seizure’ + ‘arrest’ + the species scientific name accompanied by the most frequently used common name for the species in each country as the search terms. Specifically for Chapter 5, I also considered ‘found’ as a search term. For each search, I checked the 100 first reports resulted from the search per species per country.

Because the search for jaguars and other wild cats covered a large territory and different languages (Chapter 3), the search terms were translated into Portuguese for Brazil, French for French Guiana, Dutch for Suriname, English for Belize and Guyana, and Spanish for all other countries. For each species searched, I considered the 100 first results of Google™ search engine per search combination (observed as providing enough sample size in Polisar et al. (in review), and used in similar studies such as El Bizri et al. 2015). Prior to the collection, I prepared a comprehensive list of the main common names used in each language for the species searched to ensure that the search terms would be representative and effective for each assessed country (e.g., Table 2.2). I used an equal number of search terms per countries to standardize the effort, therefore, only the most common names were used.

Table 2.2 Details on the common names of the three of the largest wild cat species used in each country and the language of the search.

Country	Panthera onca	Puma concolor	Leopardus pardalis	Language
Argentina	Not occurrent	puma	ocelot, gato onza	Spanish
Belize	jaguar, tiger	puma, mountain-lion, cougar	ocelot	English and Spanish
Bolivia	jaguar, yaguareté	puma, león de montaña	tigrecillo, gato montés, jaguarcito, gato onza, ocelote	Spanish
Brazil	onça-pintada, onça-preta	onça-parda, suçuarana, onça-vermelha	jaguatirica	Portuguese
Chile	Not occurrent	puma, león de montaña, puma chileno	Not occurrent	Spanish
Colombia	jaguar	puma	tigrillo	Spanish
Costa Rica	jaguar	puma, león de montaña, pantera	manigordo, ocelot	Spanish
Ecuador	panthera, jaguar, tigre	león	tigrillo, ocelote	Spanish
El Salvador	Not occurrent	cougar	tigrillo, ocelot	Spanish
French Guiana	tigre marqué	puma, cougar, lion des montagnes	chat tig	French
Guatemala	jaguar	puma	ocelote, tigrillo	Spanish
Guyana	jaguar	puma	ocelote	English
Honduras	jaguar	puma, león de montaña	ocelote	Spanish
Nicaragua	jaguar, tigre	puma	tigrillo ocelote	Spanish
Panama	jaguar, tigre	puma, león de montaña	manigordo, ocelote	Spanish
Paraguay	tigre, yaguareté, jaguarete	puma	ocelote, jaguarete'i, jaguarcito	Spanish
Peru	jaguar, otorongo	puma	tigrillo, ocelote	Spanish
Suriname	penitigri	puma	hétigrikati	Dutch
Uruguay	Not occurrent	puma	Gato ocelote	Spanish
Venezuela	yaguar	puma	cunaguaro	Spanish

2.3.3 Wildlife trade on E-commerce and social media platforms

Some social media and E-commerce platforms are currently members of the Coalition to End Wildlife Trafficking Online, which now counts with 34 of the world's biggest tech companies. Launched in 2018, this coalition aims at reducing wildlife trafficking online on company platforms (TRAFFIC/WWF/IFAW 2020). Among the platforms assessed in this thesis, only Facebook™ is a member of the coalition, which committed itself to banning the trade in all live

animals and all products from species listed on CITES Appendix I (TRAFFIC/WWF/IFAW 2020). Yet, I was able to record an intense commerce of live wild animals on the platform between 2016 and 2021.

Posts containing sale or displaying ownership of wild species can be found on Facebook™ directly from people's profile through general search (which only lists posts defined as public in its privacy setting), or within groups. Groups are pages specifically created to enhance communication among people with shared interests. In this thesis, I take into account posts from both public profiles and those published within groups (Chapter 4, Chapter 5, and Chapter 6). Different from other social media platforms, Facebook offers the option for creating groups, where several different profiles can post their advertisements in the same page and be in easy contact to each other. On Instagram, for instance, do not offer this option, which means that only followers of each particular profile can see what they are posting, reducing substantially the audience reach of the advertisement. In a pilot I have done in Brazil, only Facebook, among all open social media, presented advertisements devoted to sell wildlife or wildlife products, and therefore, this was the only social media platform assessed in this thesis. Prior to the data collection, I used a combination of the search terms 'exotic pets', 'trade', 'pet owner' and 'pet' (in Portuguese: 'animais de estimação exóticos', 'venda', 'criador de animal de estimação' e 'pet') to identify the main Brazilian groups related to wildlife trade. Once I became a member of some of those groups, Facebook™ frequently suggested similar groups 'based on my interest'. When I started data collection, in 2018, I was monitoring 30 different Brazilian groups dedicated to wildlife trade, which varied between 1,000 to over 45,000 members. They were frequently organized by geographical region, identified by the state or

municipality in the group's name or description. Some groups were taxa-specific while others were taxa-generalists, and some groups were active during the entire data monitoring period, while some were removed by Facebook™ or its administrators. The details on the number of groups considered for each study is detailed in each chapter. For the data collection on Facebook™, I used a combination of one or more of the following search terms: scientific and popular names of the target taxa, "trade", "purchase", "$", "price", and "available" (in Portuguese: "venda", "compro", "preço", e "disponível"). Exclusively for the venomous snakes (Chapter 5), the terms "inbox", and "experienced" (in Portuguese, "inbox" and "experiente") were added to the search. 'Inbox', which stands for 'direct message', is the term used by Brazilians to encourage people to message the seller for more information about the animal. 'Experienced', exclusively used for venomous or aggressive species, is the term the sellers used to define their target audience, i.e., to highlight that venomous or aggressive species are too dangerous to be purchased by beginner hobbyists, requiring a certain amount of maturity or experience with exotic pets.

All data collection on Facebook™ was done manually, and these data were used to conduct analyses included in Chapter 4, 5 and 6. For each post, I recorded the locality of posting, delivery type (whether using postal services or delivered directed by the vendor), the species advertised and the number of specimens on sale (when not specified, I conservatively considered one individual), and the price per specimen. For ethical considerations, I did not record the name of the vendor in my database, instead I created my own ID code for each vendor. To avoid duplication, I did not record any advertisement from the same profile in an interval of six months.

E-commerce websites are frequently reported as involved in wildlife trade globally, including advertisements involving live specimens or derivative products from legally protected species (Nguyen and Willemsen 2016; Polisar et al. in review). The platforms where illegal advertisements of wildlife products were often reported to follow the model C2C, i.e., trade from consumer to consumer, where any person can advertise products or services to another consumer. Prior to the data collection, I used the search terms 'exotic pets' and 'trade' (in Portuguese: 'animais de estimação exóticos' e 'venda') on Google, and identified one large E-commerce platform responsible for around 95% of all advertisements resulted from this search in Brazil. Exclusively for Chapter 4, I used a free web scraper software named Parsehub (https://www.parsehub.com/) to automate the data collection and collect all advertisements containing living primates on the platform within the assessed period.

I also collected evidence from public videos with displays of ownership of venomous snakes on YouTube™ (Chapter 5), since no trade was detected on this platform. For searching on this platform, I used the following search terms: scientific and popular names of the target taxa, "ownership", and "pet" (in Portuguese: "criação", "pet").

2.3.4 Official data source of seizure and trade: IBAMA

The Brazilian Institute of the Environment and Renewable Natural Resources (in Portuguese: Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis - IBAMA) is a federal agency of the Ministry of the Environment responsible for the enforcement of environmental policies and for conducting surveillance actions throughout the Brazilian territory. The agency maintains centralized databases on seizure incidents involving

environmental crimes and infractions and, on the facilities certified to breed wild species countrywide. The databases are part of the National System for the Management of Wild Fauna (in Portuguese: Sistema Nacional de Gestão de Fauna Silvestre – Sisfauna – available at https://www.gov.br/ibama/pt-br). Among the information included on the seizure reports, I compiled the species, number of individuals and date and local of the seizure. Only individuals identified by their scientific names were considered due to the high number of species that might share similar popular names.

Five breeders registered on IBAMA SisFauna database were actively trading primates as pet during the sampled period. To obtain the selling prices from legal breeders, I checked the commercial website of each breeder for the price displayed. Primates were identified up to species level whenever possible based on external morphological characteristics of individuals.

These official databases are available on request based on the Brazilian Law of Access to Information (Law No.12,527/2011), which guarantees citizens the constitutional right of access to public information of the government. I, therefore, was granted access to the seizure reports involving primates (Chapter 4) and venomous snakes (Chapter 5) owned as pets in Brazil. For Chapter 4, I was also granted access to the number of active breeding enterprises, the number of primate individuals the enterprises have in captivity and the quantity sold annually.

2.3.5 Official source of snakebites incidents: SINAN

The Brazilian Ministry of Health have created and manages the Notifiable Diseases Information System – in Portuguese, *Sistema de Informação de Agravos de Notificação* (SINAN) with the aims to collect, organize and disseminate data routinely generated by the Epidemiological Surveillance

System (Ministério da Saúde do Brasil 2006), including the occurrence of diseases and envenomation. The system was created in 1993, but its compulsory use by hospitals and health institutions throughout the national territory is in operation since 1998 (Ordinance Law Funasa/MS No.073/1998). The system was designed as a systematic instrument to assist in health planning and prioritise health interventions. The database is publicly available, and its use is authorized for research. To establish the health risk posed by pet ownership of venomous snakes (Chapter 5), I downloaded from SINAN the records of snakebites that received treatment with antivenom in any medical facility throughout the Brazilian territory, the reported location, and species involved in the accident. The city declared in those reports represents the locality of the healthcare where the person received its first treatment.

2.3.6 Data analyses

In all data chapters, I used descriptive statistics to report on the number of individuals traded or seized according to each chapter's relevant categories. For the tests that present the assumptions of normality and homoscedasticity (e.g., Student T-test, Pearson's Correlation), I applied Shapiro–Wilk's test to test normality and Levene's test for homogeneity of variances. Alternative test or data transformation was used when the assumptions were not met.

In Chapter 3, 4 and 5, to address the time and spatial nonindependence (repeated measures) of the response variable (number of individuals traded/seized), I applied both generalized linear (GLM) or additive (GAM) models. In the model selection, the nonlinear model is only selected over a linear model if the increase in fit is substantial enough to overcome the penalty. For that, I used the function generalized additive model for location, scale, and shape (GAMLSS) (Stasinopoulos and Rigby 2007). A GAMLSS, similar to

GLMs and GAMs, consists of a semiparametric statistical approach for univariate regression analysis that fits linear or nonlinear trends for the independent variables. I tested for multicollinearity among independent variables with a pair-wise correlation conducted with the function ggpairs. I considered any relationship between 2 variables with $R \geq 0.60$ collinear.

For each model, I provide the estimates and SEs for the intercept and coefficients of each variable. I selected the family of distribution and final models based on the Akaike information criterion (AIC) for generalized models. Following the recommendations of Burnham and Anderson (2004), I considered models with good support and present in results all models with ΔAIC values <2 relative to the model with the smallest AIC (best-ranked model).

In Chapter 3, to assess the influence of the socioeconomic variables on the number of individuals seized, I analysed a balanced panel data in which the cross-sectional unit was country, and the time dimension was year. I tested for temporal autocorrelation in the panel data with the autocorrelation function (Acf), and there was no significant autocorrelation in the data. I considered here additive models because in economic theory, trade usually has a nonlinear relationship with scale. Initially trade undergoes an economy of scale (process optimization), followed by a diseconomy of scale (external constraints limit productivity gains). Thus, I expected a similar trend for jaguar trade; the number of traded animals reaches an upper limit, similar to an asymptotic curve. Therefore, for economic variables and extent of distribution, I tested the fit of nonlinear effects with a penalized cubic splines function (cs). Because no wild cat seizures were reported in some years in some countries, I fitted distribution families that balance the frequency of 0 s in the count data (such as the Zero-Adjusted Gamma), provided by the GAMLSS. To account for the spatial

autocorrelation, countries were included as a fixed term in the model, rather than as a random effect. The use of random effect would not be suitable in this case due to the assumption that the non-observed variation related to the locality must be uncorrelated with the variables included in the model (Bell and Jones 2015). However, in this case, unobserved factors (such as culture, transportation infrastructure, and general state of the environment) were country-specific and the socioeconomic variables included were also obtained in a country-level, violating this assumption. In practical terms, the random term would remove between-country's variation from the model variance component by constructing constant error terms that contain the same sources of random variation, which would affect the socioeconomic (independent) variables included in the model, since they were all country-related. The fixed term, in turn, makes no such assumption. The fixed effect approach adds precision to estimates by controlling the unobserved intrinsic factors within a country considering the country's within-effects in the model variance, which ultimately translates better the underlying characteristics of the system being analysed. Here, Chinese foreign investment, exports to China, and jaguar extent of occurrence were collinear; thus, they were not included in the same model. For model selection, I ran the models with jaguar extent of occurrence. Because the model described above divided the records of trade by country (locality) by year (replicates), according to each of the independent variables tested, the complexity of the model was so high and the number of records became low (broken into many categories, low degrees of freedom) the estimative of the trend over years could not be assessed with confidence in this model. To have a more robust (less detailed though) trend over time, I pulled together the data

from all the countries assessed and tested the trend in jaguar trade in Latin America.

In Chapter 4, to account for the non-detected trade during the manual monitoring on Facebook™, I counted the number of posts recorded by each vendor on each group, and built a rarefaction curve to assess the accumulation of vendors along the increase in numbers of groups sampled (Oksanen et al. 2013). I built an estimation curve to predict the likely number of active primate vendors on Facebook™, using each group as my sampling unit, the vendors as my categories, and the number of posts as a measure of trade abundance per vendor. For the estimation curve, I used Chao 1 as my estimator since it takes into account the number of vendors that only appear once or twice in my database (statistically called singletons and doubletons) (Chao 1987). I used the proportion and mean of individuals sold per primate species per vendor to estimate the number of primates likely sold by non-detected vendors obtained through the extrapolation curve. Finally, I divided the number of primates sold per species by the sampling period to obtain the estimated annual number of primates illegally offered for sale online.

In Chapter 6, to assess temporal differences in trends in COVID-19-related posts according to the main pandemic landmarks, I ran a break point analysis using the function 'breakpoints'.

I performed all statistical analyses, in the software R (version 3.6.3) (http://www.R-project.org/). For the GLMs and GAMs, I used the R-package *gamlss* (version 5.3-2); for checking collinearity I used *GGally* (version 2.1.2); for time-series autocorrelation, I used Forecast (version 8.16); for the rarefaction curve, T test and Pearson correlation, I used *vegan* (version 2.5-6); for the break point analysis I used *strucchange* (version 1.5-2), and for plotting

the graphs I used *ggplot2* (version 3.3.0). For all statistical analyses, I considered significance of predictor variables when $p<0.05$.

I used Quantum GIS (version 2.18.9) (https://quantum-gis.en.softonic.com/) to create the maps presented in this thesis. In Chapter 3, I created a flow map with the records of legal and illegal trade of jaguar body parts and used the software to calculate the species' extent of occurrence for each country. In Chapter 5, I created a map to represent the geographical overlap in records of trade in venomous snakes and the occurrence of snakebites in the country. I used the Kernel Estimation density of 10 km around the city for representing a visual heat map of the snakebites reported.

In Chapter 6, to assess how COVID-19 was incorporated into the discourse of traders and consumers, I ran a content analysis in the software Leximancer (version 4.5.1). This program uses automated machine learning to create a concept map that details the most significant themes and concepts in posts using an algorithm that analyses word frequency and co-occurrences. A 'Topical analysis' using a linear clustering algorithm was chosen as it is the most appropriate for discriminant analysis and provides stability where overlapping of themes occur (Wilk et al. 2017). The program uses weighted word frequencies to identify 'concepts' (displayed as grey circles and identified with black text) that are grouped together with similar 'concepts' to show broader 'themes', identified with coloured circles. This process produces a concept map output that can be read as a heat map, such that the warmer the colour of the theme, the more salient it is within the data. The higher the number of concepts within a theme implies that it is more prevalent in the text; the size of the circle itself is not indicative of importance. The more overlap the themes have with one another the more linked the two are within the text and direct

lines between concepts suggests that they are directly linked through co-occurrence.

2.3.7 Notes on the caveats and limitations

I recognize that working on wildlife trade is challenging because it is difficult to obtain information directly with people involved in the trade, or on wild populations of species harvested for trade purposes. Therefore, here I discuss some of the caveats and potential limitations of the information presented in this thesis. In Chapter 3, I recognize there is difficulty in implying trade rates from seizures because of inherent biases of these kinds of data (e.g., different surveillance efforts among countries and over time, Challender et al. 2021), and due to the existence of difficult-to-assess factors in a large scale, such as aspects inherent to local culture, capacity of access to forest and transportation, status of the wild populations. To control for such biases, I used a series of proxies to test for variations in seizures, including the source country corruption perception index score as a proxy for effectiveness of local law enforcement. In addition, I made use of a panel data analysis approach, including country as a fixed effect to account for uncontrolled within-effects for each country in the model, and compared data on jaguars with those from two other wild cats as potential controls, since these species were in principle not as frequently targeted to meet the demand in China as the jaguar supposedly was.

In chapter 4, I compiled data from trade advertisements of primates online. Fieldwork for data collection in physical markets was very limited due to safety issues, and later, because of the restrictions adopted to contain the COVID-19 pandemic, so I focused most of the study on online sources. In an online environment, it is difficult to precise how many advertisements resulted in

effective buys and if the price of the final product was what was advertised, since bargain between traders and consumers may have happened in some of these transactions. In addition, in the market share calculation, it was impossible to guarantee that I was able to cover the 'entire' illegal market in detail to compare to the legal market, and not all specimens traded illegally could be identified at species level. However, so far this is the best approximation available to understand the legal and illegal primate pet market in Brazil.

In chapter 5, my biggest limitation was the lack of differentiation in the snakebites database regarding snakebites being caused incidentally by pet snakes in a domestic environment or by accidental contact with native snakes in the wild. In the medical database, the snakes were only identified at genus level, which hampered my capacity in identifying whether the species was out of their native range or not, which would ultimately facilitate the identification of individuals being potentially maintained in captivity. The main snake genera recorded are widespread over the country while specific species within the same genus may have their range limited to specific regions in Brazil. Exotic species (which presence can be a sign of pet snake in captivity) are rarely identified by health agents due to the unfamiliarity with the taxonomy and may enter in the database in the category non-identified, but it was impossible to be sure whether this is in fact the case, and how many of the snakebites were caused by exotic species. In Brazil, even big cities can be surrounded by native areas where snakes may inhabit, where encounters with wild snakes can be possible. Therefore, there was no possibility to really filter, even as an approximation, the snakebites that might be caused by pet snakes from those caused by the native snakes. In this chapter, I compared the number of snakes

traded per species with the total number of snakebites through a simple correlation. I am aware that pet snakes are likely responsible for only a minimal proportion of the total snakebites reported. Because of this, I highlight that the correlation is not reflecting causation, but pointing out that species with higher number of envenomation events are coincidently the ones more frequently present in trade.

More details on the limitations of my studies and how carefully readers should interpret the results is discussed in the discussion of each chapter and in the general discussion of this thesis.

2.3.8 Ethics

Ethical requirements for studies involving internet-mediated data are being constantly improved, especially when dealing with publicly available online data and involving non-regulated or illicit activities, such as the wildlife trade under analysis in this thesis. This thesis includes data posted on E-commerce platforms (Chapter 4), Facebook™ (Chapter 4, 5 and 6), and YouTube™ (Chapter 5). The studies presented here were waived from ethical approval from Academic Ethics Committee at Oxford Brookes University, considering that no personal data was collected, and no interview was conducted at any point with the stakeholders involved in the trade. I, therefore, followed the Ethics Guidelines for Internet-mediated Research (British Psychological Society 2017) and the Statement of Ethical Practice (British Sociological Association 2017) for defining the methods used, type of data collected, and platforms accessed. According to these guidelines, an online environment or activity can be considered public when participants expect to be observed by strangers; I therefore only considered E-commerce platforms,

Facebook™ groups and YouTube™ channels open to public or easily accessed by anyone that clicks on ‘request access’ (similar to Siriwat et al. 2019).

Considering that I did not establish any type of contact with sellers or consumers while collecting data, the authors of posts and advertisements were not considered a subject in this research. Only electronic documents such as textual or graphical contents (photographs or videos) posted were assessed, and therefore informed consent was deemed as not needed (Wilkinson and Thelwall 2011). In addition, I collated data from groups and platforms with thousands of active members (e.g., over 45,000), and consequently, it fits in the context in which Research Ethical Committees consider it not logistically possible to obtain informed consent from all people potentially involved in the online environment under assessment (Hibbin 2018).

Although some ethical boards (not all) approve the use of fake accounts to protect the researcher studying illicit activities, this act may go against the policies of some platforms, e.g., Facebook™ (Hennel et al. 2019). I, therefore, decided to collect all data on online trade using my personal Facebook™ or YouTube™ accounts. In order to protect my anonymity, my personal accounts are not frequently used for personal use, i.e., do not contain most of my personal details or pictures available and no direct contact with vendors was stablished during the period of the study.

For some social networks, the ownership of the content is transferred to the platform service provider after its publication. In order to protect the authors of the advertisements from any harm and respect the copyright issues involved with authors or platforms, I did not collect identifiable information, the data presented here is summarized, and when textual content was presented, words

were altered (and translated) to reduce traceability but yet guaranteeying the validity of content analysis performed.

Chapter 3. The role of socioeconomic factors and legislation in the legal and illegal wildlife trade

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Part of results from this chapter has been published as an article in the journal *Conservation Biology* in December 2020 https://doi.org/10.1111/cobi.13498 and part is currently an article in review in the *European Journal of Criminology*.

The published version of this article can be also found in the Appendix 8.3.

3.1 Background

Lions (*Panthera leo*), tigers (*Panthera tigris*) and leopards (*Panthera pardus*), among other big cats, are known to be threatened in part by international trade; this threat is most pronounced for tigers (Goodrich et al. 2015). Tiger parts, especially skins, teeth, meat, and bones, are in trade as decorations, jewellery, luxury food, and traditional medicine (Stoner 2014; Loginov and Loginova 2017). Much of the trade in tiger and lion body parts is driven by Chinese demand (Wong 2015) and, to a lesser degree, demand in other Asian countries (Nijman and Shepherd 2015; Saif et al. 2016). For instance, individual wild cats or their parts (teeth and claws) accounted for 31%

of all mammal seizures in airports worldwide; China was the most recorded destination (Center for Advanced Defense Studies 2018).

Conversely, the trade in the largest native cat species of the Neotropics, the jaguar (Figure 3.1), was thought to have been curbed long ago. In the 20th century, this species was subject to intense pressure from unregulated trade. Large profits were made by hunting and trading jaguars for their skins and fuelled a considerable offtake throughout the species' range (Antunes et al. 2016). Alarm at declines in populations of spotted cats, along with of crocodilians, drove initiatives to establish national and international trade regulations. The inclusion of jaguars in Appendix I of the CITES in 1975, and the subsequent national laws approved in most range countries granted this emblematic species substantial legal protection from exploitation and allowed the species to recover substantially its abundance in several parts of its original distribution (Antunes et al. 2016).

Figure 3.1 Jaguar *Panthera onca*. Photo courtesy of Thiago Lima.

Despite these efforts and regulations being effective for decades, in 2018, a report claiming that wildlife traffickers in South America were possibly seeking jaguars to satisfy the demand for wild cat body parts in Asia garnered worldwide attention (Fraser 2018). The story was prompted by the discovery of beheaded jaguars and ocelots in Belize in 2017, the interception of almost 200 jaguar canines in Bolivia before shipment to China from 2014 to 2016, and the seizure of 120 jaguar canines in China, presumably in this same period. The article stimulated additional news on this trade (e.g., McKie 2018 [U.K.]; Hong Kong Animal News 2018 [China]; Suriname Mirror 2018 [Suriname]; De Morgen 2018 [Belgium]; Taipei Times 2018 [Taiwan PoC]) that reached a global audience.

In an attempt to estimate the dimension of this new wave of trade and unveil the allegedly role of China in this market, the CITES Secretariat recommended conducting studies on the illegal trade in jaguars prior to adopting additional resolutions (Conference of Parties 2018 Doc. 77.1. and 77.2). Recent interviews with key informants, especially NGOs staff and government representatives, suggested that in Guatemala and Belize the trade in jaguar body parts was an opportunistic and domestically-driven activity rather than an organized international trade (Arias et al. 2020a). A prominent domestic market driven by local traditional use – such as skin as decoration and other parts in handcraft - was also suggested for Costa Rica (Kelly 2018). The Ayahuasca spiritual ritual tourism, which often involves foreign visitors, was also detected as linked to the trade of jaguar body parts in Peru (Braczkowski et al. 2019). In Bolivia, on the other hand, Asian expats were the second largest group mentioned as known to be involved in jaguar trade, behind Bolivian

nationals, although only a small proportion of the respondents had been personally approached by Asians (Arias et al. 2020b). Other nationalities were also mentioned as involved in trade as sellers or consumers in Bolivia, especially related to tourists, missionaries, volunteers and crafts vendors (Arias et al. 2020b).

Given the role that the Asian countries, in particular China, play in the demand for wild cats worldwide (Wong 2015; Center for Advanced Defense Studies 2018), and considering that illegal trade are often eased by the involvement of ethnically homogeneous groups throughout the supply-chain (Raab and Milward 2003), the Chinese diaspora to other countries may facilitate supplying the Chinese demand for wild cats (Skinner 2017). Recently, the Chinese influx to Latin America has been associated with specialized occupations generated by new investments from China in these countries (Poston Jr and Wong 2016; Verheij 2019). Chinese investment in Asia (~US$500 billion) and Africa (~$450 billion) has been substantial in the last decade (American Enterprise Institute 2018). Although smaller, Chinese investment in Latin America, particularly in Brazil and Peru, has increased 10-fold over the last decade (~$200 billion over the same period) and may foreshadow a potential growth in investment in illegal wildlife trade in this region. That Chinese investment and migration and an existing overseas community may lead to an increase in jaguar trade is plausible. Thus far, however, this link has not been demonstrated empirically.

In addition, given the emergence of increased illegal trade in the context of existing legislation and international agreements, it is crucial to examine whether and how the legal and the illegal chains interact. For instance, Hureau and Braga (2018) detected that a substantial part of the illegal firearms acquired

in Boston, USA, were obtained from theft of legally owned firearms, diversions from legitimate firearms commerce and off-the-books transactions. Similarly, protected wildlife is sometimes traded illegally alongside legal trade, making use of established, legal networks (Raab and Milward 2003). The flow of legal goods and capital when used to mask the illegal chain lower the cost of avoiding surveillance. Alternatively, illegal trade can occur completely separate from legal trade, using different actors, routes and financial mechanisms (Raab and Milward 2003). An analysis of what is reported to the CITES secretariat and further comparison with what has been recorded in illegal markets can provide insights on the entry of jaguar specimens and body parts into the market and its pathways.

The secretive nature of illegal wildlife trade means that researchers often resort to using indirect indicators (e.g., Ni et al. [2018] used online reports of seizures). Lacking a comprehensive database on the quantity, prices, and supply-chain elements in the trade in wild cats from Latin America to China, I used a dataset on >1000 wild cat seizures reported from 2008 to 2018. I used the dataset on wild cat seizures with two focuses: (i) assessing the current trend in the illegal trade of wild cats in Latin America and the socioeconomic drivers of this illegal trade, including the influence of the Chinese diaspora and the Chinese-led development on this market; and (ii) assessing the relationship between illegal international trade in jaguars and the legal exports declared to CITES database. I hypothesized that high availability of jaguars in natural areas, low gross national income (GNI) per capita, relatively weak law enforcement in source countries, large resident Chinese population and Chinese private investment in Latin America, and high levels of legal exports from those countries to China contribute directly or indirectly to a low cost of

supplying wild cats to the Chinese market that consequently increases illegal trade from the region. In addition, I discuss how severe or lenient the existent laws on wildlife trafficking are in the range countries and possible strategies to mitigate trade impacts on Neotropical wild cat populations.

Please refer to Chapter 1 for the literature review on the wildlife trade in Latin America, related policies and legislation, and the theoretical support for the socioeconomic variables used in this Chapter.

3.2 Data collection and analysis

For a general description of the study area, type of data collected, and databases used in this chapter please refer to sections 2.2 (study area), 2.3.1 and 2.3.2 (data collection) of the General Methods.

3.2.1 Seizures of wild cats

For the temporal trend and the influence of socioeconomic variables in the domestic and international illegal wild cat trade (January 2012 to March 2018), I consider the three cat species. For the comparison between the legal exports and illegal international trade in jaguars, I consider only the species jaguar (January 2008 to March 2018). In these reports, the only non-American country that was mentioned more than once was China (see Results); thus, I used the same search terms to locate online reports in China. For details on data collection please refer section 2.3.2 Statistical Analysis of General Methods.

For each country and each species, I categorized if there was a mention of evidence linking it to international or domestic trade. When the intended market was not mentioned, I conservatively considered the report as linked to domestic trade. I tallied the number of seizure reports and individual cats seized

and calculated the percentage of the total seizure reports that had links to China. These links could refer to Chinese nationals or descendants living in or visiting Latin America being implicated in the seizure; confiscated packages with China reported as the end destination; explicit mentioning of China as the destination of the confiscated goods; or seizures made in China with explicit links to Latin American countries. I use Chinese involvement but recognize that few and specific individuals may be involved in this illegal trade, not Chinese society as a whole. I also do not imply the Chinese government is complicit in this activity.

3.2.2 Socioeconomic variables

To assess the market structures and dynamics of the wild cat trade in Latin America, I used the following as proxies: source country GNI per capita from 2012 to 2018 as a proxy for opportunity cost of local labour; species' extent of occurrence as an indicator of the costs of obtaining specimens; source country corruption perception index score from 2012 to 2018 as a proxy for effectiveness of local law enforcement (range: 0, highly corrupt, to 100, very clean); Chinese population resident in the source country in 2015 as an indicator of the cost of establishing local networks; flow of legal exports from source country to China from 2012 to 2018 as a proxy for costs of establishing networks for transportation of goods; and flow of Chinese private investment in Latin American countries from 2012 to 2018 as a proxy for costs of establishing networks for transportation of capital.

3.2.3 Legal exports

In July 2020, I downloaded data on legal exports reported to the CITES trade database (UNEP-WCMC 2019) (data from 2019 was not yet completely

available) by importers and exporters on the legal exports in jaguars and their body parts. For further details on the data collection of legal exports, please refer to the section 2.3.1 of the General Methods.

3.2.4 Legislative framework

In collaboration with lawyers from different countries, I compiled the present legislation concerning wildlife (jaguars included) trafficking in all current Latin American jaguar-range countries (i.e., excluding Chile, Uruguay and El Salvador, in which jaguar populations are already extinct and therefore the species may not be legally considered protected). For each of these countries, I recorded whether or not the current legislation typifies involvement in the illegal wildlife trade as a serious crime (i.e., in which the maximum penalty is three or more years in prison), based on the definition of the United Nations Convention against Transnational Organized Crime.

3.2.5 Data analysis

3.2.5.1 Temporal trend and the influence of socioeconomic variables

I used descriptive statistics to present the number of reports and individuals and number and types of items recorded as seized per species (jaguar, puma and ocelot) between 2012 and 2018. To assess the difference in the number of individuals seized per report between seizures where China was implicated and seizures supposedly supplying the domestic demand, I used a t-test with unequal variance because the homoscedasticity between groups was not met.

As described in more detail in the section 2.3.6 Data analysis of General Methods, I used GLMM/GAMM to assess the influence on the number of individuals seized of the socioeconomic variables mentioned above in the

section 3.2.2. In a second analysis, I used a longitudinal approach pooling data from all countries to assess the trend in the number of jaguar, puma, and ocelot individuals seized in Latin America over the sampled period using a GLM. I selected the family of distribution and final models based on the Akaike information criterion (AIC) for generalized models.

3.2.5.2 Comparison of legal exports and transnational trafficking

I presented the descriptive results for the number of jaguar individuals legally exported and jaguar individuals illegally traded between countries over the period between 2008 and 2018, and for the proportion of countries considering illegal wildlife trafficking as a serious crime among the jaguar range countries. For this analysis I only considered those records of cross-border trade (therefore, excluding domestic trade) and with the final destination clearly identified. To assess the relationship between the legal and illegal trade I built a flow map showing the routes of the legal exports and illegal trade in jaguar and ran a Pearson's correlation between the log-transformed total number of individuals exported reported to the CITES secretariat and the log-transformed total number of individuals seized in the period per country over the entire sampled period.

3.3 Results

3.3.1 Overview and temporal trend in the illegal wild cat trade between 2012-2018

I found 489 reports of trade in jaguars, pumas, and ocelots in 171 unique events involving ≥1 species (93 included jaguars, 46 included pumas, and 59 included ocelots). These reports involved trade of at least 1,038 individual cats. Among those, 622 jaguars, 50 pumas, 99 ocelots were reported with all the details of current seizures (e.g., day, locality, arrested or investigated people,

responsible agency), and other 235 jaguars, 20 pumas, 12 ocelots were reported in retrospective testimony of seizures. Statistical analyses were done excluding the retrospective reports due to reduced reliability. Brazil had the most reports (n = 60, 35.1%), followed by Bolivia (n = 25, 14.7%), Colombia (n = 18, 10.6%), Peru (n = 12, 7.1%), and Suriname (n = 10, 5.9%) (Figure 3.2 and Table 3.1).

Two seizures of jaguars were reported in China (1.1%) that involved a minimum of 31 jaguars. For jaguars, most trade was in canines, followed by skins and heads. For pumas, most trade was in body parts (legs, claws, and tails), followed by whole bodies, and for ocelots, most trade was in live individuals (Table 3.2). When pooling all Latin American countries, the number of jaguars seized annually (Figure 3.3 a–b and Table 3.3) and reports of jaguar seizures increased ~200-fold and 5-fold, respectively, over the assessed period (Figure 3.3 and Table 3.3). Conversely, seizures of pumas or ocelots remained stable at a mean of 7 and 10 individuals seized annually (Figure 3.3 c–f and Table 3.3).

Table 3.1 Number of reports recorded per country.

Country	Number of reports	Number of individuals		
		jaguar	puma	ocelot
Argentina	7	0	5	0
Belize	2	1	0	1
Bolivia	25	482	1	13
Brazil	60	53	20	44
Chile	5	1	5	1
Colombia	14	7	3	10
Costa Rica	1	1	0	0
Ecuador	8	1	0	6
El Salvador	2	0	0	2
Guatemala	4	3	2	0
Guyana	0	0	0	0
Honduras	2	1	2	1
Nicaragua	4	5	3	1
Panama	3	3	0	0
Paraguay	4	5	0	0
Peru	12	12	5	19
Suriname	10	11	2	0
Uruguay	0	0	0	0
Venezuela	6	1	2	1
China	2	31	0	0
Total	171	622	50	99

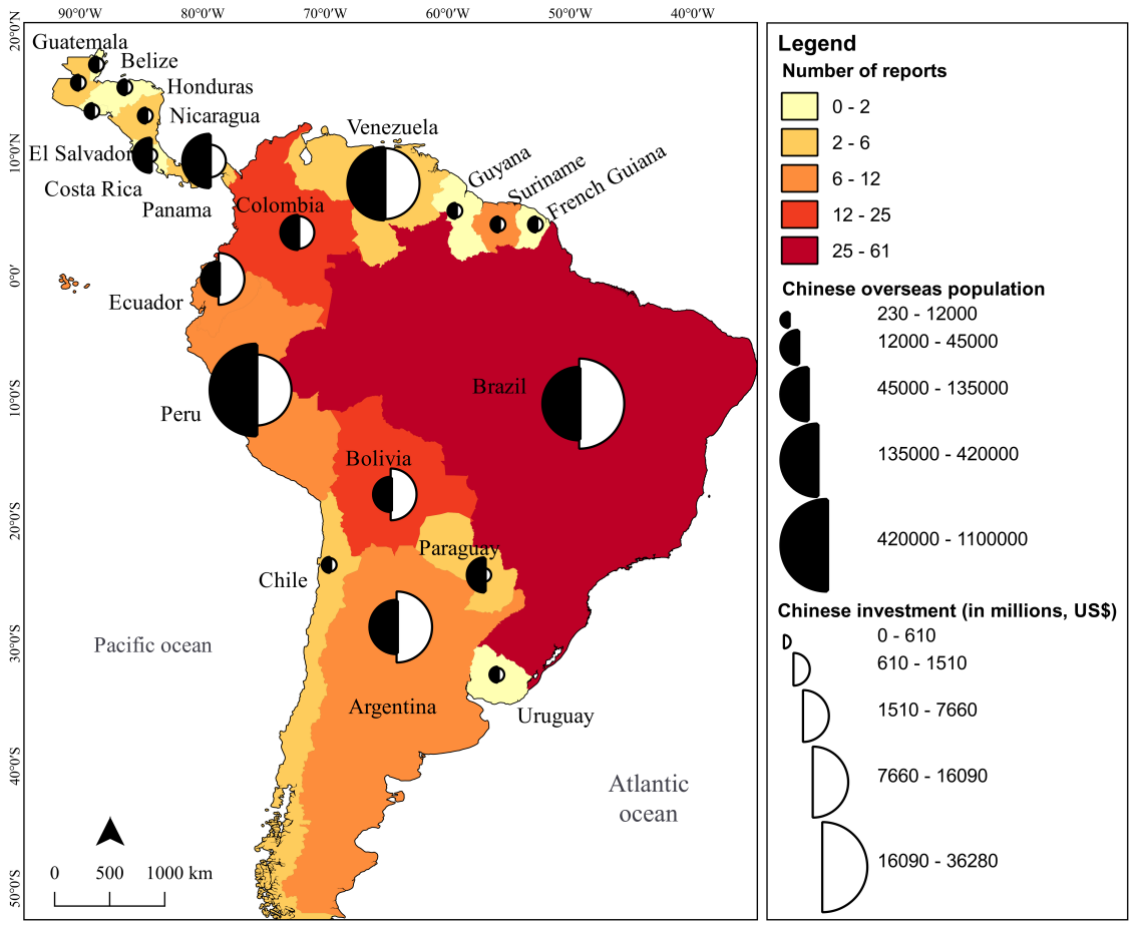

Figure 3.2 Map with the number of reports of seizures of jaguar (*Panthera onca*), number of resident Chinese, and amount of the Chinese private investment per Latin American country from 2012 to 2018.

Table 3.2 Data on jaguar, puma and ocelot seized from 2012 to 2018 in Latin American countries.

Species	Number of specimens (no. reports)	Number of countries (%)	Number seized by type						
			tooth	skin	live animal	head/ skull	body	other*	total
Jaguar	857 (93)	15 (79)	1,991	54	19	28	20	5	2117
Puma	70 (46)	11(58)	8	12	15	3	15	18	71
Ocelot	111 (59)	12 (63)	4	33	36	3	1	27	104
Total	1,038 (171)	-	2,003	99	70	34	36	50	2292

*Legs, claws, tails, and meat.

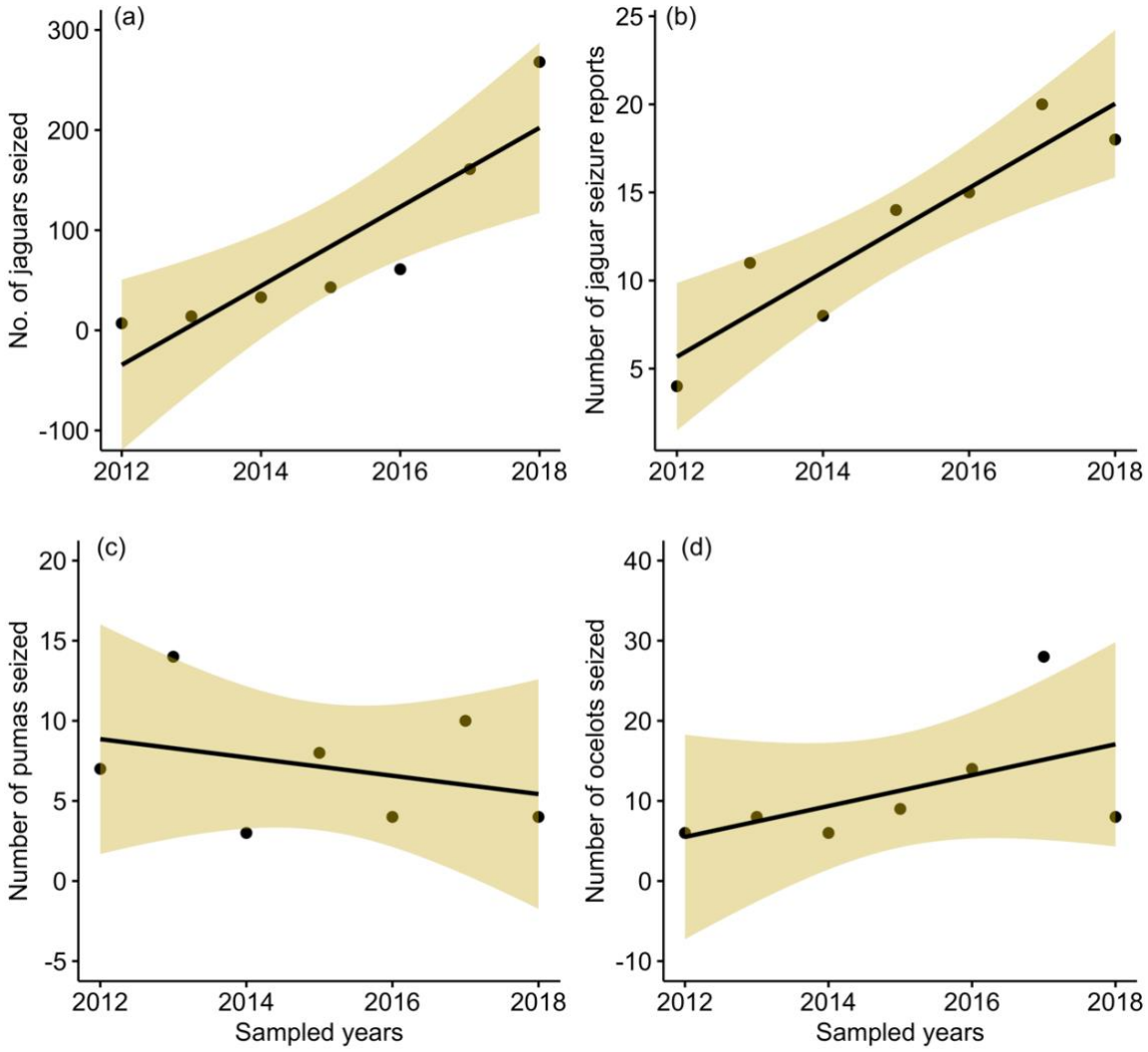

Figure 3.3 Temporal trend in number of individuals and number of reports of jaguar (*Panthera onca*) (a-b), puma (*Puma concolor*) (c), and ocelot (*Leopardus pardalis*) (d) body parts seized in all Latin American countries from 2012 to 2018 (shading, 95% CI).

Almost one-fifth (32 of 169) of the reports from Latin America specifically referred to China; all 32 reports referred to jaguars. Seven reports referred to international trade without specifying a destination country, and 1 report referred specifically to Italy. Five of these 8 reports referred to jaguars. For the 6 countries with the most reports, 30% of the reports specifically referred to China as a destination country, ranging from a high of 76% for Bolivia (19 of 25) to a low of 6.5%

for Brazil (4 of 61). Seizure reports where China was implicated, on average, involved more individual jaguars than reports that did not refer to international trade, which more likely referred to domestic trade (means of 28 vs. 2, respectively; $t = 6.45$, $df = 55$, $p < 0.001$).

3.3.2 Influence of socioeconomic variables on the illegal wild cat trade

For all cat species, the number of individuals seized was positively correlated with their extent of occurrence within each country (Table 3.3). Countries with a large number of jaguars seized had a relatively high amount of Chinese private investment and had relatively low corruption perception index scores and GNI per capita (Figure 3.4 d and Table 3.3). The amount of exports to China and the number of resident Chinese people were not significantly related to the number of jaguars seized (Figure 3.4 e–f and Table 3.3). No variable other than extent of occurrence was retained in the best-fitted model for pumas and ocelots (Figure 3.5 and Table 3.3).

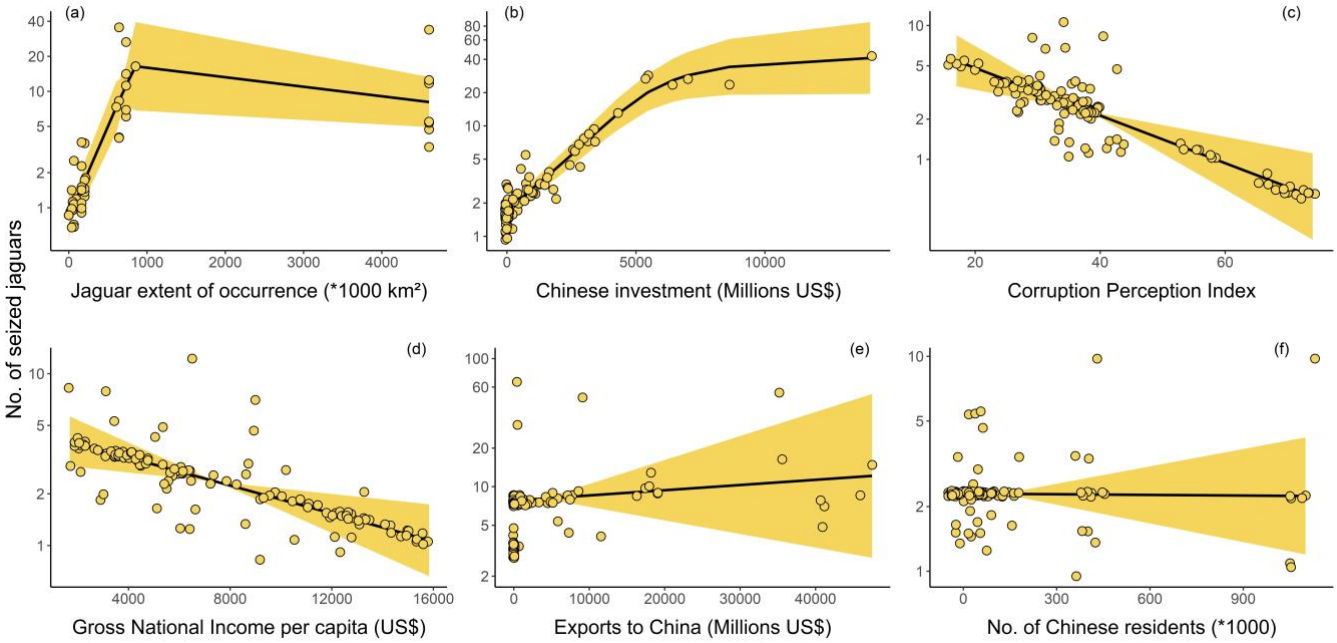

Figure 3.4 Relationship between the number of jaguar (*Panthera onca*) parts reported as seized in 19 Latin American countries (2012-2018, see Table 3.1) and the countries' attributes: (a) jaguar extent of occurrence, (b) Chinese private investment, (c) corruption perception index, (d) gross national income per capita, (e) value of goods exported to China, and (f) resident Chinese population (shaded area, 95% CI). Original values are plotted in a log-transformed (ln) y-axis. Statistical details related to these models are in Table 3.3.

Table 3.3 Details of the best-fit models using GAMLSS for each response variable for the temporal trend in the number of individuals seized and for the relationship between the number of individuals seized per country's socioeconomic factors.

Temporal trend in seizures over the monitored period							
Response variables[a]	**Predictor variables[b]**	**Estimate**	**SE**	***t***	***p***	**Family[c]**	**ΔAIC[d]**
N reports of seized jaguars	intercept	-4808.8	768.8	-6.3	< 0.001[e]	NOR	11.23
	year	2.39	0.38	6.3	< 0.001[e]		
Individual jaguars seized	intercept	-0.01	0.02	-43.2	0.01[e]	NOR	32.8
	cs(year)	3.94	0.91	43.3	0.01		
Individual pumas seized	intercept	1158.6	1316.2	0.9	0.42	NOR	1.27
	year	-0.57	0.65	-0.9	0.43		
Individual pumas seized	intercept	7.14	1.37	5.2	< 0.001[e]	NOR	0
	(null model)	-	-	-	-		
Individual ocelots seized	intercept	-3874.8	2344.5	-1.7	0.17	NOR	0.31
	Year	1.93	1.16	1.7	0.17		
Individual ocelots seized	Intercept	11.29	2.7	4.11	0.01[e]	NOR	0
	(Null model)	-	-	-	-		
Socioeconomic factors related to the trade							
Response variables[a]	**Predictor variables[b]**	**Estimate**	**SE**	***t***	***p***	**Family[c]**	**ΔAIC[d]**
Individual jaguars seized	Intercept	2.23	0.384	5.8	< 0.001[e]	ZAGA	11.02
	cs(jaguar distribution)	0.004	0.00006	6.0	< 0.001[e]		
	cs(Chinese private investment)	0.0003	0.00002	13.3	< 0.001[e]		
	Corruption Perception Index	-0.413	0.010	-3.9	< 0.001[e]		
	Gross National Income per capita	-0.0009	0.0003	-3.2	0.002[e]		
	Exports to China	0.0002	0.0001	-1.0	0.31		
	Chinese population	-2.3e-08	3.2e-07	-0.07	0.94		
Individual pumas seized	Intercept	0.089	0.078	1.1	0.26	NOR	53.4
	puma distribution	0.0003	0.00004	7.9	< 0.001[e]		
Individual ocelots seized	Intercept	0.457	0.057	8.0	0.001[e]*	ZAGA	6.0
	cs(ocelot distribution)	0.0002	0.00002	10.2	< 0.001[e]		

[a]Link function log (ln).
[b]Non-linear effect was fit with cubic splines (*cs*).
[c]Abbreviations: NOR, normal distribution; ZAGA, zero-adjusted gamma distribution.
[d] Difference between the selected model in relation to the second best-ranked model.
[e] Significant values (p<0.05).

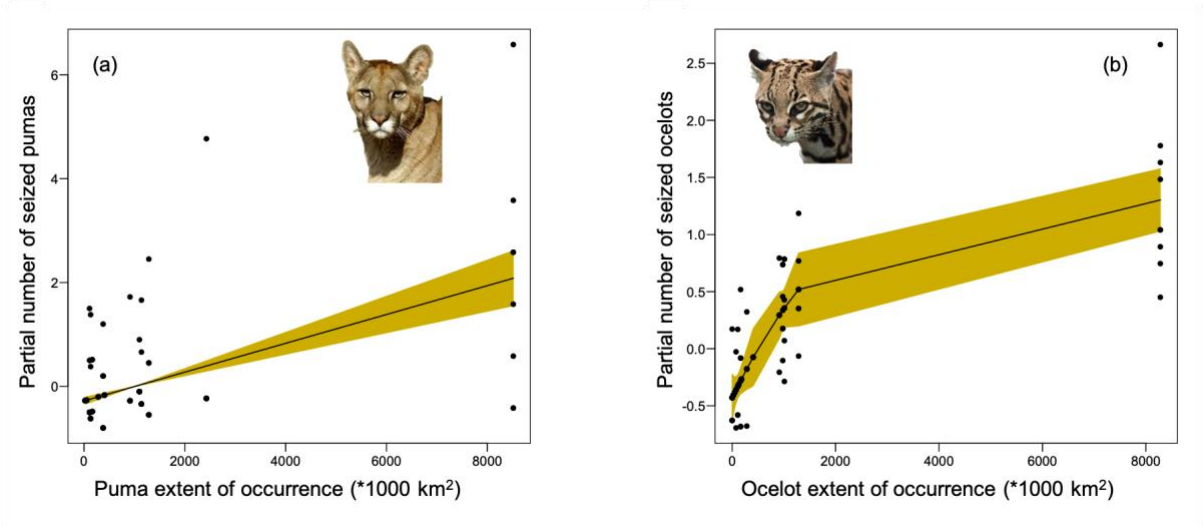

Figure 3.5 Relationship between the number of individuals seized in 19 Latin American countries and the extent of occurrence for (a) puma (*Puma concolor*) and (b) ocelot (*Leopardus pardalis*) (shaded area, 95% CI) between 2012-2018 (see Table 3.1). Y-axes are expressed as partial residuals related to the mean (μ=0).

3.3.3 Comparison of legal exports and transnational trafficking between 2008-2018

With respect to the legal international trade reported to CITES, 15/20 range countries acted as exporters, three (Argentina, Chile, and Costa Rica) acted only as importers, and two (Guyana and French Guiana) were not involved in any international trade (Figure 3.6). I estimated that a minimum of 312 jaguars were exported legally between 2008 and 2018. Mexico was the main exporter (239 jaguars), followed by El Salvador (14), Peru (10), Panama (7), Bolivia (6), and Paraguay (5). The main importers were Spain (205 jaguars), the USA (43) and Honduras (9) (Figure 3.6).

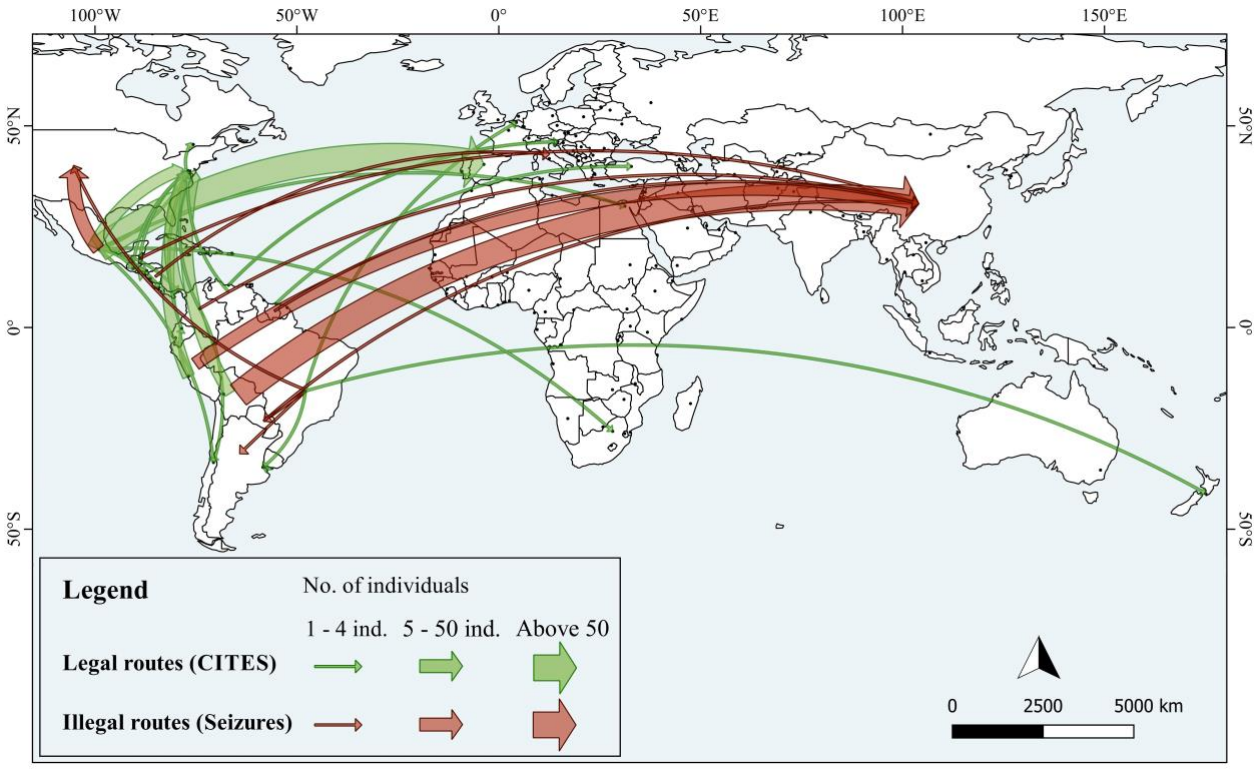

Figure 3.6 A map presenting the legal (green) and illegal (red) international trade in jaguars *Panthera onca* from Latin American range countries (2008-2018).

The illegal international trade over this period was estimated to be twice as large at a minimum of 538 jaguars; 515 of them had both the origin and destination countries disclosed in the report. It is likely that my findings represent a fraction of the illegal amount traded; because it is based upon and biased towards seizures, successful transactions are not counted and, to some degree, variable efficacy of law enforcement may be influencing the results. The main exporter was Bolivia (480 jaguars), followed by Brazil (21), Mexico (14), Peru (11), and Suriname (8) (see Figure 3.6). The main destination of illegally traded jaguars was China (494 jaguars), followed by the USA (18) and the EU (1). Legal international exports mainly comprised live jaguars while the illegal trade was dominated by teeth and skulls (Table 3.4). I found no relationship between the amount of legal exports and the illegal trade per country (Pearson: $R^2 = 0.128$, $F_{(1,18)} = 2.643$, $p = 0.12$; Figure 3.7).

Table 3.4 Number of items internationally traded reported for jaguar (*Panthera onca*) per source of data.

Source	Number of items seized by type					
	Specimen (Individual)	Live	Skin	Tooth	Head/skull Bone	Others[a]
Legal trade: CITES database	204	66	19	10	9	4
Illegal trade: Seizure reports	0	3	14	1,991	31	2

[a] Other parts refer to derivatives, claws and any amount of meat

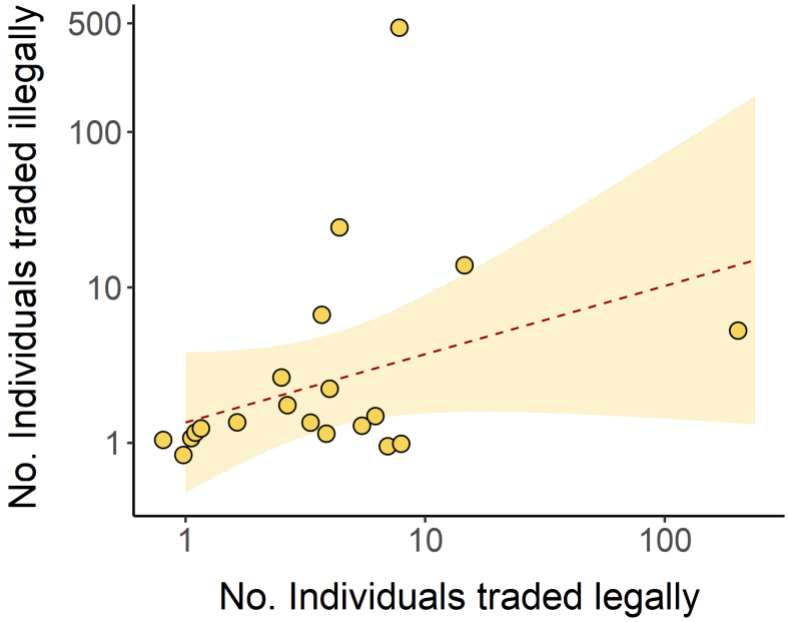

Figure 3.7 Relationship between the numbers of jaguars legally exported and internationally traded illegally from 20 Latin American range countries showing a lack of congruence. The y-axis and x-axis are plotted as original values transformed into log (ln) scale. The shaded area represents the 95% confidence interval.

3.3.4 Legislative framework related to illegal wildlife trade in Latin American countries

The involvement in wildlife trade can be considered as a serious crime in 14 (74%) out of the 19 countries I assessed the current legislation, namely Argentina, Bolivia, Colombia, French Guiana, Guatemala, Guyana, Honduras, Mexico, Panama, Paraguay, Peru, Suriname, United States, and Venezuela. In these countries, the maximum penalty possible for persecution due to involvement in wildlife trade ranges from 3 to 10 years of imprisonment as a punishment, and penalties tend to be higher if with aggravating circumstances, such as when the activity is committed by an organized crime group, a corporation, or a repeat offender. In the other 5 countries (26%), i.e., Belize, Brazil, Costa Rica, Ecuador, and Nicaragua, a few months to 2 years of imprisonment or only administrative penalties are commonly applied as punishment for involvements in wildlife trade. Among the five top illegal exporter countries, only Brazil does not consider wildlife trade as a serious crime.

3.4 Discussion

Long-term efforts to conserve populations of wild cats in Latin America may be threatened by a new wave of trade for local and international consumption (Nuñez and Aliaga-Rossel 2017; Braczkowski et al. 2019; Verheij 2019). My findings indicate a recent increase in trade in jaguars and significantly less and stable trade in pumas and ocelots over the study period.

Experts from Bolivia, Suriname, Belize, Costa Rica, Panama, and Honduras suggest there may be Chinese or Asian involvement in trade in wild cats (Kernam 2010; Nuñez and Aliaga-Rossel 2017; Reuter et al. 2018; Arias et al. 2020b). The marked proportion of analysed reports on jaguar seizures that explicitly mentioned China as an end destination or had Chinese nationals implicated in the seizure supports the contention that jaguars may be hunted to meet demand in China or

originated from the Chinese diaspora in Latin America (Kernam 2010; Verheij 2019). Seizures linked to China contained significantly more jaguar individuals, meaning this demand may be more critical than the domestic demand and has great potential to reduce jaguar populations. Apart from Brazil, countries with high levels of jaguars illegally traded domestically or internationally are not necessarily the ones with more lenient penalty, indicating that this illegal market may be more related to lack of law enforcement than to the need for tougher penalties.

I found that some Chinese-related market forces associated with the supply side of the chain and socioeconomic factors from Latin American countries were related to variation in the numbers of jaguars seized. I confirmed the hypotheses that larger jaguar extent of occurrence and Chinese private investment in the countries are related to an increase in the trade in jaguars and that increases in the corruption perception index and GNI per capita are associated with lower trade rates. I did not confirm my hypotheses that exports to China and presence of Chinese residents contribute to the establishment of the jaguar market chain.

Transportation of product and capital is the key to success of any market chain (Wyatt 2009). The positive relationship between the number of jaguars seized and the amount of Chinese private investment may indicate that the legal market chain may provide structure for the illegal chain. Once the supply chain is built, it facilitates the trade in other illegal wildlife products. For instance, scales of African pangolins were initially traded to Asia for medicine, but afterward, sellers took advantage of the established chain to sell the species' meat, increasing hunting pressure (Challender et al. 2014).

High levels of rural poverty and corruption in developing countries may lead to the involvement of local people in illegal activities. The pursuit of financial improvement or social standing is one of the main motivations for poaching in rural

communities (Cooney et al. 2017), and the lack of local governance and absence of institutions to properly manage the natural resources hinders long-term strategies for wildlife conservation (Barret et al. 2011). This is corroborated by the strong relationship I found between the corruption perception index and GNI per capita with the number of jaguars seized, which indicates the need to prioritize interventions on the supply side to generate potential reductions in jaguar trade in the region. Less corruption, and consequently more effective law enforcement, may increase in costs to people engaging in illegal activities by increasing the chances of successful prosecution with penalties (Cooney et al. 2017). Thus, as I expected, the combination of weak governance and limited sources of income in the rural areas of Latin American countries, which contain vast tropical forests, may have promoted the establishment of hidden supply chains for jaguar trafficking in the region.

Because in my models the number of Chinese residents in the sampled countries did not have a significant effect, the Chinese connection to jaguar trade may be related to the more recent influx of Chinese people encouraged especially by new investments (Verheij 2019). New foreign visitors may still have fresh contacts with the Asian market and promote influxes of people and products. Conversely, long-established foreign descendants may have integrated into the local culture and lifestyle and may have less contact with people in their native country (Skinner 2017). Furthermore, as a high-end jewellery or decoration product, jaguar teeth may be more sought after by wealthy tourists or elites living in Asia than by working-class immigrants, as in the ivory market (Gao and Clark 2014).

Illegal trade can happen on the back of legal trade or can follow distinctly different routes with its own dynamic. Since I found no relationship between the amount of legal exports and international illegal trade, the second scenario appears to be the case with the emerging illegal international trade in jaguars. The illegal

international trade at present is decisively different in that it mostly involves teeth, skulls, and claws, and significant part are traded mainly to East Asia. My findings show a close similarity to those of Everatt et al. (2019), who reported that in recent years the poaching of lions (*P. leo*) for their teeth and claws has increased. Lions are increasingly used as substitutes for tigers, with substantial international trade in their bones being used in traditional Asian medicines (Williams et al. 2017).

The main driver of trade in tiger parts is the belief held by some Chinese that the species' bones contain medicinal attributes. With the demise of tigers, body parts of other big cats, including leopards and lions, are increasingly being used as substitutes (Williams et al. 2015). Recently, jaguars were specifically alluded to as a substitute species (Nuñez and Aliaga-Rossel 2017; Reuter et al. 2018; Verheij 2019). Tiger and lion canines may also be used occasionally for medicinal purposes, but this is less common (Xin et al. 2017). Because the trade I examined seems mostly to target jaguar canines, jaguars do not appear to be a replacement for tigers in the medicinal bone market (Fraser 2018). Some of the jaguar teeth seized were carved for the jewellery market, indicating that those jaguar canines may play a role in the Asian market as jewellery or amulets. Big cats are frequently associated with strength, and their body parts are used or kept by people for imbuing personal and spiritual power (Williams et al. 2017; Kelly 2018; Braczkowski et al. 2019). Decoration and collection markets for wildlife-derived products are often rarity driven (Phelps et al. 2014), and jaguar pieces may infuse novelty to this market. For instance, in the orchid trade, mass-market buyers choose species to buy based on quality and beauty, whereas collectors look for rare species, including wild-harvested specimens (Hinsley et al. 2015). Thus, jaguar canines are likely substituting for teeth of tiger, lion, and other cats (Nowell 2000; Nijman and Shepherd 2015; Williams et al. 2017). Further research efforts on the cross-price elasticity of demand for jaguar and Asian

and African cat species are urgently needed to determine whether jaguars are market complements or substitutes for tigers or lions in the Asian market.

High-end products with notable international demand, which could be the case of jaguar body parts, often enter organized crime chains, as previously reported for ivory and rhino horn (Titeca 2019; Haas and Ferreira 2016). Most wildlife trafficking in the Americas has been yet considered only weakly connected to organized crime, with claims of traders working independently, but with strong links to legitimate businesses (Reuter and O'Regan 2017). In this sense, the influx of illegal jaguar products is likely a side effect of the economic partnership between Latin American countries and China and the high corruption rates in the supply-side chain. Reducing bilateral economic relations is not a viable strategy. Increased surveillance and improved cooperation between countries trading with China are needed to curb this threat. For processed wildlife products, there is a higher probability of detecting or confiscating illegal items close to the source or in transit (Center for Advanced Defense Studies 2018). After teeth are carved or added to jewellery pieces, it may be difficult to recognize and identify the species from which they were obtained. Thus, at the end of the chain, these products could be easily laundered as a legal item (Wyatt 2009). Plausible interventions on the demand side include the development of awareness campaigns in China regarding the illegality of and conservation problems related to the item and changing consumer perceptions regarding the possession of the product (Hall et al. 2008).

Supply-side interventions include strategic alliances among Latin American countries to amend the gaps in current legislation – increasing penalties for crimes related to wildlife trade and turning it into a serious crime –, increase border controls, and strengthen surveillance in the source countries. Community-level interventions that empower and engage local communities as active and motivated stakeholders in

law enforcement are a cost-effective and often less corruptible alternative for low-income countries (Biggs et al. 2017; Cooney et al. 2017).

The magnitude of the tooth jewellery market has not been estimated for wild cat species, especially because of the difficulty in accessing this illegal and restricted activity (Phelps et al. 2016; Nijman et al. 2019). The general jewellery market in China has grown in the last decades ($77 billion gross in 2012) (Hsu et al. 2014). I advocate for the establishment and improvement of comprehensive databases on hunting and trafficking of wild cats from Latin American countries, improved training of officials so that they can recognize objects containing wildlife, and investment in research on wildlife trafficking. I did not explore demand-side factors of the jaguar market, and these drivers need further research.

This is the first large-scale assessment that shows the coverage and effects of some drivers of the international trade in jaguars in Latin America. I acknowledge the limitation posed by gathering data only from online sources in representing the real number of seizures and the seizures represent the actual number of individuals traded, especially considering the possible effects of distinct surveillance efforts among countries and the tendency to over-report seizures implicating international countries. Seizure reports and media items have been used frequently and are claimed to be among the few sources available through which to assess hidden markets in wildlife (Ni et al. 2018) or sensitive illegal behaviours, such as hunting (El Bizri et al. 2015). They can be an important source for a first diagnosis of trade in wild cats, especially considering the absence of an official seizure database in most of the involved countries and the high risk and difficulty of conducting market surveys and interviews with traffickers. It is urgent therefore, international agencies, in particular CITES, institute or foster the establishment an illegal-trade database working group to enhance collective data collection and analysis of jaguar trade

information (Phelps et al. 2010), and with the participation of many different actors monitor this rising trade. Coordinated multi-country initiatives are now eased with the advances in technology and communication and facilitating the collaboration between developed and in-development countries, source and demand regions.

In addition to providing numbers and a perspective on the state-of-the-art and drivers of the jaguar trade in Latin America, I sought to increase awareness of this emerging threat and to suggest priorities for new assessments. Besides wildlife trade, Neotropical wild cats are threatened throughout their distribution by habitat loss and fragmentation, road mortality, and conflicts with humans due to livestock predation (Paviolo et al. 2016; Verheij 2019). Unlike these other threats, trade in Neotropical cats is understudied (Kernam 2010; Reuter et al. 2018; Verheij 2019). Thus, understanding further features of this market, such as its magnitude and stakeholders involved, is crucial for developing strategies to address this threat and promote conservation of these threatened species.

Chapter 4. Captive-breeding to prevent illegal wildlife trade: a market comparison

4.1 Background

Market-based interventions have been advocated as efficient strategies to prevent illegal wildlife trade, especially in places where law enforcement is inefficient (Archawaranon 2005; Jepson et al. 2011). The establishment of a certified trade is among the most prominent strategies suggested to curb the illegal market in wild species (Hutton and Webb 2003; Archawaranon 2005; Robinson et al. 2015). This market strategy has been adopted to meet the demand for bear bile (Foley et al. 2011), tiger bones (Kirkpatrick and Emerton 2010), black rhino horns (Brown and Layton 2001), porcupine meat (Brooks et al. 2010), pet reptiles (Nijman and Shepherd 2009), preserved butterflies (Gordon and Ayiemba 2003) and several other taxa (Tensen 2016) in an effort to avoid overexploitation of these species.

From a market perspective, substituting illegal products by genuine and legally-sourced products is only effective when the legal product can compete with the illegal product in terms of quality and/or cost (Damania and Bulte 2007; Bulte and Damania 2005; Tensen 2016). The persistence of a competitive market is influenced

by several characteristics of the players from the supply-side, in the case of wildlife trade the breeding enterprises and illegal poachers. The source capacity of production/harvest, the final price of the product and the profit they can make can differ substantially between legal and illegal markets. For legal breeders, the cost of building and running animal enclosures, paying taxes and complying with legislation may play an important role in setting the production rates and the product prices (Tapley et al. 2011). Conversely, in the illegal chain, there may be a lower cost associated with structure, since it often involves underpaid hunters or middle-man, or illegal breeding facilities that do not have to comply with animal welfare norms or to pay taxes (Yao 2006; Joossens and Raw 2012). One of the main costs associated with the illegal market is the avoidance of surveillance, which accounts for the likelihood to be detected and persecuted by control agencies, and for the costs of paying for eventual fines. These costs ultimately depend on the effectiveness of law enforcement and local level of corruption, and may play an important role on the pricing of the product by illegal dealers.

Given that the price for a certified-sourced product is often expected to be higher than the illegally-sourced equivalent, the legal product usually must have a competitive advantage to attract the custumer (e.g., quality assurance of certified cannabis: Van Ooyen-Houben et al. 2014). In the case of wildlife commodities, this may be the superior sanitary safety, animal welfare, or the absence of the imminent risk of being prosecuted and fined when purchasing or owning the animal. All these factors can encourage a consumer to choose to pay higher prices for a legal product over an illegal product. However, if the certified captive-bred and illegal wild-caught animals are identical in all aspects but price, the cheapest product is more likely to be purchased (Bulte and Damania 2005; Kirkpatrick and Emerton 2010). In addition, for the certified product or specimen to truly substitute the illegally sourced one, the

laundering of wild-caught individuals, i.e., the use of false permits to trade a specimen from an illegal origin as being a certified captive-bred one, should be completely absent (Bulte and Damania 2005; Tensen 2016). However, several assessments show the persistence of laundering in well-established certified wildlife markets (Lyons and Natusch 2011; Musing et al. 2015). Although much has been discussed about the potential of and conditions for commercial captive-breeding to serve the purpose of discouraging the illegal wildlife market, there is virtually no published evidence from real-life markets to support this strategy.

Primates are among the groups for which regulating the trade and farming of specific species has been largely advocated as a tool for their conservation (Estrada et al. 2017). Domestic and international trade in live primates has been flagged up as an urgent matter of concern for their conservation (Estrada et al. 2017; Scheffers et al. 2019; Blair et al. 2017). Currently, 60% of primate species are threatened with extinction and almost 75% are facing population declines (Estrada et al. 2017). The Neotropics comprise one-third of the world's current primate species diversity, and Brazil stands out as the richest country in terms of number of primate species worldwide (Mittermeier et al. 2013; Estrada et al. 2018). Since 1967, the harvest and trade in wild-caught primates without previous authorization have been prohibited in Brazil (Law no. 5.197/67). However, since 1997, the country has regulated the trade of live animals (IBAMA Ordinance Law 117/97, and IBAMA Normative Instruction no. 07/2015) in an attempt to curb the illegal trade. Since then, several enterprises were established in Brazil to legally breed and trade primates to be raised as pets. Whether captive-bred primates are successfully replacing wild or illegally-bred primates in the domestic market remains unknown.

In this study, I assess the contemporary legal and illegal market of primates in terms of number of animals traded, price, species composition and market share to

evaluate whether the strategy of certifying legal primate trade has been efficient to curb the illegal trade. I then discuss legal market conformity and the adjustments needed to improve its effectiveness based on the criteria listed in Tensen (2016). For that purpose, I used the Brazilian market as my case study, given the existence of a 30-year regulated trade in primates in the country. I hypothesize that, if the certification of captive-breeding and legal trade of primates is sufficient to tackle the illegal trade in Brazil, the amount of primates traded illegally will be minimal and the market share of certified breeders will be superior to that from illegal sources.

Please refer to Chapter 1 for the literature review on the wildlife trade in Latin America and Brazil, related policies and legislation, and the theoretical support for the economic variables discussed in this Chapter.

4.2 Data collection and analysis

For a general description of the study area, type of data collected, and databases used in this chapter please refer section 2.2 (study area), 2.3.3 and 2.3.4 (data collection) of General Methods.

4.2.1 Data collection

I compiled and compared data on the legal and illegal trade of primates in Brazil for the domestic market in two categories of market: illegal online market and certified captive-breeding market. Trade in primates in Brazil is considered legal only when advertised by legal breeders or certified shops; any advertisements from non-certified vendors are considered illegal, and as such were considered in this study. Some non-certified sellers advertised primates online misguidedly claiming them to be legal (hereafter ‘claimed to be legal’). These records were counted as illegal trade in this study, in accordance with the Brazilian current legislative framework, but analysed separated from the admittedly illegal primates in terms of price.

For the online market, I recorded all instances of primates being advertised on Facebook™ groups and one E-commerce website between April 2017 and August 2020; all posts were posted in Portuguese (Appendix 8.1.1).

As described in the section 2.3.4 of General Methods, for the captive-breeding enterprises, I obtained the total number of active enterprises and individuals traded by species through reports offered by IBAMA SisFauna.

For price comparison only, in this study I include one visit to a physical open fair located in Duque de Caxias city, Rio de Janeiro state, Brazil. This fair runs once a week and local vendors sell a variety of goods, including illegal animals as pets. Considering the safety concerns associated with investigating illegal activities in the above-mentioned region, I only conducted a single visit to the fair in May 2019. Acknowledging that the effort in the physical market was minimal, I did not use its data for any statistical comparison, but for descriptive purposes. I observed and took notes on the primate species and number of individuals for sale at the moment of the visit.

4.2.2 Data analysis

I used descriptive statistics to report on the number of primate individuals and species offered for sale and asking prices in the different markets. I calculated the unit market share (number of individuals) and revenue market share (prices in US dollar) between the illegal market and the certified trade and between species for 2017 and 2018. The market share was conservatively calculated based solely on the number of individuals recorded (i.e., not considering the additional individuals estimated; see below).

Based on my records, I estimated the annual number of specimens sold online and from certified breeders. To estimate the annual number of primates illegally offered for sale online accounting for the non-detected trade during the manual

monitoring on Facebook™, I built a rarefaction curve to assess the accumulation of vendors along the increase in numbers of groups sampled (for more details please refer to section 2.3.6 Data analysis in the General Methods). For that, I pooled all *Callithrix* species into the same category (i.e., *Callithrix* sp.).

I conducted a GLM to assess the differences in prices among taxa and the legality status (i.e., whether advertised as illegal, claimed to be legal by online sellers or legally traded by certified sellers). I included as predictor variables the taxa and the legality status, considering the interaction between these two factors (For more details on model selection please refer to section 2.3.6 Data analysis of General Methods. In this chapter, I used the exchange rate R$4.01 = US$1.0 to convert the Brazilian real into US dollars.

4.3 Results

4.3.1 Primate species recorded

I recorded 319 primates of at least four taxa advertised online on Facebook™ and E-commerce by non-certified sellers over the period of 2017 to 2020 (for examples, please see Appendix 8.1.1). The majority of the primates advertised online were immature individuals (n=305, 95.6%), and 4.4% were adults (n=14). For the posts which the seller reported the sex (n=34), there was a similar proportion between female and males (16 and 18, respectively). I recorded the trade of 118 common marmosets *Callithrix jacchus* (49.4%), 87 black-tuffed marmosets *C. penicillata* (36.4%), 80 capuchins *Sapajus* sp. (33.5%), 33 non-identified marmosets *Callithrix* sp. (13.8%), and one pygmy marmoset *Cebuella pygmaea* (0.4%) over the monitored period (Table 4.1). I recorded a total of 126 different sellers advertising primates online, with an average of 1.8 (SD 1.32) individuals per seller on the Facebook™ (77 sellers) and of 4 (SD 4.64) individuals on E-commerce (49 sellers).

Most of the online trade was concentrated in São Paulo State (n=250, 92.6%), followed by Rio de Janeiro (n=14, 5.1%), Goiás (n=4, 1.5%) and Pernambuco and Bahia (n=1, 0.4%). Only in 10% of the advertisements (n=13) sellers considered delivering the primate to other parts of the country, specifically through postal services. The majority of the sellers only considered selling primates upon the consumer's presence in person to collect the animal. Concerns about animal welfare and the avoidance of detection by police were reasons frequently presented on comments by the sellers.

Table 4.1 Quantity of recorded and estimated individual primates per taxa according to the market categories.

Taxa	Recorded on social media	Recorded on E-commerce	Total recorded	Estimated on social media (SD)	Total estimated[a]
Sapajus sp.	19	61	80	53 (6)	114
Callithrix jacchus	38	80	118		
Callithrix penicillata	37	50	87		
Callithrix sp.	33	0	33	256 (113)	386
Cebuella pygmaea	1	0	1	1 (0)	1
Total	109	130	239	310 (40)	501

[a] Sum of the estimated trade on Facebook™ (accounting for missed posts) and the recorded trade on E-commerce.

Of the trade occurring on social media, most sellers advertised the primate for sale in their personal Facebook™ profile (56%, n=62) and 35% (n=39) of the profiles appears to be destined only to trade wildlife (i.e., with names, posts and friends only related to wildlife trade and with no personal information displayed); in 9% of the cases (n=10) I could not precise if the profile was a personal account or not. Based on the number of unique sellers in the monitored groups on Facebook™, I estimated that an additional 182 non-recorded different sellers of primates may be active on this platform (Figure 4.1). If I consider the sale of those non-recorded but potentially active sellers, I estimated that the trade may have involved 501 primate individuals during the sampled period (386 marmosets, 114 capuchins, and 1 pygmy marmoset) (Table 4.1).

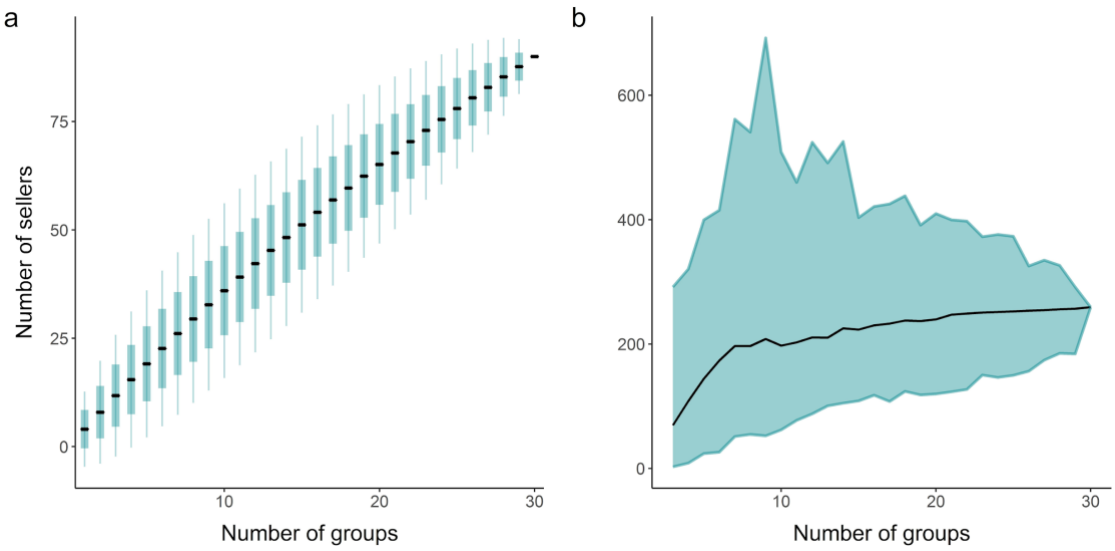

Figure 4.1 Accumulation curve (a) and estimation curve (Chao1 estimator) (b) of the number of active primate vendors on the social media groups sampled. The whiskers and shaded area represent the 95% confidence intervals.

Considering both Facebook™ and E-commerce, I estimated that annually at least 121 (SD 35.9) marmosets and 36 (SD 2.0) capuchins, and 1 (SD 0) pygmy marmoset are illegally traded online in the country. In comparison, I recorded 42 individuals of marmosets (mean 14 [SD 17.0] per year) and 16 capuchins (5.3 [SD 8.4] per year) traded legally by certified breeders. Legal breeders sell common marmosets, black-tuffed marmosets, and black-capped capuchins *Sapajus apella*. In the visited open fair, I recorded four capuchins (*Sapajus* sp.) and three black-tuffed marmosets (1 adult and 2 immatures) being sold at the time of the visit.

4.3.2 Market share

Considering only the individuals recorded in this study in years 2017 and 2018, in terms of units sold, illegal sources accounts for at least 72.9% and 72.4% of the of the entire Brazilian market share of primates as pets (legal breeders = 27.1% and 27.6%) for marmosets and capuchin, respectively. In terms of revenue, illegal sources account for 59.3% and 58.9% market share (legal breeders = 40.7% and

41.1%) for marmosets and capuchin, respectively. When comparing between species, while capuchins dominated the revenue market share (capuchin = 81%, marmosets = 19%), marmosets dominated the unit market share (marmosets = 72.4%, capuchin = 21.1%, pygmy marmoset = 0.5%).

4.3.3 Selling prices

Based uniquely on the advertisements recorded (considering that all represent successful transactions), I estimate that over 166,000 US dollars were generated by the illegal online primate trade in Brazil. Prices were different among species and between legal and illegal specimens, but no interaction was detected between these variables (i.e., differences of prices for legal and illegal specimens was similar independently of the species). Prices of specimens from legal breeders were constant at 4,239.40 USD for a capuchin, and 324.19 USD for any marmoset. On average, illegal capuchin costs 7 times more than marmosets and the pygmy marmoset (Figure 4.2; see price details in Table 4.2, and statistical details in Table 4.3). Despite the rarity on trade, *C. pygmaea* price is not significantly different from the other marmosets (Figure 4.2; Table 4.2 and Table 4.3). Some non-certified sellers advertised primates claiming them to be legal. This was alleged in three distinct situations: (i) an advertised primate specified as an offspring of certified parents, (ii) an attempt by unsatisfied owners to sell their allegedly certified primates, or (iii) a scam with a false permit; any of those cases are still illegal according to the Brazilian law, which only allows sales directly from the certified breeder or certified shop. Individuals from certified breeders and those claimed to be legal by the online seller – although still illegal – were significantly more expensive than the illegally-sourced animals advertised online and in the open fair (Figure 4.2; Table 4.2 and Table 4.3). Capuchins misguidedly claimed to be legal by non-certified sellers were on average 2.6 times cheaper than those from legal breeders (Figure 4.2; Table 4.2

and Table 4.3), while individuals confirmed as illegal were 4.4 and 3.5 times cheaper than the legally-sourced when sold online and in the open fair, respectively. In comparison to the legal breeders, illegal marmosets were twice as cheaper when sold online and 4.8 times cheaper when sold in the open fair (Figure 4.2; Table 4.2 and Table 4.3). However, marmosets claimed to be legal were on average 14% more expensive than those sold by legal breeders.

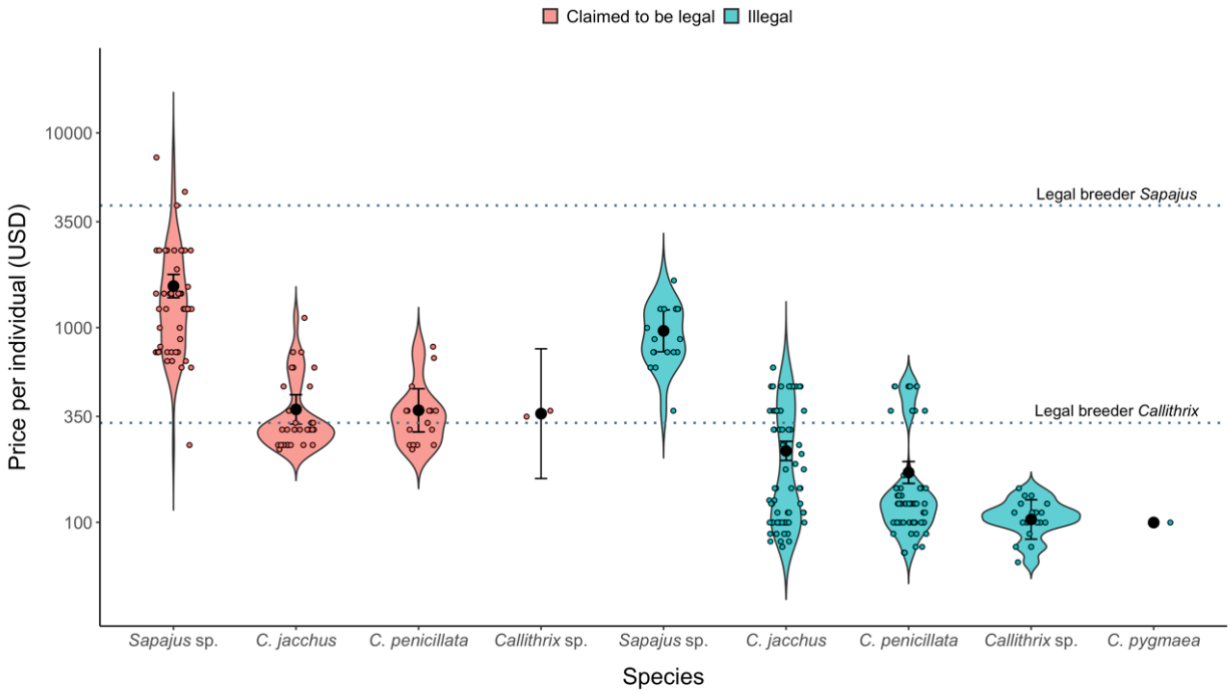

Figure 4.2 Comparison of price per individual between claimed to be legal and illegal sources from online advertisements (social media and E-commerce) per taxon, namely capuchin *Sapajus* sp., common marmoset *Callithrix jacchus*, black-tuffed marmoset *Callithrix penicillata*, marmoset *Callithrix* sp. and pygmy marmoset *Cebuella pygmaea*. The dotted lines represent the costs of a legal primate from a certified breeder. In the violin plots, the shaded area indicates the density of the data points, the whiskers indicate the estimated 95% confidence intervals, and the central black point indicates the estimated mean.

Table 4.2 Average price (in USD) and standard deviation (SD) per individual according to the market categories and taxa recorded.

Taxa	Social media (SD)		E-commerce (SD)		Certified Breeder (SD)	Open fair (SD)
	Illegal	Claimed to be legal	Illegal	Claimed to be legal		
Sapajus sp.	685.79 (216)	5,569.41 (1,697)	1,042.04 (327)	1,383.66 (678)	4239.40 (0)	1,250 (0)
Callithrix jacchus	114.56 (31)	748.13 (193)	269.04 (167)	301.48 (65)	324.19 (0)	73.50 (4)
Callithrix penicillata	104.24 (23)	592.27 (191)	221.41 (158)	309.80 (59)	324.19 (0)	73.50 (4)
Callithrix sp.	103.49 (27)	361.60 (18)	-	-	-	-
Cebuella pygmaea	99.75 (0)	-	-	-	-	-

Table 4.3 Details of the generalised linear model (GLM) for the comparison of price per individual among taxa and legality as advertised.

Response variable[a]	Predictor variable[b]	Estimate	Std. error	*t*	*p*
Price	Intercept	5.941	0.095	62.4	
	Legality: Illegal	-0.491	0.117	-4.2	< 0.002*
	Taxon: *Callithrix penicillata*	-0.011	0.165	-0.1	0.95
	Taxon: *Callithrix* sp.	-0.050	0.404	-0.1	0.91
	Taxon: *Cebuella pygmaea*	-0.847	0.560	-1.5	0.13
	Taxon: *Sapajus* sp.	1.458	0.123	11.8	< 0.001*
	Interaction: *Callithrix penicillata* * Illegal	-0.244	0.193	-1.3	0.21
	Interaction: *Callithrix* sp. * Illegal	-0.760	0.428	-1.8	0.08
	Interaction: *Sapajus* sp. * Illegal	-0.038	0.192	-0.2	0.8

[a] The family of distribution used was Gamma and the link function was log (ln).

[b] Reference classes: Claimed to be legal for legality and *Callithrix jacchus* for taxon.

I detected evidence of animal laundering in both the online market and the open fair. I recorded three online sellers advertising permits and microchips for primates, for both marmosets and capuchins. The seller at the fair also offered the service of providing certificates for capuchins upon the payment of 70% more in the price of the individual purchased.

4.4 Discussion

Assessing wildlife markets to compare the magnitude of legal and illegal trade is crucial to guide decision-making and strategies to reduce the illegal trade. Regulating enterprises to breed and sell primates was a market-based intervention intended to reduce the impact of illegal primate trade in Brazil. Here I show that despite the efforts by the Brazilian government to regulate primate breeding enterprises, most of this market still comprises illegal traded animals. Illegal sources hold over 70% of the unit market share of the primate market. To the best of my knowledge, there is no study assessing the market share of trade in wildlife, and estimating the market share between wild and captive-bred individuals regarded as a challenge to overcome (Coals et al. 2021). Compared to other illegal markets, the unit market share found in this study is considerably higher, e.g., the unit market share of illegal and counterfeit pesticides reaches up to 30% in developing countries (Miszczyk et al. 2018), while illegal cigarettes respond for 8.6% of cigar market share in Gambia (Chisha et al. 2020).

Tensen (2016) listed some market criteria for captive-breeding to fulfil the role of weaken the illegal wildlife market and benefit species conservation, as follow: (i) captive-bred individuals should be considered equal or better in quality in relation to the wild-sourced ones; (ii) captive-breeding should be more cost-efficient than collecting from the wild; (iii) breeding enterprises should not depend on wild populations for restocking; (iv) laundering of illegal wildlife products into the certified trade should be absent; and (v) the certified market cannot promote increase in the demand for wildlife. Here I discuss the primate market in Brazil in light of those criteria.

Both the legal and illegal trade target typically the same primate groups, *Sapajus* and *Callithrix* genera, acting, therefore, as direct competitors in the market.

The only exception was *Cebuella pygmaea*: the species was recorded on the online market and is not bred in captivity for commercial purposes. Iconic for being the smallest Neotropical primate, *C. pygmaea* was advertised on an online post in Rio de Janeiro state, at least 3,000 kilometres from its natural habitat in the Amazon. *Cebuella pygmaea* is currently classified as Vulnerable, while *C. jacchus* and *C. penicillata* are currently Least Concern according to the IUCN Red List (de la Torre et al. 2021; Valença-Montenegro et al. 2021; Valle et al. 2021). Nascimento et al. (2013) recorded three threatened *Sapajus* species among the individuals being kept as a pet in Bahia State, Brazil. Although individual *Sapajus* could not be confidently identified to species level, it is likely that some threatened species may be among those traded illegally (Figure 4.3).

Figure 4.3 A capuchin monkey *Sapajus macrocephalus* kept as a pet.

Two factors are likely driving consumers to still buy primates from illegal sources, i.e., the demand does not match that what can be supplied from certified sources, and legally sourced primates are more expensive than illegally sourced ones. In terms of the supply shortage, it is likely that considerably more people are interested in purchasing a primate in the country than the current capacity of the certified breeders to fulfil that demand. In terms of price, usually consumers that have equal access to similar products tend to buy products from the cheapest source. I did not find any reason other than price in potential customers' comments for preference between a primate from a certified or an illegal seller. They frequently reported that they were looking for an illegal specimen because legally-sourced ones are too expensive (*pers. obs.*). Clearly, the superior sanitary safety, animal welfare, and the absence for the consumer of the imminent risk of being prosecuted and fined when purchasing the animal is still not seen by the population as a competitive advantage that overcomes the difference in price between certified and legal sources. High prices have been an obstacle for the success of other wildlife trade interventions in the world, such as those for porcupines in Vietnam, where wild-caught specimens cost half the price of farm-bred ones (Brooks et al. 2010). The same relationship was found for other markets where illegal products are available, such as the marijuana market in the USA. Amlung et al. (2018) showed that although the legal marijuana was seen as superior in terms of quality by consumers, an overpriced marijuana was projected to boost the consumption from illegal sources.

As I show here, both online and open fair sellers were involved in using false licenses and permits to sell wild-caught or illegally-bred individuals as legally-sourced. Those documents could be completely made up or come from officially certified animals who died. Although not assessed here, the process of laundering animals is not restricted to illegal sellers; it can also be used by certified breeders.

For instance, one in every five certified breeders in Vietnam admitted to continuously purchasing wild-caught porcupines for keeping stock (Brooks et al. 2010). Lyons and Natusch (2011) also tracked 60 wild-caught green python individuals in Indonesia that were later advertised in shops and farms as captive-bred specimens. Unfortunately, a legal wildlife market can only be an effective conservation tool when the capture of wild specimens is avoided and controlled, and laundry is not present.

Given that the suppliers of illegally-sourced primates cannot advertise their products massively to a general public, the existence of a legal commerce in primates is the main way to stimulate people's desire to purchase them as pets (Bulte and Damania 2005). Several celebrities have called attention in the media by raising and displaying supposedly legally-sourced Neotropical primates as pets in the last years, including worldwide famous singers (e.g., Justin Bieber, Chris Brown, Rihanna, Latino), Brazilian soccer players (e.g., Emerson Sheik) and Brazilian digital influencers (e.g., Berti Brothers – with 9.2 million YouTube™ Subscribers as of 24 June 2021). The attention driven by Justin Bieber's capuchin was referred to as "Justin Bieber's monkey fever" by journalists. Public displays of wild animals as pets have been shown to boost the pet trade. Viral online videos of people tickling primates such as slow lorises (*Nycticebus* spp.) or portraying primates such as lemurs (*Lemur catta*) were reported as driving the interest of people in having wild primates (Nekaris et al. 2019; Clarke et al. 2019), while the release of Harry Potter movies were associated with a rise in trade of owls in Indonesia (Nijman and Nekaris 2017). The general public, influenced by celebrities and media, may not be aware of the impacts of buying an illegally-sourced animal, and often end up fuelling the illegal market.

In addition to the market forces, the responsibility related to the existence of trade in primates as pets also extends to a risk posed to human health and to the

environment due to pathogen transmission and exotic species invasion. Contact with wild animals is one of the main drivers of pathogen spillover for emerging infectious diseases, including the recent COVID-19 pandemic (Johnson et al. 2020). Given the phylogenetic proximity, the potential of transmitting pathogens between humans and non-humans primates is increased (Johnson et al. 2020; Ceballos-Mago and Chivers 2010). Invasive primates can also carry diseases to wild animal populations and threat native primate species through direct competition or hybridization (Oliveira and Grelle 2012). It is not uncommon for unsatisfied owners to release their pets in the wild (Ceballos-Mago and Chivers 2010), which makes introduction of exotic species a relevant unintended consequence of the wildlife trade (Lockwood et al. 2019). For instance, *C. jacchus*, endemic to the North-eastern Brazil, is now found as far south as Rio de Janeiro state (Oliveira and Grelle 2012). Amazonian squirrel monkeys (*Saimirii* sp.) are now invasive not only in North-eastern Brazil, but also in several other countries, such as Japan, South Africa, and the USA (Anderson et al. 2017).

According to my assessment, the current certified primate trade in Brazil has failed in all assessed criteria proposed by Tensen (2016) for the use of captive-breeding as a tool for tackling wildlife trafficking. Only one criterion – reliance on wild populations from restoking – could not be assessed in this study and deserves further investigation. Instead of alleviating pressure on wild populations, the legal trade may rather be increasing demand for primates as pets and stimulating the illegal market leading to higher levels of wild-capture than if the trade was prohibited. To face this challenge, market strategies should be revisited. Based on the market share and price competition found here, my recommendations involve driving down prices from legal sources to marginal costs, which may possibly require government interventions, such as subsidies or tax exemptions to help to undercut the prices

(Damania and Bulte 2007). It is crucial, however, to concomitantly adopt strategies to detect and reduce animal laundering.

In addition to these market-based interventions, awareness campaigns to educate consumers are essential. The role of social media in the wildlife trade has become more apparent in recent years (Alves et al. 2019; Nijman et al. 2019; Chng and Bouhuys 2015; Siriwat and Nijman 2018b). Strategies to detect, deflate and investigate illegal trade posts have been developed and must be under continuous improvement. Considering the massive potential of reaching a large number of people in different areas, social media can also be a tool to educate consumers and reduce the illegal trade (Nekaris et al. 2013).

This is the first assessment comparing illegal and certified primate trade from a market perspective. According to my findings, the role of the certified trade in preventing primate trafficking in Brazil needs to be better scrutinized. Here I discussed the uncritical decision of establishing a certified trade in primates without a proper assessment of effectiveness in protecting wild populations from overexploitation, assessed factors that currently prevent the legal market to be more competitive compared to illegal market, and highlighted the need for increased law enforcement to avoid laundering and restocking from the wild, and discourage people to sell or buy illegally-sourced primates. As the claim that certifying wildlife trade is an effective strategy to curb wildlife trafficking is global and permeates several taxa, this Brazilian experience should encourage new critical assessments of these market interventions and development of further strategies for the conservation of primates and other wild species worldwide.

Chapter 5. Wildlife trade and the risk posed to human health: envenomation by pet snakes

SCAN ME

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The published version of this article can be also found in the Appendix 8.3.

5.1 Background

Among the animals affected by the pet market are an array of venomous or poisonous species. Differing from poisonous animals, venomous animals possess the ability to inject venoms in another organism by using specialised anatomical structures (Ericsson et al. 2006; Fry et al. 2008). Despite their fearsome reputation, snakes, frogs, spiders, scorpions, fish and centipedes arise interest among pet hobbyists (Souza et al. 2007; Magalhães and São-Pedro 2012; Hierink et al. 2020; Hauke and Herzig 2021). For instance, in 2012, there were 1.15 million pet snakes traded solely in the USA, including venomous snakes (Hierink et al. 2020). Furthermore, venomous snakes accounted for almost 10% (over 500,000 individuals) of all live traded snakes

reported to the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) between 1975 and 2018, being at least 15% supposedly used to supply the pet market. The worldwide trade in venomous snakes, which are mostly wild-caught, exposes owners, sellers, customs officials, and others involved in their transport and maintenance to potentially serious accidents by envenomation (Hierink et al. 2020). Although the primary use for the venom by a snake is to kill their prey, it can also be used for defence, which is the reason for most of the accidents involving humans.

Brazil stands out in terms of the number of snake species currently regulated by CITES for international trade (Hierink et al. 2020). Considering the domestic market, the trade, breeding and possession of any venomous species in Brazil are currently prohibited by law, as is the import of any exotic snakes, whether venomous or not (Alves et al. 2019). Conversely, a few states have allowed the trade in non-venomous native snake species, despite the national prohibition. In Brazil, since 1967 it is prohibited to capture and keep native species from the wild without previous permission (Law nº 5197/67). In order to meet the domestic demand for wild pets, in 1997, the Brazilian Institute of the Environment and Renewable Natural Resources (IBAMA) regulated breeding enterprises of native wild species for commercial purposes, including snakes (IBAMA Ordinance nº 118-N/1997). However, due to the high risk of accidents involving venomous species in households, in 2002, IBAMA prohibited the establishment of commercial breeders aimed at selling all reptile species (along with amphibians and invertebrates) to the domestic pet market (Normative Instruction IBAMA nº 31/2002). Meanwhile, in 1998, IBAMA regulated imports of live exotic animals under CITES recommendations and banned the import of live specimens of reptiles for breeding purposes and for keeping in captivity as

a pet (IBAMA Ordinance nº 93). Therefore, since 1998 and 2002, respectively, with no exception, it has not been possible to breed or import any live exotic venomous snakes for the pet market, nor to keep native venomous snakes as pets in Brazil. Despite the prohibitions, previous data on official seizures, voluntary surrender (Magalhães and São-Pedro 2012; IBAMA 2019) and interviews with pet owners (Alves et al. 2019) show evidence that several species of venomous snakes are being illegally owned as pets in the country, all of them with potential to threaten human health by envenomation (Souza et al. 2007). Although those past studies reported cases of venomous snakes being kept as pets in Brazil, instances of trade have not heretofore yet been recorded; neither was their relationship with the occurrence of snakebites. Brazil has one of the most comprehensive and complete databases on snake bites worldwide; the Brazilian Ministry of Health through the Notifiable Diseases Information System platform – in Portuguese, Sistema de Informação de Agravos de Notificação (SINAN) (see section 2.2.5 of General Methods of this thesis). This database can be a valuable source of information to understand whether there is a convergence between the taxa with most cases of envenomation and the venomous snake species that are traded as pets.

Here I aimed to assess the online pet trade and pet ownership of venomous snakes in Brazil and its potential risk to human health. For that purpose, I recorded native and exotic venomous species traded as pets online and seized in Brazil, and compared the composition found in the pet market with the species responsible for snakebite events in the country.

Please refer to Chapter 1 for the literature review on the wildlife trade in Brazil and the risk to human health posed by the illegal wildlife trade discussed in this Chapter.

5.2 Data collection and analysis

For a general description of the study area, type of data collected, and databases used in this chapter please refer to section 2.2 (study area) and 2.3.2 to 2.3.5 (data collection) of the General Methods.

5.2.1 Data collection on snake bites

I compiled data on snakebites reported to SINAN between 2015 and 2019 (data from 2020 was not yet available). I gathered information on the number of snakebite events per year, city where it happened and snake species. There is no differentiation in the database whether the snakebite was caused incidentally by pet snakes in a domestic environment or by accidental contact with native snakes in the wild.

5.2.2 Data collection on Facebook™ and YouTube™

Between July and August 2020, I searched data on online trade, abandonments and official seizures of venomous pet snakes in Brazil, compiling reports from August 2015 to July 2020 on Google™, YouTube™ and Facebook™ (for further details please refer to section 2.3.3 of General Methods. I classified venomous snakes to be those species with the morphological, and histological capability of producing and delivering toxins which have led to recorded accidents resulting in systemic symptoms and hospitalization; hence, I opted to include the South American green racer *Philodryas olfersii*. Although the species is not often considered as a venomous snake, the species produces similar toxins as Viperidae and has been involved in snakebite accidents (Ching et al. 2006; Fry et al. 2008; Correia et al. 2010; Barbosa et al. 2020). I searched for all Brazilian native species and the main exotic venomous snake groups traded worldwide according to Hierink et al.

(2020). All recorded posts were in Portuguese. For prices, in this chapter, I used the exchange rate R$5.30 = US$1.0 to convert the Brazilian real into US dollars.

5.3.3 Data collection on seizures

Official seizure data were obtained from reports from IBAMA on my request (for further details, please refer to section 2.3.4 of General Methods). I also considered additional seizures and abandonments reported on the news (for further details, please refer to section 2.3.2 of General Methods). The species involved were included when their scientific names were provided, or when identification was possible through pictures. To avoid duplicated data, I prioritized the official database over media reports in case of similarity.

5.3.5 Data analysis

I first used descriptive statistics (mean and standard deviation) to present an overview of trade in venomous pet snakes and of snakebites in Brazil. I ran a Student T-test to assess the difference in the average price per individual between the two most traded genera (*Bothrops* and *Crotalus*). I ran a GLM to assess, at the species level, the relationship between the total number of snake bite events and the total number of individuals recorded in the pet trade (seizures plus trade/pet ownership) per species. I log-transformed both the number of snake bite events and the number of individuals recorded per species. I used the family of distribution Zero-Adjusted Gamma.

Based on the reports of snakebites, I built a map with the total number of reports considering all venomous species during the period per Brazilian city, and the locations of instances of trade, seizure or pet ownership of venomous

snakes. I included a heat gradient based on Kernel Estimation Density, considering a 10 km diameter surrounding each city.

5.3 Results

5.3.1 Snakebites

A total of 140,929 snakebite events were reported between 2015 and 2019 in Brazil, of which at least 82% involved venomous snakes (n = 114,931), resulting in 614 human deaths (Table 5.1). There are no details on the circumstances in which the accident occurred, which means that it is not possible to determine what fraction of the snakebites reported involved pet snakes as opposed to bites from snakes in the wild. An annual average of 22,986 (SD 1085) snake bites by venomous snakes were recorded in the period, with *Bothrops* spp. and *Crotalus* spp. being responsible for 86% and 10% of these events, respectively (Table 5.1). All species identified are native to Brazil, but an additional 33,350 cases did not have the species identified. The Brazilian states with the highest concentration of snakebites were Pará, Minas Gerais and Bahia, which reported 23,928, 14,988 and 12,203 cases, respectively (Figure 5.1). It is noteworthy that at least 14 cases of snakebites happened between 717 and 1,700 km from the species' known native distribution range, 12 in São Paulo state, and one in Santa Catarina and Rio Grande do Sul states. All of them involved species of the genus *Lachesis*, which includes mainly Amazonian species.

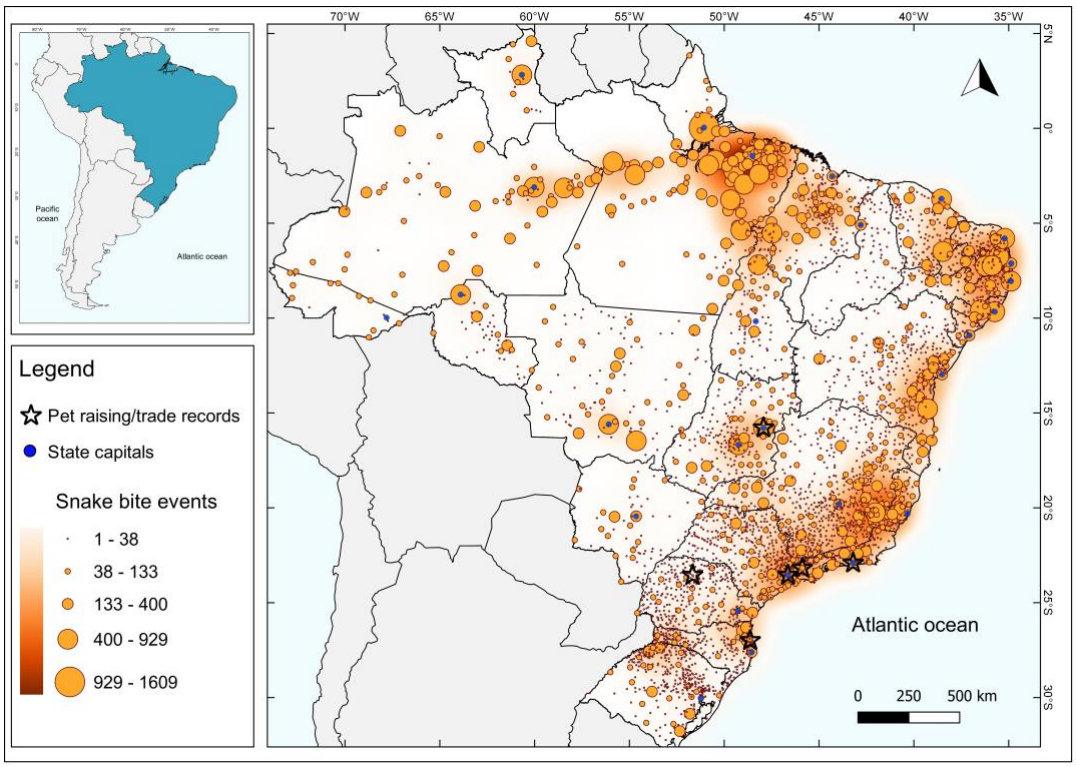


Figure 5.1 Map of the occurrence of snakebite events per Brazilian city considering all venomous species between 2015 and 2019, and regions where I recorded trade advertisements, pet ownership or seizure of venomous snakes.

Table 5.1 Details on the records of snake bite events per year and genera, and the number of deaths resulted from the snake bites from the Brazilian Ministry of Health through the Notifiable Diseases Information System platform (SINAN). All reported taxa are native to Brazil.

Year	Total snake bites	Total venomous snakebites	Genera					Deaths
			Bothrops	*Crotalus*	*Lachesis*	*Micrurus*	Not identified	
2019	30,482	24,453	20,897	2,610	620	326	3,680	159
2018	28,641	23,184	19,859	2,513	549	263	3,342	119
2017	28,500	23,373	20,134	2,485	477	277	3,229	113
2016	26,365	21,596	18,677	2,162	516	241	3,267	116
2015	26,941	22,325	19,453	1,949	715	208	3,157	107
Total	140,929	114,931	99,020	11,719	2,877	1,315	16,675	614

5.3.2 Trade and maintenance of venomous snakes as pets

Considering all sources, I recorded 241 individuals of venomous snakes being traded or kept as pets, accounting for at least 16 different species, seven native species and nine non-native species (Table 5.2; for examples, please see Appendix 8.1.2). Although I acknowledge that correlation may not be causation, I noticed that the taxa involved in higher numbers of snakebite events, genera *Bothrops* and *Crotalus*, were also the taxa that were most often kept as a pet (GLM: Est: 0.237, St. Err = 0.091, t = 2.6, p = 0.04; Figure 5.2).

Table 5.2 Number of individuals of venomous snakes recorded in the pet trade or pet ownership in Brazil according to the species and the type of record, and the average advertised prices.

Species	Common name	Quantity	Type of record	Price per individual in US$ (SD)
Bothrops jararaca	Jararaca	3	Advertisement	69.06 (23.74)
		2	Owner	-
		29	Seizure	-
B. jararacussu	Jararacussu	1	Advertisement	113.21 (0)
		1	News report	-
B. moojeni	Brazilian lancehead	1	Advertisement	66.04 (0)
		1	Seizure	-
B. alternatus	Urutu	1	News report	-
		3	Seizure	-
B. leucurus	Whitetail lancehead	2	Advertisement	66.04 (0)
Bothrops sp.	Lancehead	1	Advertisement	-
		1	Owner	-
		1	News report	-
		1	Seizure	-
Total *Bothrops*		**48**		-

Crotalus durissus	Cascabel rattlesnake	3	Advertisement	66.04 (0)
		6	Owner	-
		155	News report	-
		13	Seizure	-
		1	Seizure/News report	-
Crotalus sp.	Rattlesnake	4	Seizure	-
Total *Crotalus*		**182**		
Lachesis muta	Bushmaster	1	Seizure	-
Total *Lachesis*		**1**		
Naja kaouthia	Monocled cobra	2	Seizure/News report	-
N. atra	Chinese cobra	1	Advertisement	-
Total *Naja*		**3**		
Bitis gabonica	Gabon viper	1	News report	-
B. nasicornis	Rhinoceros viper	1	Seizure	-
Total *Bitis*		**2**		
Trimeresurus vogeli	Vogel's pit viper	1	Seizure/News report	-
T. sabahi	Barat bamboo pit viper	1	Seizure	-
Total *Trimeresurus*		**2**		
Ophiophagus hannah	King cobra	1	Seizure/News report	-
Total *Ophiophagus*		**1**		
Oxyuranus microlepidotus	Inland taipan	1	News report	-
Total *Oxyuranus*		**1**		
Philodryas olfersii	Lichtenstein's green racer	1	Seizure	-
Total *Philodryas*		**1**		
TOTAL		**241**		

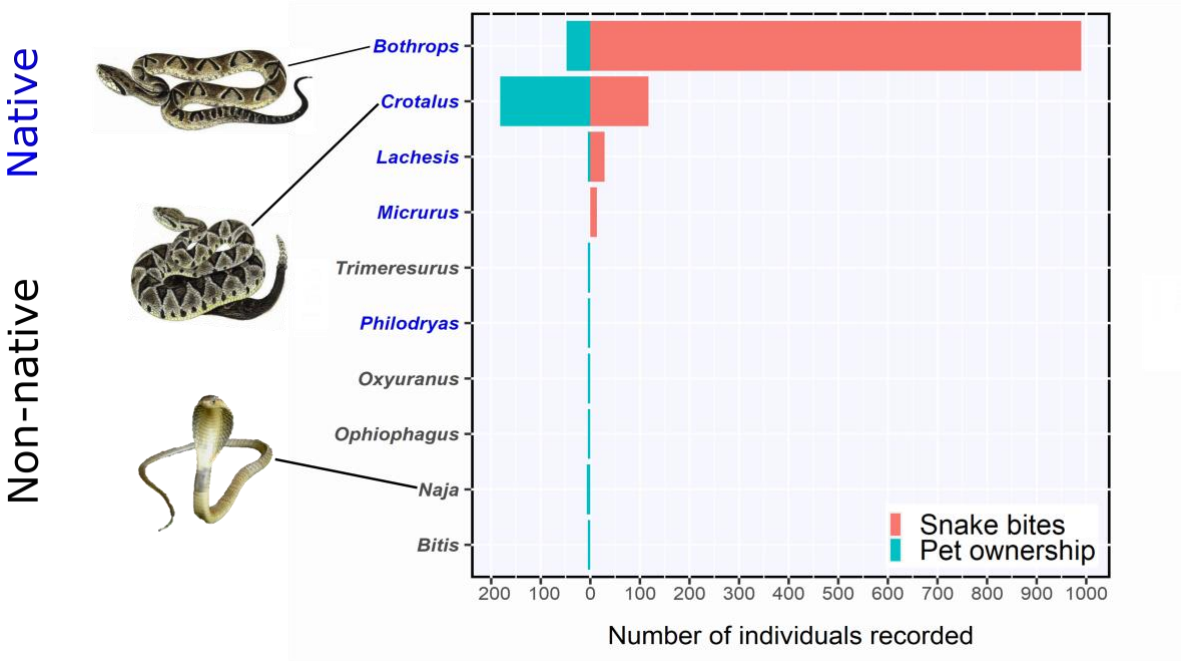


Figure 5.2 Comparison between the number of snake bite events (in thousand events; red bars, right side) and the number of individuals recorded as being traded or raised as a pet (blue bars, left side) per snake genus.

I recorded 24 individuals of at least 9 different species being traded or exhibited on social media. Brazilian native species encompassed ~90% of all individuals recorded (Table 5.2). Based on official seizures, I recorded 60 venomous pet snakes of at least 9 different species, five native and four non-native (Table 5.2). Based on news reports, I recorded an additional 159 individuals seized of at least 5 different species; two of them are non-native species (Table 5.2). Cascabel rattlesnake *Crotalus durissus* was the most recorded species (178 individuals), followed by jararaca *Bothrops jararaca* (34), both native species. Among the exotic species, only monocled cobra *Naja kaouthia* was recorded more than once (Table 5.2). Considering all records, I identified at least six different cities over the country with venomous snakes being traded or kept as pets (Figure 5.1); the majority of the reports were in São

Paulo (38% of all reports), but the report with highest number of individuals kept as pet was recorded in Mandaguari, Parana state (92% of all individuals recorded). The place of origin of the exotic species recorded varied largely, including the Gaboon viper *Bitis gabonica*, native to Sub-Saharan Africa, the Chinese cobra *Naja atra*, native to East Asia, and the Northern copperhead *Agkistrodon contortrix*, native to Eastern North America.

The average price per pet snake was US$ 71.70 (SD 18.44), with prices not differing between the most recorded genera (*Bothrops* vs *Crotalus*, US$ 75.70 vs US$ 66.04, T-test = 0.78, df = 8, p = 0.46). The most expensive pet snake advertised was a *B. jararacussu* priced at US$ 113.21, and the cheapest was a *B. jararaca* priced at US$ 47.17. In addition, I recorded a Brazilian YouTube™ channel devoted to exhibiting snakes as pets, with three videos showing three venomous pet snakes (*Bothrops moojeni*, *Bothrops alternatus*, and *Bitis gabonica*), totalling over 77,000 views as of September 5 2020.

5.4 Discussion

Increased access to the Internet has enhanced online pet trade worldwide and promoted access to animals that were previously rare to find and buy, such as venomous snakes (Hierink et al. 2020). Given that one of the alleged motivations of having a venomous animal as a pet is related to the social status of keeping a dangerous animal, social media also allows owners to show off the specimen and their ability and audacity while handling the animal. This matches with the stereotypical profile of the owner-victims of exotic snakes in the USA and Europe, young men, often hypermasculine, tattooed, and that frequently had used alcohol before the accident (Warrell 2009). In addition to being a serious conservation concern for some target species and the

environment, especially when in synergy with other impacts, such as habitat loss and fragmentation, this segment of the pet trade also poses risks to public health. Despite being illegal, the ownership and trade in venomous reptiles as pets has increased in Brazil over the last few years (Alves et al. 2019). The illegal possession of venomous animals, especially snakes, has been occasionally reported since 2007, based on official seizures and voluntary surrender (Souza et al. 2007; Magalhães and São-Pedro 2012; IBAMA 2019). By interviewing owners on social media, Alves et al. (2019) recorded three venomous snake species not included in my study, while I complement their list with an additional 10 species. In sum, so far there are at least 19 venomous snake species and 9 genera recorded as pets in Brazil.

Worryingly, the taxa responsible for the majority of snakebite events in the country coincide with the ones most frequently raised as pets. Thousands of snakebites occur annually in Brazil, causing hundreds of deaths or permanent injuries to survivors, even upon treatment (Bertolozzi et al. 2015; WHO 2019). Agricultural workers, particularly men between 20 and 59 years-old, and rural inhabitants, are the most affected by snakebites in Brazil (da Silva et al. 2015). I acknowledge here that correlation is not causation, and that pet snakes are possibly responsible for only a minimal proportion of the total snakebites reported. The lack of details on the circumstances of the accident impedes a proper estimative of the importance of pet snakes within the accidents reported. Nonetheless, ownership of venomous pet snakes adds potential risks to a situation that is already a concern from the public health point of view (Warrell 2009; (Gutiérrez et al. 2010; WHO 2019). Only Brazilian native species were reported in the database, but considering that the taxa identification is often made by the healthcare worker based on the clinical diagnosis (symptoms) of

the patient, some species may be misidentified. In this sense, exotic pet species are harder to identify and may account for some of the non-identified species in the database. Records of snakebites outside species' known natural range, for instance, if correctly identified, are unlikely to be a natural accident in the wild and may be a consequence of pet ownership too. Nevertheless, the possibility of misidentification should still be considered, since such accidents would have required specific antivenom that is not regionally available, thus being likely reported by the media.

Bothrops species stand out as the most recorded taxa in online pet trade advertisements, while *Crotalus* species stand out as the most seized taxa as a pet; together, these taxa are responsible for 96% of the snakebites across Brazil. The wide distribution and high abundances of the genus *Bothrops* in the wild (Melgarejo 2009) may turn the group into a promising target for the pet market through the ease of obtaining wild-caught individuals at the same time that it favours the risk of encounters in rural areas that results in a snakebite (Silva et al. 2020). It is noteworthy to address the genus defensive behaviour, since most *Bothrops* species occurring in Brazil possess a cryptic coloration that aids in their outstanding camouflage. Once approached by an unaware predator or human, these snakes are prone to strike when there is no escape route available (Araujo and Martins 2006), which leads to accidents where people end up accidently stepping on the animals and consequently being bitten. This defensive behaviour might be especially dangerous to snake keepers, since the animals are usually kept in closed spaces like boxes and terrariums.

Bothrops currently comprises 27 different species, including *B. pirajai* from northeast Brazil that is currently classified as Vulnerable, and the endemic

B. insularis and *B. alcatraz* that inhabit islands very close to São Paulo coast, both Critically Endangered according to the International Union for Conservation of Nature (IUCN). Martins et al. (2008) presented evidence that the removal of *Bothrops insularis* from its insular habitat is responsible for the species' population decline, and found that there were people at the Santos city harbour willing to pay U$30.000 for an individual. Therefore, the venomous snake pet market may lead to the reduction of some populations, putting species at risk and adding threat to the conservation of sensitive or already endangered snake species.

Although recorded in this study in lower quantities than native taxa, the variety of exotic species raised as pets is substantial. Occurrences of bites by exotic pet snakes have been reported in North America (Warrick et al. 2014), Europe (de Haro 2014), and Asia (Wong et al. 2009). A worldwide challenge when dealing with snakebites by exotic species is the low availability or even complete absence of specific antivenom serum, together with the limited experience of local healthcare (Hierink et al. 2020), which are potentially life threatening for the patients. In July 2020, a Brazilian pet owner was bitten by an illegally-owned monocled cobra *Naja kaouthia* when handling the animal. However, Brazil does not produce antivenom for cobras, since their possession is not expected to occur in the country. The owner-victim received a single sample of antivenom stored in the country for research purposes, and additional samples had to be imported from the USA to complete the treatment. He has been recovering after a period of coma but remains severely affected with sequelae. The repercussions of this accident led to a country-wide discussion on the hidden pet trade and further investigations that dismantled a huge operation of snake trafficking in Brazil (Agence France Presse 2020).

Poor information and identification of snakes by sellers and buyers is also a major issue. The lack of knowledge about the biology and ecology of species by owners may lead to violations of welfare directives, which may lead to a mortality rate that can reach up to 75% due to inadequate care (Toland et al. 2012). Inadequate care may also lead to higher rates of abandonment, escape and inappropriate release of the animals in urban environments or in a nearby forested area, posing risks to humans and native species. Several improperly introduced non-venomous pet snakes have turned into an environmental problem by becoming invasive species and competing or predating native species, such as the Burmese python (*Python bivittatus*) in the USA, corn snake (*Pantherophis guttatus*) in Australia and the notorious case of the brown catsnake (*Boiga irregularis*) in Guam Island, which was responsible for extirpating the majority of the native birds from the island (McFadden et al. 2017; Siers et al. 2017; Harvey and Mazzotti 2019). In Brazil, two individuals of *Pantherophis guttatus* were recently found in the wild in Bahia on different occasions (Fonseca et al. 2014). It has been shown that common pet species, such as *Pyhon bivittatus* and *Pantherophis guttatus*, have a concerning potential of establishment in Brazil (Fonseca et al. 2017). The impacts could be immeasurable and even more serious in case of venomous species becoming invasive.

Imports of venomous snakes and pet ownership has been prohibited in Brazil for over two decades (since 1998); however, my findings indicate that the law is often not enforced sufficiently. Given its large area, keeping efficient surveillance in the entire Brazilian territory is challenging. In addition, wildlife crimes such as collecting native specimens from the wild or trafficking prohibited and protected species are not considered a serious crime in Brazil. I

therefore recommend amendments in the legislation that focus on increasing penalties for wildlife traffickers and, possibly, owners that break the law. Additional actions, such as training personnel in order to increase the accuracy of snake identification and proper release spots for removal of unwanted or seized snakes, could be beneficial for the conservation of these species and to avoid risking biological invasions by snakes. Finally, to discourage new purchases or the maintenance of current venomous snake, massive public campaigns must address the potential risk of keeping venomous snakes as pets by informing the serious damages made by different types of venom in the human body and warning owners about the risk posed to other people in case of abandonment or escape of the individuals kept as a pet.

Chapter 6. The effects of COVID-19 pandemic in the online pet trade

SCAN ME

The results from this chapter has been published as an article in the journal *Environmental Research* in February 2021 https://doi.org/10.1016/j.envres.2020.110439

The published version of this article can be also found in the Appendix 8.3.

6.1 Background

Amidst the current global pandemic of COVID-19 (respiratory disease caused by the virus SARS-CoV-2), the topic of emerging infectious diseases (EID) has come to the spotlight once again (Morens et al. 2020). The World Health Organization (WHO) defines EID as those diseases that appear or reappear in a population and that demonstrate a rapid spreading in terms of the number of infected people or new geographical areas (WHO 2014). Many of these EID are zoonoses, i.e., the disease has originated from an animal and crossed the species barrier to infect humans (e.g., Nipah virus - Epstein et al. 2006).

For COVID-19, although not yet confirmed, it was initially reported that the intermediate animal hosts of SARS-CoV-2, the virus responsible for the

COVID-19 pandemic, were among the wildlife species sold and killed in a live-animal market in Wuhan, where many of the initial COVID-19 cases were associated (Ye et al. 2020). As a precaution to the possibility that some animals in that live-animal market were involved in the SARS-CoV-2 epidemic, China issued a nationwide ban on terrestrial wild animal consumption, including captive-bred exotic species (Wang et al. 2020). Subsequently, the potential association of COVID-19 with wet markets featured in the media drew attention from those who disagreed with wild animal consumption; thus petitions and campaigns emerged to discourage the purchase of wildlife products and to demand governments to ban wildlife trade in several countries (e.g. Anonymous 2020a,b).

While the ultimate impact on wild populations remains unclear, some have argued that these measures could be a blessing in disguise for wildlife if halting wild animal trade reduces over-harvesting and limits the contact between human populations and wild species (Pearson et al. 2020). It has been shown, however, that when prohibitions are implemented, clandestine markets often expand to supply the demand; in this context, wildlife trade prevails and monitoring becomes nearly impossible (Harrison et al. 2016). Thus, consumer behaviour change, which involves promoting a reduction in the demand for wildlife by understanding consumers' motivations and preferences, has been suggested as a complementary or alternative strategy to blanket bans (Veríssimo and Wan 2019). The hypothetical but well-advertised link between the COVID-19 pandemic and wildlife trade may reduce consumer demand for wild animals. For instance, when domestic pets and animals from zoos tested positive for COVID-19 after having contact with infected humans, the fear of pets spreading the disease, even with no scientific evidence, resulted in pets

being abandoned or killed worldwide (Parry 2020). However, it remains yet unknown whether on-the-ground actors involved in the wildlife trade responded to the COVID-19 pandemic and campaigns dissuading wildlife trade or discouraging consumer desire at some level.

Here, I aimed to assess whether, when and how COVID-19 was incorporated into the discourse of traders and consumers of wild animals when selling or purchasing wild species online as pets, and the need of additional strategies to curb wildlife pet trade. Physical wildlife markets were forced to close or lessen due to measures to slow the spread of COVID-19, but trade via Web 2.0 platforms such as Instagram and Facebook™ have largely replaced brick and mortar trade in many countries (Lavorgna 2015; Sung and Fong 2018; Siriwat and Nijman 2020) and does not suffer the same limitations. For this reason, I recorded the occurrence of wildlife trade over 20,000 posts in 41 social media groups devoted to wild pet trade in two megadiverse countries, Brazil and Indonesia, during the COVID-19 pandemic and examined mentions of pandemic-related terms in posts uploaded by vendors and potential consumers. I discuss my findings in the light of the potential for behaviour change in relation to trading and purchasing wildlife.

Please refer to Chapter 1 for the literature review on the wildlife trade in Brazil, related policies and legislation, and the risk to human health posed by the illegal wildlife trade as discussed in this Chapter.

6.2 Data collection and analysis

For a general description of the study area, type of data collected, and databases used in this chapter please refer to sections 2.2 (study area) and 2.3.3 (data collection) of General Methods.

6.2.1 Data collection

I monitored the online trade in two megadiverse countries, Brazil and, as a matter of comparison, Indonesia, which is closer to the first COVID-19 epicentre. The monitoring in both countries was conducted over seven weeks between 15 February and April 5, 2020. I focused on the early phase of the COVID-19 pandemic, when the public attention was concentrated on the origin of the pandemic associated with wildlife wet markets. I monitored ten Facebook™ groups in Brazil and 31 Facebook™ groups in Indonesia, previously known to advertise wildlife for sale (for further details, please refer the section 2.3.3 of General Methods). I compiled the number and content of the posts containing reference to 'COVID-19', 'corona virus', 'lockdown' or 'quarantine', in Portuguese for Brazil and Bahasa Indonesia for Indonesia (Appendix 8.1.3).

6.2.2 Data analysis

I conducted a linear regression analysis to assess the trends of accumulated number of posts related to COVID-19. Afterwards, to assess temporal trends in COVID-19-related posts, I ran a break point analysis to investigate any links between the main pandemic landmarks – first case reported, national lockdown, and World Health Organization (WHO) classifying COVID-19 as a pandemic (Ali et al. 2020) – and the incorporation of COVID-19-related terms into the advertisements.

To assess how COVID-19 was incorporated into the discourse of traders and consumers, I translated the text content of the posts related to COVID-19 from both countries into English and ran it through the content analysis (for further details, please refer to section 2.3.6 Data analysis of General Methods.

6.3 Results

6.3.1 Number of posts and main landmarks

I compiled 20,615 advertisements including legal and illegal wild species or wildlife-related products – 11,243 in Indonesia and 9,372 in Brazil – posted on the monitored groups. Of these, only 90 posts (0.44% of the total) contained expressions related to COVID-19 (for examples, see Appendix 8.1.3). Together, the groups presented a potential to reach an upper bound of 201,803 members. The largest monitored group was found in Brazil, which holds around 45,000 members, but the average number of members was 9,305 (SD 1,355). For Indonesia the largest group had 27,253 members, but the average number of members was 5,254 (SD 6,769). The average number of comments per post was 5 (SD 6.7).

The first posts mentioning COVID-19 were published right after the first case confirmed in Brazil and slightly before the first case confirmed in Indonesia (Figure 1). For both countries, there was a significant increase in the number of COVID-19-related posts over time (Brazil: $R2 = 0.91$, $R = 0.95$, $p < 0.01$; Indonesia: $R2 = 0.65$, $R = 0.80$, $p < 0.01$). The break point analysis showed that in the week of March 11, 2020, which coincided with when WHO officially declared the disease as a pandemic, there was a major change in the number posts related to COVID-19 for Brazil (March 09, 2020 ± 1 day CI, $F = 88.15$, $p < 0.01$). The same happened a week later for Indonesia (March 20, 2020 ± 1 day CI, $F = 563.85$, $p < 0.01$) (Figure 1).

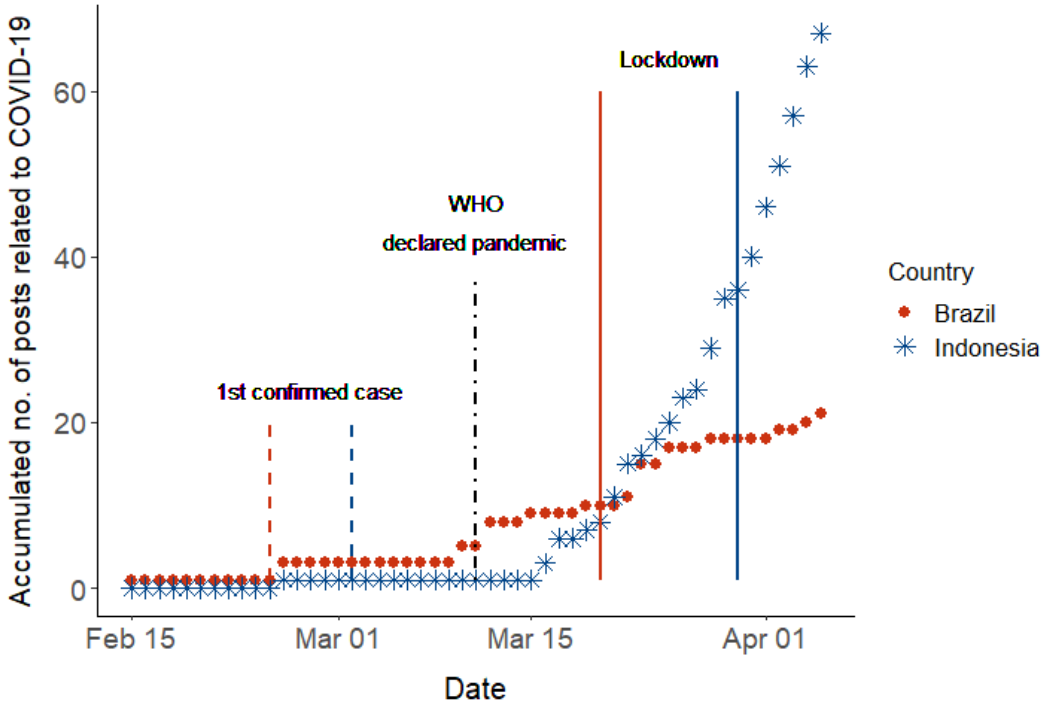


Figure 6.1 Accumulated number of posts with COVID-19-related content on Facebook™ groups focused on wildlife trade in Indonesia and Brazil, with the respective important landmarks, i.e., first confirmed case and decreed lockdown in each country and WHO classifying COVID-19 as pandemic.

6.3.2 Contents of COVID-19-related posts

The topical concept map identified Sales to be the most prominent theme within the discourse, followed by ‘COVID-19’ and ‘lockdown’ (Figure 6.2). The importance of the theme was supported by the clear overlap and close connection between the concepts recommended, services, delivery services, transport and time, all of which reflect the traders' ability to complete their sale successfully and deliver their product to the consumer. This theme also showed direct links to the themes ‘sorry’ and ‘WhatsApp’, which were found to be due to the traders apologizing for delays in delivery and offering further information using the mobile application WhatsApp, which offers encrypted messaging services (Figure 6.2).

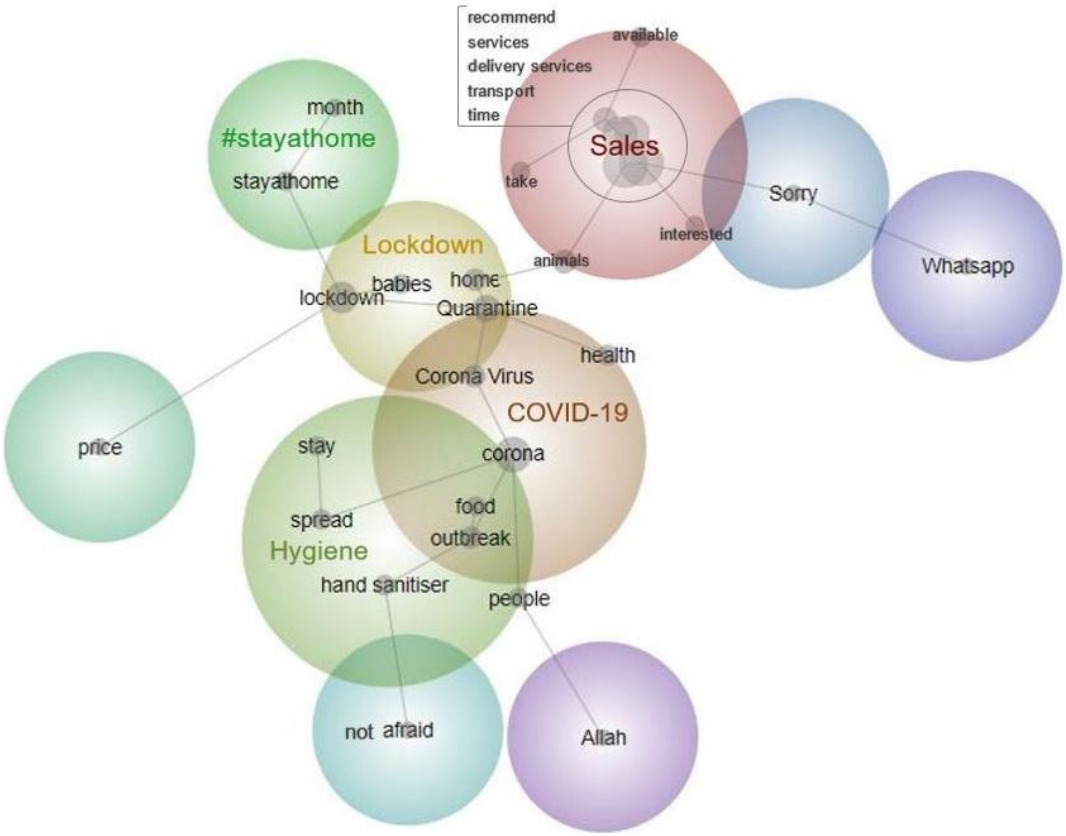


Figure 6.2 Heat map showing the greatest overlap between the concepts recommended, services, delivery services, transport and time, and the most prominent themes: Sales (red), followed by COVID-19 (orange) and Lockdown (yellow). The warmer the colors (i.e., the closer to red tones) the more salient the theme is within the data. The size of the circle does not indicate importance.

The second most important theme was COVID-19, reflecting that while all posts refer to COVID-19 or lockdown within their text, more posts mentioned it only as context to their trading activities, such as delivery delays, as opposed to discussing the impact or risk of the virus actively as their main thought. Three posts from Brazil specifically mentioned the link between animals and COVID-19: two of them stated that animals could not be infected with or transmit COVID-19 and one linked the outbreak to Asian pangolins (*Manis* spp.). One post from Indonesia mentioned the link between SARS and wildlife but prompted no discussion regarding COVID-19. Where posts did have the main

theme of COVID-19 itself, the concepts were mostly linked around personal health and hygiene (Table 6.1).

The concept quarantine exists on the map at the exact overlap of lockdown and COVID-19, perhaps indicating a change of meaning due to semantics between lockdown and quarantine. Within the lockdown theme, the only concept that did not relate specifically to staying at home was the concept ‘babies’. I found this to be due to the number of baby animals being offered as lockdown was deemed a good time to spend with infant animals, as one would have more time to care for them.

I identified a direct pathway between the concepts of lockdown and price as many of the traders in both countries were offering discounted prices throughout the duration of lockdown. The theme ‘not afraid’ represents a facet of the posts, in which commenters encouraged others not to be afraid of the virus, as illustrated in the quotes “Death is determined by Allah, so don't be scared of corona virus” and “Only ’LosGan’ (a prestigious class of bird) hunters aren’t afraid of corona virus”. The themes not afraid and Allah were only recorded in Indonesian groups; the remaining themes were shared between Indonesian and Brazilian groups.

Table 6.1 Illustrative quotes from the posts and comments that were qualitatively analyzed show no discourse that positively links the wildlife trade to the spread of COVID-19.

Country	Posting date	Content of the post
Indonesia	1/4/2020	All available, ready to be sold. Lovebird babies and adults. If you come to the warehouse, we will have hand sanitizer to prevent the spread of *Corona Virus*.
Indonesia	31/3/2020	Baby long-tailed macaque available, male female ready. Healthy and tame. Suitable as a *lockdown* friend.
Indonesia	28/3/2020	We are eager to fulfil the requests from government about *lockdown #stayathome*, but if our warriors, our family's backbone *#stayathome* who will take care of our household? our stomach, our children, our debt repayment? We are not those who have a bank account with zeros lined up and even when used for a month or two the money never diminishes. We are daily fighters and the impact will be felt if we don't earn a day's income. We are not following the government's plea to *#stayhome* but as I stated above if we don't work, we don't eat.
Indonesia	21/3/2020	Death is determined by Allah, so don't be scared of *corona virus*. In Banyumas, one person is infected. For people who hoarded the face masks and hand sanitizer, please donate. Please don't use it for yourself.
Indonesia	17/3/2020	Silver linings of the *corona virus*. Flowerpecker birds discount 10-30 percent. For more information please call or chat via WhatsApp.
Brazil	2/4/2020	Animals do not transmit *corona virus* to humans. There is no need to abandon or sacrifice any animal (such as we have seen in the yellow-fever outbreak when people killed monkeys).
Brazil	23/3/2020	Hello customers, I come to inform everyone that up to this date we do not have any information about likely suspension in the delivery services. We do not know how long the delivery services will be maintained during *lockdown*. To help you, we will give a 10% discount to all, and free delivery fees for São Paulo State. Stay at home!
Brazil	15/3/2020	A large proportion of mammals can be infected by a type of *corona virus*, however, COVID19 only infects humans.
Brazil	15/3/2020	It is a pangolin, a rare animal found in Asia, who they suspect that can carry *corona virus*.
Brazil	12/3/2020	I am interested in buying if you can bring me the animal because in times of *corona virus*, it is not suitable to take public transportation.

6.4 Discussion

Although there are yet few examples of confirmed clinical diseases in humans arising from the wildlife trade, this activity may have the potential to pose a threat to public health. For instance, with increased Internet access and transportation, the origins of traded animals can be (and often are) many hundreds of miles from their point of sale (Bell et al. 2004; Bush et al. 2014) and during transportation or sale, species that would not naturally contact each other are often kept close in facilities (Woo et al. 2006; Reed et al. 2004). Those are examples of paths to break existent geographical, ecological or behavioural separations between humans, livestock and wild animals, which increases the likelihood of cross-species pathogen transmission (Johnson et al. 2020). Although the COVID-19 pandemic represents a challenge for human health, it also offers an anthropocentric argument for persuading people to stop wildlife trade and consumption.

My findings show the actors involved in the trade of wild pets discussed the connection to zoonosis at a low rate, despite public outcry generated around COVID-19 and calls for widespread wildlife market bans. Among all landmarks, the WHO declaration of COVID-19 as a pandemic seems to have sparked the most engagement in COVID-19 discussions for both countries. My breakpoint findings differ substantially to those for the number of comments containing COVID-19 related terms recorded on Twitter by Lopez et al. (2020). In their study, both Portuguese and Bahasa Indonesia comments on COVID-19 peaked when each country had their first case confirmed. It is possible that the WHO declaration may have increased awareness of the risk posed by the virus and influenced the inclusion of COVID-19 related terms in the advertisements (Wise et al. 2020). Considering that many posts addressed concerns about

maintenance of sales and delivery services due to a possible lockdown, the breakpoint likely reflects changes in their logistical and operational arrangements during the pandemic.

Importantly, neither sellers nor consumers discussed the risk of local wildlife trade or human-wildlife interactions as a source of spillover for zoonotic diseases on the monitored online groups. Among the c. 20,000 posts recorded, only one post in an Indonesian group shared a link from ProFauna, an Indonesian wildlife organization, quoting a Chinese doctor, Dr. Zhong Nanshan, attesting a suspicion that SARSCoV-2 had spread from wild animals in a Wuhan market; no comments were prompted by this post. This lack of response is shared by two culturally different countries assessed, one geographically close to the first COVID-19 epicentre and the second far away. Surprisingly, some of the posts and comments encouraged trade in wild animals during the pandemic, affirming that wild animals would provide good companionship during the quarantine period and promoting temporarily reduced prices to stimulate purchases before lockdown.

It is important to recognize that the degree to which people can fully comprehend a risk is based on their own lived experiences. It is possible that if the majority of the traders and consumers have not experienced a known event of direct contamination from contact with animals, they may not perceive a risk. Spillover of pathogens through a pet trade chain was unequivocally confirmed in the past, as in 2003, when a large shipment intended to supply the pet market entered the USA containing some African rodents infected by Monkeypox virus (Reed et al. 2004). Those infected individuals were housed in close proximity to other animals at pet shop facilities, and infected prairie dogs (*Cynomys* spp.), a North American rodent (Guarner et al. 2004; Reed et al. 2004). Several people

from six different states became ill exclusively after having contact with infected prairie dogs purchased as pets, and ever since the importation of African rodents is banned in the country (CDC 2018). In addition, consumer demand for rodent species in the USA changed considerably after this event (Lankau et al. 2017).

A different situation is described for Ebola, in which the natural reservoir of Ebola virus still remains unknown. Close contact with wildlife during Ebola outbreaks has been discussed as a factor of risk after some primary human infections of 2001–2003 Ebola outbreaks were traced back to butchering or contact with infected carcasses of dead gorillas, chimpanzees and duikers in the wild (Leroy et al. 2004). After the Ebola outbreak in 2018 in the Democratic Republic of the Congo, local wild meat vendors did not consider themselves at occupational risk for infection (Lucas et al. 2020). Yet, local populations interviewed during the Ebola outbreak in West Africa recognized wild meat consumption as associated with the risk of Ebola infection. However, they did not support the decision of banning wild meat consumption because they believed the ban occurred for political reasons instead of human health concerns (Mufunda et al. 2016).

I believe a similar perception may be occurring in the case of COVID-19 and its relationship with wildlife trade. The most common way to be infected by SARS-CoV2 is by human-to-human contact. This causality can lead to misconceptions. For example, it has been reported that Dayak hunters in Indonesian Borneo associate COVID-19 with modern life and technology due to their perception that the disease travels by plane and impacts urban areas as opposed to the isolated forests in which they live (Thung 2020). Similarly, Shepherd et al. (2020) found from analysis of both in person interviews and

online discussions that Indonesian bird traders were not convinced that Avian influenza existed. They reported that there were instead numerous theories about existence and spread of the virus, including a belief that songbird competitors from other countries had concocted it as a rumour, and determined that while it was recognized as a hindrance to acquiring birds, it was not considered a health threat to the traders. While my sample did not include any markets that were outside of urban cities, nor explore the theories or rumours regarding its origin, I believe sellers and buyers may similarly reject the association of the pandemic with their own activities if they do not experience this pathway of infection themselves. Rather, they may see the claims for banning wildlife trade as a conservationist or political debate that does not reach people involved on the ground. A study of Hong Kong inhabitants detected that 25% of the interviewees had not ceased going to live-animal markets during the pandemic. Although 70% mentioned avoiding visiting live-animal markets as a precautionary measure to prevent transmission of COVID-19, this proportion was considerably lower compared to other activities, such as going to other crowded places (93%) (Kwok et al. 2020).

There was no clear evidence that the volume of online wildlife trade decreased amidst the pandemic and I still found thousands of posts advertising wild individuals, with a potential audience of 200,000 people. These results mirror those of Ordaz-Németh et al. (2017) on wild meat consumption during the 2014–2016 Ebola outbreak. Despite widespread health and hygiene campaigns and the consequent temporary ban on wild meat trade, wild meat consumption never stopped – although it was temporarily reduced – and some wild meat markets were still operating in West African countries during the critical phase of the Ebola outbreak (Georges-Courbot et al. 1997; Leroy 2004;

Lucas et al. 2020). In contrast, the 2003 outbreak of Avian Flu, Influenza A (H5N1), originated from domestic birds, and the 2009 outbreak of Swine Flu, Influenza A (H1N1), originated from farmed pigs, caused the consumption and export of poultry and pork to decrease substantially, especially as a result of consumers' fear of being infected by consuming the meat (Taha 2007; Rassy and Smith 2013). It is unclear whether this pattern demonstrates a difference in consumer perception of wild and domestic species, given that the knowledge of zoonoses from pigs and poultry is established and sustained by the educational system and cultural practices (Burniston et al. 2015; Kuiken et al. 2012; Pappas 2013), or whether it is a result of nomenclature, with pandemics named after vector species creating more evocative mental imagery and a stronger association between the species and the disease in consumers' minds (Mikhailitchenko et al. 2009).

The intense media coverage and public pressure to ban wildlife trade and consumption in Asian countries, such as China and Vietnam, may contribute to encouraging the development of governmental policies on the matter (Carpenter and Song 2016; TRAFFIC 2020). I found no evidence that they produce behavioural or attitudinal changes within the trade actors selling online. Behaviour change literature has shown that health initiatives that aim to reduce risky behaviours trigger psychological reactance in which the campaign viewer becomes angry that their behaviours and freedoms are being restricted (Kim et al. 2020). This reaction has been best illustrated with respect to COVID-19 through the commitment to health and hygiene initiatives (Kirk and Rifkin 2020); it appears possible that this is occurring within wildlife trade communities as well. Campaigns aimed at reducing wildlife trade deal with a complex and uncertain scenario, in which interventions must be context-specific to reduce the

impact of psychological pushbacks and increase the likelihood of success (Esmail et al. 2020; Thomas-Walters et al. 2020). The majority of interventions aimed at reducing wildlife demand still do not result in major behaviour changes (e.g., Chaves et al. 2018). For instance, only 8% of the target audience changed people's behaviour due to the mediated health campaigns (Thomas-Walters et al. 2020).

Although associating wildlife trade with the COVID-19 pandemic initially seemed like an opportune behaviour change campaign, I could not find evidence that it discourages trade in wild pet markets. Governments, private sectors and communities have to work in collaborative partnerships to develop strategies that also include stakeholders directly involved in the trade (Roe et al. 2020). Additional efforts are needed to ensure that stakeholders interpret the information on discouraging trade, especially if unregulated or illegal, as economically, morally and medically relevant. In addition, I still lack information on the transmissibility of different zoonoses between humans and wildlife, especially the mode of transmission and the role of intermediate hosts (Daszak et al. 2007). At the same time, countries still lack policies to require mandatory testing for pathogens before or after imports and exports of wild animals (e.g. Smith et al. 2009). Therefore, efforts to detect and monitor pathogens in wild reservoirs and disease outbreaks in animal populations targeted by wildlife markets are particularly relevant. Other actions may include improved regulations addressing enforced hygiene and sanitation procedures by certified breeders (Webster 2004). Given the evident potential of traded wild animals in increasing the risk of disease spread, educational campaigns directed towards sellers and especially consumers to inform them about the health risks of trading and keeping wild pets would be beneficial. As advocated by Karesh et

al. (2005), improved market regulations, or reduction in trade in wild-caught animals could provide a cost-effective approach to decrease the risks for disease for humans, domestic animals, wildlife, and ecosystems. Thus, it is essential to create long-term strategies that are rooted in socio-cultural contexts that adapt to emerging global phenomena such as new pandemics.

Chapter 7. General Discussion

The overall aim of this PhD thesis was to assess the scale, correlates, and implications of the trade of wildlife in Latin America through a multidisciplinary approach. At a broader landscape level, I investigated the international illegal trade of jaguar body parts from Latin American countries to other countries, and the interactions between the illegal market and the contemporary exports of jaguar individuals and derivative products reported to the CITES Secretariat. I also focussed on the domestic trade in Brazil, the most megadiverse country globally, to characterize the illegal wildlife market and demonstrate (i) the limitations of the current certified trade in primates in preventing the illegal trade, (ii) the risk that trade and pet ownership of venomous snakes may pose to public health, despite the outright ban, and (iii) the inefficiency of public campaigns, about the wildlife trade-related origin of the COVID-19 pandemic, in promoting behaviour change of sellers and consumers of wildlife, and subsequent trade bans in some countries. The information presented in this thesis highlights the importance of (i) understanding the illegal wildlife market from a multidisciplinary perspective, including biological, social, economic, and legislative factors that interact or influence the trade, and (ii) evaluating the effectiveness of interventions currently in place to tackle the illegal wildlife trade, such as outright bans, captive-breeding and certified trade. Additional papers related to wildlife trade that I have authored or co-authored during the course of my PhD, that are not part of the thesis, are listed in the Appendix 8.2.

In this concluding chapter, I summarize my findings, emphasize the novel aspects of my work, and explain how it fills knowledge gaps existent in the wider

context of wildlife trade research. I also highlight opportunities for future research on this topic and make recommendations to be potentially considered by researchers, governmental agencies, and conservation practitioners to efficiently tackle the wildlife trade in Brazil and other Latin American countries.

Although Latin American countries are seen as important sources of wildlife specimens and products globally (Scheffers et al. 2019; Esmail et al. 2020 Olsen et al. 2021), the dimension of the illegal or non-regulated market, both international and domestic, were largely unknown in regard to most taxa. A considerable part of the literature reporting on wildlife trade in Latin America is not currently published in scientific journals, but available in difficult-to-access conference abstracts or regional governmental reports (Roldán-Clarà et al. 2014).

In Chapter 3, I was able to compile and put together governmental reports and news articles on seizures of a top predator from Latin America to produce the first large-scale study on the so-far allegedly new wave of illegal trade in jaguars to fulfil the demand from Asian countries. In addition, in this study I filled a particular gap of knowledge on how socioeconomic factors may drive the establishment and persistence of illegal wildlife trade and furnished information on the typology and structure of the wildlife trade in Latin America. Similar to my findings on jaguar trade in Latin America, recent studies also found that economic factors, poverty in particular, were the most important drivers of rhino horn trafficking in the borders of Kruger National Park, Mozambique (Lunstrum and Givá 2020), and that the increase in wealth from the recent economic growth in Asian countries, in special China, has been fuelling the international trade in tigers from Indonesia (Linkie et al. 2018).

While trade in big cats has been occurring for decades in Asia, in this thesis I presented evidence that trade in jaguars is indeed worryingly resurging after 30 years of protection of this species with the advent of CITES in 1975. Although I recognize there is difficulty in implying trade rates from seizures because of inherent biases of these kind of data (i.e. different surveillance efforts among countries and over time, Challender et al. 2021), I believe that my results are sufficiently strong to support this evidence because I (i) limited my compilation of seizures up to March 2018, before the release of the news report by Fraser (2018) to avoid over-reporting data, since from that date on wild cat seizures took the spotlight of news outlets worldwide; (ii) used a series of proxies to test for biases and variation in seizures, including the source country corruption perception index score as a proxy for effectiveness of local law enforcement; (iii) used a panel data analysis approach, including country as a fixed effect to account for uncontrolled within-effects for each country in the model; and (iv) compared data on jaguars with those from two other wild cats (*Puma concolor* and *Leopardus pardalis*) for which seizures, in contrast with those of jaguars, remained stable over time in the same periods and places sampled.

In fact, my research prompted further studies by colleagues on the trade in jaguars in several countries in Latin America, most of them agreeing with the results I found. As identified in my study, Arias et al. (2020a) have also not found evidence of a prominent international trade in jaguars in Belize and Guatemala. In contrast, Arias et al. (2020b) found that Asian people were amongst the important group referred as involved in the demand for jaguars in Bolivia, the country which is the one with the highest number of jaguar individuals seized and highest proportion of reports related to China (76%) in my research. There is no doubt,

however, that a more complete dataset and information on jaguar trade and its impacts in other countries from Latin America is required to fully understand and develop effective actions to tackle this new wave of trade.

Apart from seizure reports, in this thesis I also assessed advertisements posted on social media by vendors of wildlife to understand the illegal wildlife market in Latin America. Being such a recent activity, there is still a large knowledge gap on the role of the Internet in enabling or boosting wildlife trade; this gap is evidently more critical in Latin America. Aiming to fulfil this gap, this thesis brings three chapters in which I collected data online, using Brazil as a case study. In Brazil, to the best of my knowledge, only Magalhães and São-Pedro (2012) had collected online data on the trade in wild species in Brazil, more than 9 years ago on Orkut™, a social media platform that was shut down in 2014. By analysing a more recent and widespread social media platform (Facebook™), in Chapter 4 I recorded 319 primates of at least four taxa being illegally advertised online by non-certified sellers over the last 3 years, and in Chapter 5 I recorded 241 individual venomous snakes kept as pets of at least 16 species within the last 5 years in Brazil. In addition, although I did not record the species nor counted the number of individuals on sale, in Chapter 6 I could identify a high rate of trade posts in groups devoted to wild pet trade in a few weeks of 2020 alone, with more ~20,000 posts on 41 Facebook™ groups advertising multiple taxa in Brazil and Indonesia. The possibility of creating fake user accounts, connecting with people from different regions, and reaching a very large audience may attract wildlife sellers and consumers to these online platforms, where illegal trade transactions can be performed with less risk of being identified and prosecuted (Fukushima et al. 2021). Brazil's Internet penetration rate currently stands near the average among

Latin American countries, which means that this country may be a good proxy of what is happening in the rest of Latin America in terms of online wildlife trade. This highlights the importance Internet is gaining in promoting and facilitating illegal wildlife trade worldwide, including in Latin America, and the need for better monitoring and controlling of this activity in the digital environment.

In this thesis, based on economic theory, I was able to identify some drivers underlying the establishment of illegal wildlife markets, and the interactions and convergences between legal and illegal trade. From Chapter 3, it became clear that the investment of international enterprises in Latin American countries, those from China in particular, may be driving the establishment of a new wave of international trade in jaguars. However, no interaction between legal and illegal trade was found, since the countries with the highest rates of illegal trade in jaguars were different from those with the highest rates of legal trade retrieved from CITES data. In addition, the type of product on trade were dissimilar; legal trade was mostly on live specimens, while illegal trade was mostly on teeth. This means that the legal and illegal jaguar trade follows distinct routes and have their own specific dynamics; thus, the flow of illegal jaguar products may be occurring alone or in the back of the trade of other products apart from legal jaguar products, and the legal trade itself may not be stimulating higher demand for jaguars.

In contrast, in Chapter 4 I detected strong similarities between the legal and illegal domestic trade in primates for pets in Brazil. I found that the species on trade were the same between the two markets, and illegal sources held over 70% of the unit market share of the primate market. Hence, despite the efforts by the Brazilian government to regulate primate breeding enterprises, the legal trade may be providing structure for the illegal trade and even increasing the desire for raising

primate specimens through the creation of a specific line of products and through advertisements. Further studies on market share of wildlife trade are still deficient everywhere in the world (Coals et al. 2021). As legal primates are more expensive and their production is not sufficiently high to fulfil the demand, this demand is then supplied by the illegal market. Similarly, farming pangolins in Asia to supply the trade is expected to be unable to discourage the collection of wild specimens, since farmed pangolins are unlikely to be equal in price or cheaper than wild-caught pangolins, and there is an inability to breed pangolins on a commercial scale (Challender et al. 2019).

These contrasting results between those two chapters (Chapter 3 and 4) show that distinct markets may behave differently, with or without interactions between the legal and illegal trade, depending on the context and taxa. Much is still unknown about how the illegal international and domestic trade may interact with, resemble or diverge from the legal trade for most species (e.g., ‘t Sas-Rolfes et al. 2014), and what I show here is that solutions to address the impacts arisen by these markets should not be of the type ‘one-size-fits-all’, but contrastively be tailored according to each specific case.

Wildlife trade may seriously threaten wild species and humans in many ways. Studies on the impacts of wildlife trade focus mostly on the reduction of wild populations by overexploitation or on the effects of introduction of exotic species (e.g., Lockwood et al. 2019; Gippet and Bertelsmeier 2021; Morton et al. 2021). In Chapter 5, I showed that the trade in species with particular features and characteristics, such as poisonous or venomous species, may bring additional risks. In that chapter, I showed that, in Brazil, venomous snake taxa responsible for higher numbers of snakebites reported were also those most often kept as pets.

This, combined with low price of the species on sale and the lack of available anti-venom for exotic species, pinpoints this market as very dangerous to the public health. I believe this situation may be mirrored in other countries in Latin America. Exotic pet snakes have been consistently involved in accidents worldwide, including in North America (Warrick et al. 2014), Europe (de Haro 2014), and Asia (Wong et al. 2009). In England alone, between 2004 and 2010, the National Health Service – NHS – reported 709 admissions in hospital due to injuries caused by exotic pets, the majority caused by humans being bitten or having contact with venomous reptiles and amphibians, and scorpions (Warwick and Steedman 2012). A recent study based on interviews with owners of snakes as pets in Indonesia revealed that raising snakes is growing in popularity, attracting especially young males, mostly in their early teenage years, which is a concern in terms of safety (Kusrini et al. 2021). Assessing the coverage and scope of markets as well as the profile of the owners that target venomous or poisonous species is critical to evaluate the risks involved in owning these taxa and develop regulations and educational measures aimed at suppressing this trade and avoid accidents (Hierink et al. 2020).

Several initiatives and strategies may be taken to reduce the impacts of wildlife trade on both wild species and humans; one of the most adopted is the complete ban of trade in wildlife. This strategy was largely advocated during the COVID-19 pandemic, given the alleged origin of this disease being linked to the trade of wildlife in wet markets. However, in Chapter 6, I detected those campaigns for bans on wildlife trade were barely disclosed or discussed within social media groups devoted to wildlife trade, both in Brazil and in Indonesia. Traders have not discussed the role of trade in spreading diseases, but instead their posts

stimulated the trade in wild species during lockdown. To detect the effect of the pandemic on the desire of owning a wild pet, Moorhouse et al. (2021) interviewed people in several countries worldwide and detected that for non-owners of pet, the desire remained the same as it was in pre-pandemic times. In contrast, the desire by people who already owned wild pets decreased in countries such as Brazil, China, and the USA, but increased in Vietnam. In India, for instance, pangolin seizures increased substantially during lockdown months due to the increase in illegal hunting and trade, likely because of the financial crisis caused by the pandemic that may have led people to rely more on selling wildlife (Aditya et al. 2021). Therefore, the claimed risk of disease transmission has been not sufficient to discourage the demand for wildlife in several places. Bans in wildlife trade under that reason alone will not be sufficient, and additional strategies are clearly needed. My aspiration with this thesis is to provide useful information that can inform better strategies to tackle wildlife trade in Latin America.

My data chapters are among the few studies focussed on wildlife trafficking in Latin America, and more specifically in Brazil, for most of the taxa included in this thesis. Studying illegal wildlife trade is challenging due to difficulties in accessing data on such a secretive activity, and obtaining information on the many socioeconomic, cultural, and structural factors that can influence the establishment of a trade chain. Therefore, studies often focus on some specific aspects of a given wildlife trade chain, using specific taxonomic groups as models, to unveil drivers that may determine the trade in a wider scale, and use this information to improve policies and mitigate impacts on wild populations targeted by trade. To minimize the effects of the limitations posed by the difficulties in accessing wildlife trade data, but still present enough evidence to support policy changes, I based my

hypotheses and data analysis on well-established theories, including macroeconomic theory, and on previous evidence from the literature. In addition, to ensure that my studies were target-oriented and effective in addressing questions about drivers and patterns of trade, I used certain species as models and dedicated different chapters to different aspects of the trade (e.g., economic aspects, health aspects). That limited my conclusions regarding each trade chain and context assessed, but at the same time it was useful to understand the system as whole since different illegal chains can interact or have similar drivers.

My findings in Chapter 3, for instance, are supported by micro and macroeconomy theories, based on which it is expected that the level of availability of the commodity (wild cats) in the country, the level of corruption and the rate of income per capita would influence the susceptibility of people to engage themselves in the illegal trade. Because this is supported by economic theory, it is feasible to consider that my results represent strong evidence to support the policy or legal changes recommended in this thesis for the hotspot countries in terms of jaguar trade. However, because the analysis was made at the country level, details of the regions within countries most involved in the trade, as well as the profile of people involved in the illegal chain, are yet to be assessed to guide strategies at local level. Therefore, on-the-ground research in these countries is still needed. Qualitative methods such as interviews with local people and assessment of infractions and persecutions made at local level that were not available to me, can be useful to get more detailed information on the plight of jaguars targeted by trade in those areas.

Apart from Chapter 6, my main approach to unveil the context of wildlife trade was quantitative, and all the wildlife trade systems studied here could benefit

from applying additional qualitative data to further understand their context. For instance, interviews could be made with traders to understand their reasons for trading wildlife illegally, know the origins of the specimens traded, and unveil their modus operandi. In addition to the supply side, already considered in this thesis, there is the demand side (consumers of wildlife) that still needs to be investigated. Qualitative approaches can be quite useful to understand the profile of these consumers and the reasons that lead them to buy wildlife from illegal sources, or to keep dangerous animals as pets, such as venomous snakes, to develop effective awareness campaigns, socioeconomic policies and law enforcement strategies that discourage the illegal trade.

7.1 Future directions and opportunities for research

Understanding the drivers of and comparing legal and illegal trade, including origin, destination and the type of items and quantities on trade, are key to understand the representativeness of the illegal trade, uncover whether illegal trade is established in the back of legal trade, whether the regulations in place are being effective, and find out what legislative amendments could be undertaken to prevent this to happen (Tittensor et al. 2020). I suggest that research efforts on these aspects should be undertaken for other taxa in Latin America that may be similarly threatened by illegal trade. In addition, I did not explore demand-side factors of the trade in any of the chapters of this thesis, and hence these drivers need further research, especially because it is essential to identify whether awareness campaigns and substitution of the illegal product by a similar legal product may be efficient strategies to be taken in the consuming countries/regions.

More specifically for wild cats, I believe that further research on the cross-price elasticity of jaguar products and other Asian and African cat species are urgently needed to determine whether jaguars are market complements or substitutes for tigers and lions in the market. In addition, understanding further the specificities of the domestic trade in this species in the range countries is necessary. In Mozambique and South Africa, there was a change in the motivation for killing lions over time, from killings occurring as a by-catch during wild meat hunting or as retaliation due to livestock conflict between 2011 and 2013 (with mostly lion meat being utilized from after these events) to the intentional poaching of this species to obtain their heads and paws from 2014 to 2018 (Everatt et al. 2019). There is still no similar study for jaguars. Arias (2020a, b) advanced in the knowledge about identifying the likely actors involved in the jaguar trade in Bolivia, Belize and Guatemala, and the importance of the international demand compared to domestic uses. As a joint effort led by the Wildlife Conservation Society team, there was also an exhaustive assessment of online advertisements containing jaguar body parts in all range countries (Polisar et al. in review).

The claim that certifying trade is an effective strategy to curb wildlife trafficking is widespread and permeates several taxa. However, based on my results from the Brazilian experience with primates, I advocate for critical assessments of these market interventions. Tensen (2016) listed some market criteria for captive-breeding to fulfil the role of reducing the illegal wildlife market and promoting target species conservation. According to my assessment, the current certified primate trade in Brazil has failed in all assessed criteria proposed by Tensen (2016) – except for ‘reliance on wild populations for re-stocking’ which could not be assessed in this study and deserves further investigation. Strategies

that intend to meet the demand of consumers with certified and legally bred wild species should be better researched, scrutinized, monitored, and revised, because they may backfire, increasing the demand, stimulating the illegal market, and leading to higher numbers of wild-captured specimens in the market than if the trade was prohibited. Further research on the effectiveness of strategies of this kind already in place should furnish better evidence of whether this is also happening for other taxa.

For poisonous and venomous species on trade, it is important to understand the profile and motivations of the owners to prepare tailored campaigns in order to discourage the raising of these dangerous species or provide alternatives. In addition, since in my work I could not identify how many of the envenomation cases were directly related to pet raising, it is crucial to assess the specific events where accidents were related to the illegal trade in venomous species. More detailed investigations of hospital admissions due to snakebites, or interviews with bitten people may provide insightful data to estimate the risk and costs of this activity for the owners and the public healthcare system, not only for snakes but also for other venomous or poisonous species, such as spiders, scorpions and amphibians.

Finally, with the advent of the COVID-19 pandemic, parasitological research in wildlife markets became a priority worldwide. With increased Internet access and improved transportation, the origins of traded animals can be very far from their point of sale (Bell et al. 2004; Bush et al. 2014). During transportation or sale, species that would not naturally have contact with each other are often kept close within facilities (Woo et al. 2006; Reed et al. 2004). There is still a large lack of information on the transmissibility of different zoonoses between humans and

wildlife, especially on the mode of transmission and the role of intermediate hosts (Daszak et al. 2007). The sanitary quality of the environment and individuals sold in Latin America, both illegally and legally, need to be assessed to understand the risks of pathogen spillover from wildlife markets.

7.2 Recommendations

Illegal wildlife trade is a complex issue that involves different market forces and contexts of the supply actors and demands from the consumers. Although further studies addressing the knowledge gaps pointed out in the previous section may help make more informed decisions, I am already able to draw some recommendations based on the results presented in this thesis, the literature available and my knowledge about the Brazilian and Latin American social and political contexts.

A notable barrier to discouraging people from engaging in illegal wildlife trade is the deficient criminal sanctions applied to this activity. According to the United Nations Convention against Transnational Organized Crime, serious crimes are those punishable by a minimum of three years in prison; however, the penalty in Brazil for catching or trafficking wild species varies from administrative penalties to three months, or a maximum of two years, in prison (Environmental Crime Law nº 9.605/1998). As presented in the Chapter 3 of this thesis, in many Latin American countries, including Brazil, wildlife trafficking is considered a lesser offensive crime and, usually, the penalty involves exclusively small fines. The fines are, very often, insignificant in value compared to the profit obtained from the illegal trade. Therefore, amending gaps in legislation in those countries is urgently needed, as well as enforcing the application of the penalties, since a small

proportion of them are actually paid. In Brazil, for example, Silva and Bernard (2015) analysed 12 years of notifications of environmental crimes in Brazil (2000-2012) and reported that only 37.6% of all processes were concluded during the period and less than 1% of the fines charged was effectively paid, being many pardoned or converted to a warning. I also highlight here the need for the inclusion of crimes related to online wildlife trade in the Brazilian legal framework. As shown in Chapters 4, 5 and 6, social media and E-commerce platforms play important roles in the illegal wildlife trade in Brazil, but the country lacks regulation addressing specifically the particularities of the online environment, which frequently hinder surveillance and persecution (Fonseca et al. 2021).

Another important aspect in terms of international trade or illegal import of exotic species is how penetrable to traffickers the countries' borders are. In Brazil, for instance, there are no restrictions on the entry in the country of foreign people that have been previously convicted for trafficking wildlife (Fonseca et al. 2021). Therefore, in Brazil and in other countries that also present this legislation loophole, the amendment of the legal frameworks in order to restrict the entrance of international traffickers may reduce the feeling of impunity, discourage illegal traffickers and consequently the likelihood of incidence of illegal wildlife products crossing the borders, including jaguar body parts and exotic venomous snakes recorded in this thesis (Fonseca et al. 2021).

In the case of jaguar trade, it is essential that the governments build strategic alliances among Latin American countries to support each other's capacities to address this issue. This is fortunately already happening to some extent. The previous anecdotal observations in jaguar exploitation for international trade in some countries and the paper produced from the Chapter 3 of this thesis,

published in 2020, prompted several initiatives to promote a synergy in countries' government's actions. In 2021, the Specialized Investigation Group (SIG) Jaguar was established, involving official agents from several Latin American countries, to which I was invited to present my results from Chapter 3 in a special meeting. The SIG is a tool created in 1997 in the Amsterdam Treaty for international cooperation that includes law enforcement officers, prosecutors, and other relevant personnel from different countries, and bases itself on scientific and judiciary information to find strategies to curb illegal wildlife trade. In addition, in 2019, it was established the First High-Level International Conference on Illegal Wildlife Trade in the Americas, that took place in Lima, Peru, in which governmental and non-governmental bodies from different countries met to discuss strategies the fight against IWT, making jaguars the flagship species. I hope that the success of these partnerships can also stimulate other joint work among Latin American countries to address cross-border trafficking of other taxa and illegal domestic trade faced similarly by different countries, with the sharing of successful and failing experiences to tackle wildlife trafficking in their territories. I also advocate for the CITES Big Cats Task Force to expand its strategy, which has so far been limited primarily to Asian and African big cats, and focus more attention on the threats faced by jaguars and Neotropical wild cats. The 2030 Jaguar Conservation Road Map, a multi-thematic forward-looking document drafted by the United Nations Development Programme (UNDP), NGOs and institutions from the jaguar range countries, urges for effective national and international law enforcement as a prevention of poaching of jaguars for trafficking and of demand for jaguar products (UNDP et al. 2018). It is urgent therefore, for international agencies, in particular CITES, to develop or foster the establishment of an illegal-trade database working

group to enhance collective data collection and analysis of jaguar trade information (Phelps et al. 2010).

In Brazil and some other Latin American countries, environmental agencies have been suffering from successive budget cuts, which directly affect surveillance efforts and chances of persecution. Therefore, I recommend increasing the investment in the enforcement sector, including the expansion of staff and better training for agents to recognize parts of wild animals in objects on trade, as well as correct species identification. In terms of investment, governments could support expansion of research on wildlife trafficking in Latin America, which would help to fill knowledge gaps and inform decision-making, with more cost-effective strategies to curb and reduce the social and financial costs of the illegal wildlife trade in the country.

More investment in law enforcement is needed in Latin American countries; however, considering that these are developing countries, and some, such as Brazil, has a large and considerably forested territory to be inspected, surveillance can be challenging. Therefore, relying uniquely on this strategy can be unsuccessful. Governments, private sectors and communities have to work in collaborative partnerships to develop strategies that also include stakeholders directly involved in the trade (Roe et al. 2020). Based on my large-scale assessment of the trade in jaguar body parts in Latin America, I recommend immediate action for different sectors of the society to improve the social and economic conditions of the local communities living in rural areas close to jaguar habitats, especially in some of the hotspot of trade such as Bolivia, Suriname, and Brazil, enforcing local governance and alleviating poverty in those communities. More governance may reduce corruption and involvement in illegal activities at the

local level, which may work better than official law enforcement in remote areas (Franco et al. 2021). Strategies that increase the income in rural areas and the value of the presence of the wildlife through, for example, eco-tourism and sustainable forest-product extraction, may offer incentives for people and reduce the likelihood of them being involved in illegal activities due to financial needs. (Biggs et al. 2017; Cooney et al. 2017). These recommendations can be expanded to the domestic market and other taxa as well, reinforcing the role of local people in supporting conservation and not be part of the poaching or illegal collection of wild animals to supply the illegal market.

Regulatory and prohibitive strategies alone are often insufficient to curb illegal wildlife trade (Challender and MacMillan 2014; Kideghesho 2016; Biggs et al. 2017; Cooney et al. 2017). Some market assessments and interventions can also contribute to reducing the illegal wildlife trade, especially in cases of an existing and established legal wildlife market. In the case of primates, the certified trade in Brazil needs to be better scrutinized. According to my assessment in Chapter 4, the current certified primate trade in Brazil has failed in all assessed criteria proposed by Tensen (2016) for the use of captive-breeding as a tool for tackling wildlife trafficking. From a market perspective, substituting illegal products by genuinely, legally sourced products is only effective when the legal product can compete with the illegal product in terms of quality and/or cost (Damania and Bulte 2007; Bulte and Damania 2005; Challender et al. 2015). Based on the market share and price competition found in Chapter 4, my recommendations involve driving down prices from legal sources to marginal costs, which may possibly require government interventions, such as subsidies or tax exemptions to help undercut the prices (Damania and Bulte 2007). It is crucial, however, to

concomitantly adopt strategies to detect and reduce animal laundering. The investment in tools for differentiating illegally-sourced individuals from those originated from certified breeders is essential. The use of tagging systems and genetic markers are promising tools that could be used to fulfil this role, although they can also demand high financial costs (Lyons and Natusch 2011; Tensen 2016; Alacs et al. 2010). It is imperative that periodic auditions of certified breeders and shops occur, and samples be taken to precise whether the breeding specimens or those on sale have the expected precedence. Birds are the most commonly seized taxa in Brazil, and as a consequence of several studies demonstrating the prevalence of illegal bird trade and breeding in Brazil (Ferreira and Glock 2004; Pagano et al. 2009; Nascimento et al. 2015; Oliveira et al. 2020), in 2011 the Brazilian government launched the System for Control and Monitoring of Amateur Bird Breeding Activity (in Portuguese: Sistema de Controle e Monitoramento da Atividade de Criação Amadora de Pássaros - SisPass). The system is part of an initiative to avoid breeding protected species and stimulate bird ownership from certified sources only. Strategies such this can also be applied for primates or other taxa under certified trade. However, in case it is detected that wild animal laundering occurs in high-intensity and cannot be prevented, banning the trade may be more beneficial to species conservation than the captive-breeding regulation (Tensen 2016).

In terms of public health, different aspects should be considered for recommendations regarding wildlife trade. According to the Brazilian legislation, as an effort to minimize the risk of disease transmission, avoid introduction of exotic species and reduce animal suffering, certified breeders or shops in Brazil are obligated by law (IBAMA Ordinance Law 117/97) to at the time of animal purchase

offer guidelines on (i) how to provide appropriate food, water source, shelter, exercise and rest to the animal; (ii) sanitary aspects of the installations and how to care for animals to avoid disease transmission; and, (iii) the prohibition of releasing the animal in nature. There is no monitoring or inspection of sellers to guarantee that they are providing these guides – I have personally observed certified shops not complying with this law - or of owners to guarantee that they are indeed following these recommended guidelines. Properly informing owners about the biological, behavioural, sanitary, and nutritional requirements of the desired species may discourage impulsive buys. In addition, previous research has found that providing information on the risk of zoonotic disease transmission or legal consequences involved in the illegal ownership of wild animals is more effective in reducing demand for wild pets than conservation, ethical or welfare arguments (Moorhouse et al. 2017; Moorhouse at al. 2021). Therefore, I advocate for that information to be added to the array of information that sellers are legally obligated to provide before any purchase. The legal requirement obviously only affects the certified trade, while the illegal traders are unlikely to provide sufficient information on the care of and risks of owning the animals to the consumers, and given their clandestine nature, illegal chains often involve substantial welfare violations when capturing, transporting, or stocking the animals. While the Brazilian legislation defining the information provision by the sellers to the owners as compulsory, which can be seen as a feasible model for neighbouring countries, more enforcement is needed to guarantee that this law is in fact properly followed in Brazil.

In addition to that, constant clinical assessment of the animals bred, collected or imported to be legally sold alive and regulations addressing proper

hygiene and sanitation procedures by certified breeders are needed to guarantee that the traded animals would not pose sanitary risk to the human population (Webster 2004). Enclosures in breeders, transportation, and shops should avoid direct contact between different species to avoid spillover of potential pathogens. In fact, a study involving a large legal pet wholesaler in the US showed that about 80% of animals traded (including invertebrates, amphibians, reptiles, and mammals) had some illness or injury, and that a mortality rate of over 70% of the animals after six-week period was considered standard (Ashley et al. 2014). Most countries still lack policies to require mandatory testing for pathogens before or after imports and exports of wild animals, or in domestic breeders (e.g., Smith et al. 2009). Therefore, efforts to detect and monitor pathogens in wild reservoirs and disease outbreaks in animal populations targeted by wildlife markets are particularly relevant and should be included in the regulation.

All wildlife trade situations addressed in this thesis would also benefit from awareness campaigns to reduce people's participation in the trade chain and discourage consumer demand for wild animals. In the case of jaguar trade, plausible interventions on the demand side include the development of awareness campaigns in China regarding the illegality of and conservation problems related to the item and changing consumer perceptions regarding the possession of the product (Hall et al. 2008). In the case of primates, given that the suppliers of illegally-sourced primates cannot advertise their products massively to a general public, the existence of a legal commerce in primates is the main way to stimulate people's desire to purchase them as pets (Bulte and Damania 2005). The general public, influenced by celebrities and media, may not be aware of the impacts of buying an illegally-sourced animal, and often end up fuelling the illegal market. In

the case of venomous snakes, to discourage new purchases or the maintenance of venomous snake as pets, massive public campaigns must address the potential risk of keeping venomous snakes as pets by informing the serious damages made by different types of venom in the human body, highlighting the lack of antivenom to be used in case of injuries by exotic species, and warning owners about the risk posed to other people in case of abandonment or escape of the individuals kept as a pet. These campaigns need to be carefully developed in a way that stakeholders correctly interpret the information on discouraging trade, connect to its social-cultural aspects, and see it as economically, morally and medically relevant; different from what we have seen in Chapter 6 of no effect of claims relating the origins of COVID-19 with wildlife trade.

Coordinated effort between public authorities and social media and E-commerce platforms is also needed. Although some social media and E-commerce platforms joined the global effort to tackle illegal wildlife trade by committing to shut down posts and profiles involved in wildlife trade advertisements, many others – including some recorded in this thesis - still need to commit to this action. In addition, social media and E-commerce platforms should consider more citizen participation in detecting and reporting crimes online. Very recently, Instagram™ offers the option for the users to report ‘sale of illegal or regulated goods’, and Facebook™ offers the option to report ‘unauthorized sales’. Most E-commerce platforms and YouTube™, on the other hand, do not offer any similar option for reporting. None of the options detailing the complaint mention the term wildlife trade, and violations of animal welfare are not contemplated either in any online platform assessed. Not all users are aware of that reporting system as well as it is still unclear for the users whether the posts reported will be investigated by official

police or will be only checked by the social media system and deleted. In addition to sale advertisements, attention should be given to posts, profiles and channels devoted to show wild animals in the domestic environment, especially as pets, with demonstrations of non-professionals free handling and of interactions between wild specimens and humans or other domestic animals. Those online displays help normalise keeping wild and exotic animals in captivity and increase the demand for those in the pet trade.

I hope my findings provide a better understanding of the drivers of illegal wildlife trade, as well as help define effective strategies to curb this activity. Considering the great advance in knowledge obtained for several taxa and in different situations pertaining to the wildlife trade in Latin America, I hope the multidisciplinary approach adopted in this thesis could be used as a role-model for future studies on wildlife trade in Latin America.

References

Aditya, V., Goswami, R., Mendis, A., & Roopa, R. (2021). Scale of the issue: Mapping the impact of the COVID-19 lockdown on pangolin trade across India. Biological Conservation, 257, 109136.

Agence France Presse. (2020). Brazil's Most Famous Cobra' Sparks Trafficking Probe, Draws Fans. Barrow's magazine. Published on 24 July 2020. https://www.barrons.com/news/brazil-s-most-famous-cobra-sparks-trafficking-probe-draws-fans-01595641804 (accessed on 29 September 2020).

Alacs, E. A., Georges, A., FitzSimmons, N. N., & Robertson, J. (2010). DNA detective: a review of molecular approaches to wildlife forensics. Forensic Science, Medicine and Pathology, 6(3), 180-194.

Ali, M. G., Ahmad, M. O., & Husain, S. N. (2020). Spread of coronavirus disease (COVID- 19) from an outbreak to pandemic in the year 2020. Asian Journal of Research in Infectious Diseases, 3(4), 37-51.

Alves, R. R. N., de Araújo, B. M. C., da Silva Policarpo, I., Pereira, H. M., Borges, A. K. M., da Silva Vieira, W. L., & Vasconcellos, A. (2019). Keeping reptiles as pets in Brazil: Ethnozoological and conservation aspects. Journal for Nature Conservation, 49, 9-21.

Alves, R. R. N., Lima, J. R. D. F., & Araujo, H. F. P. (2013). The live bird trade in Brazil and its conservation implications: an overview. Bird Conservation International, 23(1), 53-65.

Alves, R. R., Rosa, I. L., Neto, N. A. L., & Voeks, R. (2012). Animals for the gods: magical and religious faunal use and trade in Brazil. Human Ecology, 40(5), 751-780.

American Enterprise Institute. 2018. China Global investment tracker. The American Enterprise Institute and the Heritage Foundation, Washington, D.C. Available at http://www.aei.org/china-global-investment-tracker/ (accessed March 2018).

Andersson, A.A., Tilley, H.B., Lau, W., Dudgeon, D., Bonebrake, T.C. & Dingle, C. 2021. CITES and beyond: Illuminating 20 years of global, legal wildlife trade. Global Ecology and Conservation, 26, e01455.

Anonymous. (2020a). World Animal Protection End the global wildlife trade. Forever. Available at: https://www.worldanimalprotection.org/take-action/end-global-wildlife-trade-forever

Anonymous. (2020b). Coalition to End the Trade. Available at: https://endthetrade.com/

Antonelli, A., Zizka, A., Carvalho, F. A., Scharn, R., Bacon, C. D., Silvestro, D., & Condamine, F. L. (2018). Amazonia is the primary source of Neotropical biodiversity. Proceedings of the National Academy of Sciences, 115(23), 6034-6039.

Antunes, A. P., Fewster, R. M., Venticinque, E. M., Peres, C. A., Levi, T., Rohe, F., & Shepard, G. H. (2016). Empty forest or empty rivers? A century of commercial hunting in Amazonia. Science advances, 2(10), e1600936.

Araujo, M. S., & Martins, M. (2006). Defensive behaviour in pit vipers of the genus *Bothrops* (Serpentes, Viperidae). The Herpetological Journal, 16(3), 297-303.

Archawaranon, M. (2005). Captive Hill Mynah Gracula religiosa breeding success: potential for bird conservation in Thailand? Bird Conservation International, 15(4), 327-335.

Argolo, A.J.S. 2000. *Bothrops pirajai*. The IUCN Red List of Threatened Species 2000: e.T39902A10280801. https://dx.doi.org/10.2305/IUCN.UK.2000.RLTS.T39902A10280801.en.

Arias, M., Hinsley, A., & Milner-Gulland, E. J. (2020a). Characteristics of, and uncertainties about, illegal jaguar trade in Belize and Guatemala. Biological Conservation, 250, 108765.

Arias, M., Hinsley, A., Nogales-Ascarrunz, P., Negroes, N., Glikman, J. A., & Milner-Gulland, E. J. (2020b). Prevalence and characteristics of jaguar trade in north-western Bolivia. SocArXiv. DOI:10.31235/osf.io/s4p6r

Ashley, S., Brown, S., Ledford, J., Martin, J., Nash, A. E., Terry, A., Tristan, T., & Warwick, C. (2014). Morbidity and mortality of invertebrates, amphibians, reptiles, and mammals at a major exotic companion animal wholesaler. Journal of Applied Animal Welfare Science, 17(4), 308-321.

Bagley, B. (2004). Globalisation and Latin American and Caribbean organised crime. Global crime, 6(1), 32-53.

Barbosa, A. R., Nishida, A. K., Costa, E. S., & Cazé, A. L. R. (2007). Abordagem etnoherpetológica de São José da Mata-Paraíba-Brasil. Revista de Biologia e Ciências da Terra, 7(2).

Barbosa, V. D. N., Amaral, J. M. D. S., Alves, Á. A. A., & França, F. G. R. (2020). A new case of envenomation by neotropical opisthoglyphous snake *Philodryas olfersii* (Lichtenstein, 1823) in Recife, State of Pernambuco, Brazil. Revista da Sociedade Brasileira de Medicina Tropical, 53.

Barrett, C. B., Travis, A. J., & Dasgupta, P. (2011). On biodiversity conservation and poverty traps. Proceedings of the National Academy of Sciences of the United States of America, 108:13907–13912.

Barton, D., Chen, Y., & Ji, A. (2013). Mapping China's middle class. McKinsey Quarterly, 3, 54–60.

Bastos, H. M., Lopes, L. F. L., Gattamorta, M. A., & Matushima, E. R. (2008). Prevalence of enterobacteria in *Bothrops jararaca* in São Paulo State: microbiological survey and antimicrobial resistance standards. Acta Scientiarum. Biological Sciences, 30(3), 321-326.

Belhabib, D., Le Billon, P., & Wrathall, D. J. (2020). Narco-Fish: Global fisheries and drug trafficking. Fish and Fisheries 21(5): 992-1007.

Bell, A., & Jones, K. (2015). Explaining fixed effects: Random effects modeling of time-series cross-sectional and panel data. *Political Science Research and Methods*, 3:133-153.

Bell, D., Roberton, S., & Hunter, P. R. (2004). Animal origins of SARS coronavirus: possible links with the international trade in small carnivores. Philosophical Transactions of the Royal Society of London. Series B: Biological Sciences, 359(1447), 1107-1114.

Bergenas, J., & Knight, A. (2015). Green Terror: Environmental Crime and Illicit Financing. SAIS Review of International Affairs, 35(1), 119–131.

Bergin, D., Atoussi, S., & Waters, S. (2018). Online trade of Barbary macaques *Macaca sylvanus* in Algeria and Morocco. Biodiversity and Conservation, 27(2), 531-534.

Bertolozzi, M. R., Scatena, C. M. D. C., & França, F. O. D. S. (2015). Vulnerabilities in snakebites in São Paulo, Brazil. Revista de Saúde publica, 49, 82.

Biggs, D., Cooney, R., Roe, D., Dublin, H. T., Allan, J. R., Challender, D. W., & Skinner, D. (2017). Developing a theory of change for a community-based response to illegal wildlife trade. Conservation Biology, 31, 5–12.

Biscola, N. P., Fornazari, F., Saad, E., Richini-Pereira, V. B., Campagner, M. V., Langoni, H., Barraviera, B., & Ferreira Junior, R. S. (2011). Serological investigation and PCR in detection of pathogenic leptospires in snakes. Pesquisa Veterinária Brasileira, 31(9), 806-811.

Blair, M. E., Le, M. D., Thach, H. M., Panariello, A., Vu, N. B., Birchette, M. G., Sethi, G., & Sterling, E. J. (2017). Applying systems thinking to inform studies of wildlife trade in primates. American Journal of Primatology, 79(11), e22715.

Borsky, S., Hennighausen, H., Leiter, A., & Williges, K. (2020). CITES and the Zoonotic Disease Content in International Wildlife Trade. Environmental and Resource Economics, 76(4), 1001-1017.

Braczkowski, A., Ruzo, A., Sanchez, F., Castagnino, R., Brown, C., Guynup, S., Winter, S., Gandy, D., & O'Bryan, C. (2019). The ayahuasca tourism boom: an undervalued demand driver for jaguar body parts? Conservation Science and Practice, 1(12), e126.

Brashares, J. S., Golden, C. D., Weinbaum, K. Z., Barrett, C. B., & Okello, G. V. (2011). Economic and geographic drivers of wildlife consumption in rural Africa. Proceedings of the National Academy of Sciences, 108(34), 13931-13936.

British Psychological Society (2017). Ethics Guidelines for Internet-mediated Research. INF206/04.2017. Leicester: Author. Available at:

www.bps.org.uk/publications/policy-and-guidelines/ research-guidelines-policy-documents/research- guidelines-poli

British Sociological Association (2017). Statement of Ethical Practice. Durhan, UK: BSA publications. Available at: https://www.britsoc.co.uk/ethics

Brooks, E. G. E., Roberton, S. I., & Bell, D. J. (2010). The conservation impact of commercial wildlife farming of porcupines in Vietnam. Biological Conservation, 143(11), 2808-2814.

Brooks, T. M., Mittermeier, R. A., da Fonseca, G. A., Gerlach, J., Hoffmann, M., Lamoreux, J. F., Mittermeier, C. G., Pilgrim, J. D., & Rodrigues, A. S. (2006). Global biodiversity conservation priorities. Science, 313(5783), 58-61.

Brown, G., & Layton, D. F. (2001). A market solution for preserving biodiversity: the black rhino. Cambridge: Cambridge University Press, UK.

Bruckner, A. W. (2001). Tracking the trade in ornamental coral reef organisms: the importance of CITES and its limitations. Aquarium Sciences and Conservation, 3(1), 79-94.

Bulte, E. H., & Damania, R. (2005). An economic assessment of wildlife farming and conservation, Conservation Biology, 19(4), 1222-1233.

Burnham, K. P., & Anderson, D. R. (2004). Multimodel inference: understanding AIC and BIC in model selection. Sociological Methods & Research, 33, 261–304.

Burniston, S., Okello, A. L., Khamlome, B., Inthavong, P., Gilbert, J., Blacksell, S. D., Allen, J., & Welburn, S. C. (2015). Cultural drivers and health-seeking behaviours that impact on the transmission of pig-associated zoonoses in Lao People's Democratic Republic. Infectious Diseases of Poverty, 4, 1-12.

Burridge, M. J., Simmons, L. A., & Allan, S. A. (2000). Introduction of potential heartwater vectors and other exotic ticks into Florida on imported reptiles. Journal of Parasitology, 86(4), 700-704.

Bush, E. R., Baker, S. E., & Macdonald, D. W. (2014). Global Trade in Exotic Pets 2006- 2012. Conservation Biology, 28(3), 663–676.

Bush, E. R., Baker, S. E., & Macdonald, D. W. (2014). Global trade in exotic pets 2006–2012. Conservation Biology, 28(3), 663-676.

Busilacchi, S., Butler, J. R., van Putten, I., Cosijn, M., Posu, J., Fitriana, R., & Slamet, A. (2021). Why does illegal wildlife trade persist in spite of legal alternatives in transboundary regions? Human Dimensions of Wildlife, 10.1080/10871209.2021.1876963.

Carpenter, A. F., & Song, W. (2016). Changing attitudes about the weak: Social and legal conditions for animal protection in China. Critical Asian Studies, 48(3), 380-399.

Carpenter, A. I., Andreone, F., Moore, R. D., & Griffiths, R. A. (2014). A review of the international trade in amphibians: the types, levels and dynamics of trade in CITES-listed species. Oryx, 48(4), 565-574.

CDC. 2003 U.S. Outbreak. (2018). Available at: https://www.cdc.gov/poxvirus/monkeypox/outbreak.html

Ceballos-Mago, N., & Chivers, D. J. (2010). Local knowledge and perceptions of pet primates and wild Margarita capuchins on Isla de Margarita and Isla de Coche in Venezuela. Endangered Species Research, 13(1), 63-72.

Center for Advanced Defense Studies (C4ADS). 2018. In plane sight: wildlife trafficking in the air transport sector. C4ADS and USAID- ROUTES, Washington, D.C.

Central Intelligence Agency (CIA). 2016. Profile guide in the world fact-book. CIA, Washington, D.C. Available at https://www.cia.gov/ library/publications/the-world-factbook/geos/br.html (accessed March 2018).

Challender, D. W. S., & MacMillan, D. C. (2014). Poaching is more than an enforcement problem. Conservation Letters, 7(5), 484–494.

Challender, D. W., Brockington, D., Hinsley, A., Hoffmann, M., Kolby, J. E., Massé, F., Natusch, D.J., Oldfield, T.E., Outhwaite, W., ’t Sas-Rolfes, M., & Milner-Gulland, E. J. (2021). Mischaracterizing wildlife trade and its impacts may mislead policy processes. Conservation Letters, e12832.

Challender, D. W., Ades, G. W., Chin, J. S., Sun, N. C. M., lian Chong, J., Connelly, E., ... & Nash, H. C. (2019). Evaluating the feasibility of pangolin farming

and its potential conservation impact. Global Ecology and Conservation, 20, e00714.

Challender, D. W., Harrop, S. R., & MacMillan, D. C. (2015). Understanding markets to conserve trade-threatened species in CITES. Biological Conservation, 187, 249-259.

Challender, D., Waterman, C., & Baillie, J. (2014). Scaling up pangolin conservation. IUCN SSC pangolin specialist group conservation action plan. Zoological Society of London, UK.

Chao, A. (1987). Estimating the population size for capture-recapture data with unequal catchability. Biometrics 43, 783-791.

Chaves Baía-Júnior, P., Guimarães, D. A., & Le Pendu, Y. (2010). Non-legalized commerce in game meat in the Brazilian Amazon: a case study. Revista de biología tropical, 58(3), 1079-1088.

Chaves, W. A., Valle, D., Tavares, A. S., Morcatty, T. Q., & Wilcove, D. S. (2020). Impacts of rural to urban migration, urbanization, and generational change on consumption of wild animals in the Amazon. Conservation Biology, DOI: 10.1111/cobi.13663.

Ching, A. T., Rocha, M. M., Leme, A. F. P., Pimenta, D. C., Maria de Fátima, D. F., Serrano, S. M., ... & Junqueira-de-Azevedo, I. L. (2006). Some aspects of the venom proteome of the Colubridae snake Philodryas olfersii revealed from a Duvernoy's (venom) gland transcriptome. FEBS letters, 580(18), 4417-4422.

Chippaux, J. P. (1998). Snake-bites: appraisal of the global situation. Bulletin of the World Health Organization, 76(5), 515–24.

Chisha, Z., Janneh, M. L., & Ross, H. (2020). Consumption of legal and illegal cigarettes in the Gambia. Tobacco control, 29(Suppl 4), s254-s259.

Chng, S. C., & Bouhuys, J. (2015). Indian Star Tortoises: Shop sales fall as internet trade increases. TRAFFIC Bulletin, 27(2), 73.

Clarke, T. A., Reuter, K. E., LaFleur, M., & Schaefer, M. S. (2019). A viral video and pet lemurs on Twitter. PloS one, 14(1), e0208577.

Coals, P., Loveridge, A., Kurian, D., Williams, V. L., Macdonald, D. W., & Ogden, R. (2021). DART mass spectrometry as a potential tool for the differentiation of captive-bred and wild lion bones. Biodiversity and Conservation, 30(6), 1825-1854.

Cook, D., Roberts, M., & Lowther, J. (2002). The international wildlife trade and organised crime: a review of the evidence and the role of the UK. World Wide Fund for Nature.

Cooney, R., Roe, D., Dublin, H., Phelps, J., Wilkie, D., Keane, A., Travers, H., Skinner, D., Challender, D. W. S., Allan, J. R., & Biggs, D. (2017). From poachers to protectors: engaging local communities in solutions to illegal wildlife trade. Conservation Letters, 10(3), 367-374.

Correia, J. M., Santana Neto, P. D. L., Pinho, M. S. S., Silva, J. A. D., Amorim, M. L. P., & Escobar, J. A. C. (2010). Poisoning due to *Philodryas olfersii* (Lichtenstein, 1823) attended at Restauração Hospital in Recife, State of Pernambuco, Brazil: case report. Revista da Sociedade Brasileira de Medicina Tropical, 43(3), 336-338.

D'Cruze, N., Galarza, F. E. R., Broche, O., El Bizri, H. R., Megson, S., Elwin, A., Machado, F. C., Norrey, J., Coulthard, E., & Megson, D. (2021). Characterizing trade at the largest wildlife market of Amazonian Peru. Global Ecology and Conservation, 28, e01631.

Dalberg, W. (2012). Fighting illicit wildlife trafficking: A consultation with governments. WWF International, Gland, Switzerland.

Damania, R., & Bulte, E. H. (2007) The economics of wildlife farming and endangered species conservation. Ecological Economics, 62(3), 461-472.

Daszak, P., Epstein, J. H., Kilpatrick, A. M., Aguirre, A. A., Karesh, W. B., & Cunningham, A. A. (2007). Collaborative research approaches to the role of wildlife in zoonotic disease emergence. In: *Wildlife and emerging zoonotic diseases: the biology, circumstances and consequences of cross-species transmission* (pp. 463-475). Springer, Berlin, Heidelberg.

de Haro, L. (2014). Injury and Envenomation by Exotic Snakes and Other Venomous Pets in Europe. In P. Gopalakrishnakone, SMA Faiz, CA Gnanathasan, AG Habib, R. Fernando, C.-C. Yang, pp. 471–483. Springer Netherlands.

de la Torre J. A., González-Maya, J. F., Zarza, H., Ceballos, G., & Medellín, R. A. (2018) The jaguar's spots are darker than they appear: assessing the global conservation status of the jaguar Panthera onca. Oryx, 52, 300-315.

de La Torre, S., Shanee, S., Palacios, E., Calouro, A.M., Messias, M.R. & Valença-Montenegro, M.M. 2021. *Cebuella pygmaea* (amended version of 2020 assessment). The IUCN Red List of Threatened Species2021: e.T136926A191707442.

De Morgen. 2018. Chinese illegale handel kost leven van tientallen jaguars: "Dit is echt onrustwekkend". De Morgen. Mar 4. Available at https://www.demorgen.be/nieuws/chinese-illegale-handel-kost-leven-van-tientallen-jaguars-dit-is-echt-onrustwekkend~baaed5c4/?referrer=https%3A%2F%2F (acessed March 2018).

Di Minin, E., Fink, C., Hiippala, T., & Tenkanen, H. (2019). A framework for investigating illegal wildlife trade on social media with machine learning. Conservation Biology, 33(1), 210–213.

Dutton, A. J., Gratwicke, B., Hepburn, C., Herrera, E. A., & Macdonald, D. W. (2013). Tackling unsustainable wildlife trade. In: Macdonald, D. W., & Willis, K. J. (Eds.). Key topics in conservation biology 2. John Wiley & Sons, Chichester, UK.

Ebani, V. V. (2017). Domestic reptiles as source of zoonotic bacteria: a mini review. Asian Pacific Journal of Tropical Medicine, 10(8), 723-728.

El Bizri, H. R., Morcatty, T. Q., Valsecchi, J., Mayor, P., Ribeiro, J. E., Vasconcelos Neto, C. F., Oliveira, J. S., Furtado, K. M., Ferreira, U. C., Miranda, C. F., Silva, C. H., Lopes, V. L., Lopes, G. P., Florindo, C. C., Chagas, R. C., Nijman, V., & Fa, J. E. (2020a). Urban wild meat consumption and trade in central Amazonia. Conservation Biology, 34(2), 438–448.

El Bizri, H. R., Morcatty, T. Q., Ferreira, J. C., Mayor, P., Neto, C. F. V., Valsecchi, J., Nijman, V., & Fa, J. E. (2020b). Social and biological correlates of

wild meat consumption and trade by rural communities in the Jutaí River basin, central Amazonia. Journal of Ethnobiology, 40(2), 183-201.

El Bizri, H. R., Morcatty, T. Q., Lima, J. J., & Valsecchi, J. (2015). The thrill of the chase: uncovering illegal sport hunting in Brazil through YouTube™ posts. Ecology and Society, 20(3), 30.

Epstein, J. H., Field, H. E., Luby, S., Pulliam, J. R., & Daszak, P. (2006). Nipah virus: impact, origins, and causes of emergence. Current Infectious Disease Reports, 8(1), 59-65.

Ericsson, C. D., Hatz, C., Junghanss, T., & Bodio, M. (2006). Medically important venomous animals: biology, prevention, first aid, and clinical management. Clinical Infectious Diseases, 43(10), 1309-1317.

Esmail, N., Wintle, B. C., t Sas-Rolfes, M., Athanas, A., Beale, C. M., Bending, Z., Dai, R., Fabinyi, M., Gluszek, S., Haenlein, C., Harrington, L. A., Hinsley, A., Kariuki, K., Lam, J., Markus, M., Paudel, K., Shukhova, S., Sutherland, W. J., Verissimo, D., Wang, Y., Waugh, J., Wetton, J. H., Workman, C., Wright, J., & Milner-Gulland, E. J. (2020). Emerging illegal wildlife trade issues: A global horizon scan. Conservation Letters, 13(4), e12715.

Estrada, A., Garber, P. A., Mittermeier, R. A., Wich, S., Gouveia, S., Dobrovolski, R., Nekaris, K.A.I., Nijman, V., Rylands, A. B., Maisels, F., Williamson, E. A., Bicca-Marques, J., Fuentes, A., Jerusalinsky, L., Johnson, S., de Melo, F. R., Oliveira, L., Schwitzer, C., Roos, C., Cheyne, S. M., Kierulff, M. C. M., Raharivololona, B., Talebi, M., Ratsimbazafy, J., Supriatna, J., Boonratana, R., Wedana, M., & Setiawan, A. (2018). Primates in peril: the significance of Brazil, Madagascar, Indonesia and the Democratic Republic of the Congo for global primate conservation. PeerJ, 6, e4869.

Estrada, A., Garber, P. A., Rylands, A. B., Roos, C., Fernandez-Duque, E., Di Fiore, A., Nekaris, K. A. I., Nijman, V., Heymann, E. W., & Lambert, J. E. (2017). Impending extinction crisis of the world's primates: Why primates matter. Science Advances, 3(1), e1600946.

Everatt, K. T., Kokes, R., & Pereira, C. L. (2019). Evidence of a further emerging threat to lion conservation; targeted poaching for body parts. Biodiversity and Conservation, 28(14), 4099-4114.

Farias, T. C., Belo, R. P., da Silva, S. R., & Júnior, P. C. B. (2019). Comércio ilegal de aves silvestres em Feiras Livres da Amazônia: um estudo de caso no Município de Abaetetuba, Pará, Brasil. Biota Amazônia, 9(4), 24-28.

Ferreira, C. M., & Glock, L. (2004). Diagnóstico preliminar sobre a avifauna traficada no Rio Grande do Sul, Brasil. Biociências, 12(1), 21-30.

Ferreira, F. S., Albuquerque, U. P., Coutinho, H. D. M., Almeida, W. D. O., & Alves, R. R. D. N. (2012). The trade in medicinal animals in northeastern Brazil. Evidence-based Complementary and Alternative Medicine, 2012, 1-20.

Fields AT, Fischer GA, Shea SKH, Zhang H, Abercrombie DL, Feldheim KA, Babcock EA, Chapman DD. 2017. Species composition of the international shark fin trade assessed through a retail-market survey in Hong Kong. Conservation Biology 32(2):376–389.

Figueroa, J. (2014). Tráfico de partes e individuos del oso andino Tremarctos ornatus en el Perú. Revista de la Academia Colombiana de Ciencias Exactas, Físicas y Naturales, 38(147), 177-190.

Fisher, S. J., & Reeves, R. R. (2005). The global trade in live cetaceans: implications for conservation. Journal of International Wildlife Law and Policy, 8(4), 315-340.

Foley, K. E., Stengel, C. J., & Shepherd, C. R. (2011). Pills, powders, vials and flakes: the bear bile trade in Asia. Petaling Jaya, Malaysia: TRAFFIC Southeast Asia.

Fonseca, E., Marques, R., & Tinôco, M. S. (2014). New records of *Pantherophis guttatus* (Squamata: Colubridae) in the state of Bahia, an alien species to Brazil. Salamandra, 50, 241-244.

Fonseca, E., Solé, M., Rödder, D., & de Marco, P. (2017). Pet snakes illegally marketed in Brazil: Climatic viability and establishment risk. PloS One, 12(8), e0183143.

Fonseca, É., Zank, C., Cechin, S. Z., & Both, C. (2021). Reptile pet trade in Brazil: A regulatory approach to sustainable biodiversity conservation. Conservation Science and Practice, e504.

Formentão, L., Saraiva, A. S., & Marrero, A. R. (2021). DNA barcoding exposes the need to control the illegal trade of eggs of non-threatened parrots in Brazil. Conservation Genetics Resources, 1-7.

Franco, C. L., El Bizri, H. R., e Souza, P. R., Fa, J. E., Valsecchi, J., de Sousa, I. S., & De Queiroz, H. L. (2021). Community-based environmental protection in the Brazilian Amazon: Recent history, legal landmarks and expansion across protected areas. Journal of Environmental Management, 287, 112314.

Fraser, B. (2018). China's lust for jaguar fangs imperils big cats. Nature, 555, 13–14.

Fry, B. G., Scheib, H., van der Weerd, L., Young, B., McNaughtan, J., Ramjan, S. R., Vidal, N., Poelmann, R. E., & Norman, J. A. (2008). Evolution of an arsenal: structural and functional diversification of the venom system in the advanced snakes (Caenophidia). Molecular & Cellular Proteomics, 7(2), 215-246.

Fukushima, C. S., Mammola, S., & Cardoso, P. (2020). Global wildlife trade permeates the Tree of Life. Biological Conservation, 247, 108503.

Gao Y., & Clark, S. G. (2014). Elephant ivory trade in China: trends and drivers. Biological Conservation, 180, 23–30.

Gastañaga, M., MacLeod, R., Hennessey, B., Nunez, J. U., Puse, E., Arrascue, A., Hoyos, J., Chambi, W. M., Vasquez, J., & Engblom, G. (2011). A study of the parrot trade in Peru and the potential importance of internal trade for threatened species. Bird Conservation International, 21(1), 76-85.

Georges-Courbot, M. C., Sanchez, A., Lu, C. Y., Baize, S., Leroy, E., Lansout-Soukate, J., Tévi-Bénissan, C., Georges, A. J., Trappier, S. G., Zaki, S. R., Swanepoel, R., Leman, P. A., Rollin, P. E., Peters, C. J., Nichol, S. T., & Ksiazek, T. G. (1997). Isolation and phylogenetic characterization of Ebola viruses causing different outbreaks in Gabon. Emerging Infectious Diseases, 3(1), 59-62.

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

Gonzalez, J. A. (2003). Harvesting, local trade, and conservation of parrots in the Northeastern Peruvian Amazon. Biological Conservation, 114(3), 437-446.

Goodrich J, et al. 2015. Panthera tigris. The IUCN Red List of threatened species 2015. International Union for Conservation of Nature, Gland, Switzerland. Available at http://doi.org/10. 2305/IUCN.UK.2015-2.RLTS.T15955A50659951.en (accessed May 2019).

Gordon, I., & Ayiemba, W. (2003). Harnessing butterfly biodiversity for improving livelihoods and forest conservation: the Kipepeo Project. The Journal of Environment & Development, 12(1), 82-98.

Guan, Y., Zheng, B. J., He, Y. Q., Liu, X. L., Zhuang, Z. X., Cheung, C. L., Luo, S. W., Li, P. H., Zhang, L. J., Guan, Y. J., Butt, K. M., Wong, K. L., Chan, K. W., Lim, W., Shortridge, K. F., Yuen, K. Y., Peiris, J. S. M., & Poon, L. L. M. (2003). Isolation and characterization of viruses related to the SARS coronavirus from animals in southern China. Science, 302(5643), 276-278.

Guarner, J., Johnson, B. J., Paddock, C. D., Shieh, W. J., Goldsmith, C. S., Reynolds, M. G., Damon, I. K., Regnery, R. L., & Veterinary Monkeypox Virus Working Group. (2004). Monkeypox transmission and pathogenesis in prairie dogs. Emerging Infectious Diseases, 10(3), 426–431.

Gutiérrez, J. M., Williams, D., Fan, H. W., & Warrell, D. A. (2010). Snakebite envenoming from a global perspective: Towards an integrated approach. Toxicon, 56(7), 1223-1235.

Haas, T. C., & Ferreira, S. M. (2016). Combating rhino horn trafficking: the need to disrupt criminal networks. Plos One, 11(11), e0167040.

Hall, R. J., Milner-Gulland, E. J., & Courchamp, F. (2008). Endangering the endangered: the effects of perceived rarity on species exploitation. Conservation Letters, 1, 75–81.

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

Harrison M, Roe D, Baker J, Mwedde G, Travers H, Plumptre A, Rwetsiba A, Milner-Guland EJ. 2015. Wildlife crime: a review of the evidence on drivers and impacts in Uganda. IIED, London.

Harrison, J. R., Roberts, D. L., & Hernandez-Castro, J. (2016). Assessing the extent and nature of wildlife trade on the dark web. Conservation Biology, 30(4), 900-904.

Harvey, R. G., & Mazzotti, F. J. (2019). Conflict and Coexistence with Invasive Wildlife Examining Attitudes and Behaviours towards Burmese Pythons in Florida. In Frank, B., Glickman, J. A, Marchini, S. (Eds.), Human–Wildlife Interactions: Turning Conflict into Coexistence (pp.265-287)
Cambridge: University Printing House.

Hauke, T. J., & Herzig, V. (2021). Love bites–Do venomous arachnids make safe pets?. Toxicon, 190, 65-72.

Herrel, A., & van der Meijden, A. (2014). An analysis of the live reptile and amphibian trade in the USA compared to the global trade in endangered species. The Herpetological Journal, 24(2), 103-110.

Herrera, M., & Hennessey, B. (2007). Quantifying the illegal parrot trade in Santa Cruz de la Sierra, Bolivia, with emphasis on threatened species. Bird Conservation International, 17(4), 295-300.

Hibbin, R. A., Samuel, G., & Derrick, G. E. (2018). From “a fair game” to “a form of covert research”: Research ethics committee members’ differing notions of consent and potential risk to participants within social media research. Journal of Empirical Research on Human Research Ethics, 13(2), 149-159.

Hierink, F., Bolon, I., Durso, A. M., de Castañeda, R. R., Zambrana-Torrelio, C., Eskew, E. A., & Ray, N. (2020). Forty-four years of global trade in CITES-listed snakes: Trends and implications for conservation and public health. Biological Conservation, 248, 108601.

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

Hinsley, A., Verissimo, D., & Roberts, D. L. (2015). Heterogeneity in consumer preferences for orchids in international trade and the potential for the use of market research methods to study demand for wildlife. Biological Conservation, 190, 80–86.

Hong Kong Animal News. 2018. A British researcher points out that Chinese construction projects stimulate illegal wildlife hunt- ing in South America — many jaguars have been killed in re- cent years (in Chinese). Hong Kong Animal News, 5 March. Available at http://www.hkanimalpost.com/2018/03/05/%E8%8B%B1%E7%0%94%E7%A9%B6/ (accessed April 2018).

Hsu, T., Lucas, A., Qiu, Z., Li, M., & Yu, Q. (2014). Exploring the Chinese gem and jewelry industry. Gems & Gemology, 50, 2–29.

Hughes, A. C., Lechner, A. M., Chitov, A., Horstmann, A., Hinsley, A., Tritto, A., Chariton, A., Li, B. V., Ganapin, D., Simonov, E., Morton, K., Toktomushev, K., Foggin, M., Tan-Mullins, M., Orr, M. C., Griffiths, R., Nash, R., Perkin, S., Glémet, R., Kim, M., & Douglas, W. Y. (2020). Horizon scan of the Belt and Road Initiative. Trends in Ecology & Evolution, 35(7), 583-593.

Hureau, D. M. & Braga, A. A. (2018). The trade in tools: The market for illicit guns in high-risk networks. Criminology 56(3): 510-545.

Hutton, J., & Webb, G. (2003). 'Crocodiles: legal trade snaps back', *The trade in wildlife: Regulation for conservation,* 108, pp. 114.

IUCN (International Union for Conservation of Nature). 2019. The IUCN Red List of threatened species. Version 2019-1. IUCN, Gland, Switzerland. Available at https://www.iucnredlist.org (accessed May 2019).

Jepson, P., Ladle, R. J., & Sujatnika, U. (2011). Assessing market-based conservation governance approaches: a socio-economic profile of Indonesian markets for wild birds. Oryx, 45(4), 482-491.

Johnson, C. K., Hitchens, P. L., Pandit, P. S., Rushmore, J., Evans, T. S., Young, C. C. W., & Doyle, M. M. (2020). Global shifts in mammalian population trends reveal key predictors of virus spillover risk. Proceedings of the Royal Society B: Biological Sciences, 287(1924), 20192736.

Joossens, L., & Raw, M. (2012). From cigarette smuggling to illicit tobacco trade. Tobacco Control, 21(2), 230-234.

Karesh, W. B., Cook, R. A., Bennett, E. L., & Newcomb, J. (2005). Wildlife trade and global disease emergence. Emerging Infectious Diseases, 11(7), 1000-1002.

Kasturiratne, A., Wickremasinghe, A. R., de Silva, N., Gunawardena, N. K., Pathmeswaran, A., Premaratna, R., Savioli, L., Lalloo, D.G., & de Silva, H. J. (2008). The global burden of snakebite: a literature analysis and modelling based on regional estimates of envenoming and deaths. PLoS Medicine, 5(11), e218.

Kelly, J. R. (2018). Insights into the illegal trade of feline derivatives in Costa Rica. Global Ecology and Conservation, 13, e00381.

Kernam, I. (2010). Exploitation of the jaguar, Panthera onca and other large forest cats in Suriname. WWF Guianas species conservation. World Wildlife Fund for Nature, Paramaribo.

Kideghesho, J. R. (2016). Reversing the trend of wildlife crime in Tanzania: challenges and opportunities. Biodiversity and Conservation, 25(3), 427-449.

Kim, H. J., Lee, H., & Hong, H. (2020). Scale development and validation for psychological reactance to health promotion messages. Sustainability, 12(14), 5816.

Kirk, C. P., & Rifkin, L. S. (2020). I'll trade you diamonds for toilet paper: Consumer reacting, coping and adapting behaviors in the COVID-19 pandemic. Journal of Business Research, 117, 124-131.

Kirkpatrick, R. C., & Emerton, L. (2010). Killing tigers to save them: fallacies of the farming argument. Conservation Biology, 24, 655–659.

Kretser, H. E., Nuñez-Salas, M., Polisar, J. & Maffei, L. (2022). A range-wide analysis of legal instruments applicable to jaguar conservation. *Journal of International Wildlife Law and Policy*, in press.

Kuhnen, V., & Kanaan, V. (2014). Wildlife trade in Brazil: A closer look at wild pets welfare issues. Brazilian Journal of Biology, 74(1), 124-127.

Kuiken, T., Fouchier, R., Rimmelzwaan, G., van den Brand, J., van Riel, D. and Osterhaus, A., 2012. Pigs, poultry, and pandemic influenza: how zoonotic pathogens threaten human health. In *Hot Topics in Infection and Immunity in Children VIII* (pp. 59-66). Springer, New York, NY.

Kulkarni, R., & Di Minin, E. (2021). Automated retrieval of information on threatened species from online sources using machine learning. Methods in Ecology and Evolution, DOI: 10.1111/2041-210X.13608.

Kusrini, M., Palesa, S. P., & Masy'ud, B. (2021). Snake pet ownership in the city: A case study in Greater Jakarta, Indonesia. Biodiversitas Journal of Biological Diversity, 22(4).

Kwok, K. O., Li, K. K., Chan, H. H. H., Yi, Y. Y., Tang, A., Wei, W. I., & Wong, S. Y. S. (2020). Community Responses during Early Phase of COVID-19 Epidemic, Hong Kong. Emerging Infectious Diseases, 26(7), 1575-1579.

Lankau, E. W., Sinclair, J. R., Schroeder, B. A., Galland, G. G., & Marano, N. (2017). Public Health Implications of Changing Rodent Importation Patterns–United States, 1999–2013. Transboundary and Emerging Diseases, 64(2), 528-537.

Lavorgna, A. (2015). The social organization of pet trafficking in cyberspace. European Journal on Criminal Policy and Research, 21(3), 353-370.

Leberatto, A. C. (2016). Understanding the illegal trade of live wildlife species in Peru. Trends in Organized Crime, 19(1), 42-66.

Leroy, E. M., Rouquet, P., Formenty, P., Souquière, S., Kilbourne, A., Froment, J. M., Bermejo, M., Smit, S., Karesh, W., Swanepoel, R., Zaki, S. R., & Rollin, P. E. (2004). Multiple Ebola virus transmission events and rapid decline of central African wildlife. Science, 303(5656), 387-390.

Lima, B. S., Souza, M. M., Souto, N. L., & Barros, A. B. (2018). Investigando o conhecimento etnoherpetológico dos cafeicultores sobre as serpentes do município de Inconfidentes, Minas Gerais, Brasil. Brazilian Journal of Ethnobiology and Ethnoecology, 2.

Linkie, M., Martyr, D., Harihar, A., Mardiah, S., Hodgetts, T., Risdianto, D., Subchaan, M., & Macdonald, D. (2018). Asia's economic growth and its impact on Indonesia's tigers. Biological Conservation, 219, 105-109.

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

Loginov, O., & Loginova, I. (2017). Reverse side of Chinese medicine. International Journal of Environmental Studies, 74, 915–919.

Lopez, C. E., Vasu, M., & Gallemore, C. (2020). Understanding the perception of COVID-19 policies by mining a multilanguage Twitter dataset. arXiv preprint, DOI: arXiv:2003.10359.

Lucas, A., Kumakamba, C., Lange, C. E., Obel, E., Miningue, G., Likofata, J., Gillis, A., LeBreton, M., McIver, D. J., Euren, J., Johnson, C. K., Goldstein, T., Muyembe-Tamfum, J. J., & Saylors, K. (2020). Serology and behavioral perspectives on Ebola Virus Disease among bushmeat vendors in Equateur, Democratic Republic of the Congo, after the 2018 Outbreak. Open Forum Infectious Diseases, 7(8), ofaa295.

Lunstrum, E., & Givá, N. (2020). What drives commercial poaching? From poverty to economic inequality. Biological Conservation, 245, 108505.

Lyons, J. A. and Natusch, D. J. D. (2011). Wildlife laundering through breeding farms: Illegal harvest, population declines and a means of regulating the trade of green pythons (*Morelia viridis*) from Indonesia, Biological Conservation, 144(12), pp. 3073-3081.

MacMillan, D. C., & Nguyen, Q. A. (2014). Factors influencing the illegal harvest of wildlife by trapping and snaring among the Katu ethnic group in Vietnam. Oryx, 48(2), 304-312.

Magalhães, A. L. B., & São-Pedro, V. A. (2012). Illegal trade on non-native amphibians and reptiles in southeast Brazil: the status of e-commerce. Phyllomedusa: Journal of Herpetology, 11(2), 155-160.

Maldonado A. M., Nijman V., Bearder S. K. (2009). Trade in night monkeys Aotus spp. in the Brazil-Colombia-Peru tri-border area: international wildlife trade regulations are ineffectively enforced. Endangered Species Research 9: 143–149.

Marques, M. F. S. Ribeiro, L.P.S. Pessoa, T.S.A. Neco, E.C., Abreu, D.B.O. & Wagner, P.G.C. (2012). Mastofauna nativa conduzida ao Centro de Triagem de Animais Silvestres da Paraíba. Revista de Biologia e Farmácia, 8(2), 1.

Marques, O.A.V., Martins, M. & Sazima, I. (2004). *Bothrops alcatraz*. The IUCN Red List of Threatened Species 2004:e.T46344A11050246.

Martins, M., Sawaya, R. J., & Marques, O. A. (2008). A first estimate of the population size of the critically endangered lancehead, *Bothrops insularis*. South American Journal of Herpetology, 3(2), 168-174.

Mayor, P., El Bizri, H. R., Morcatty, T. Q., Moya, K., Solis, S., & Bodmer, R. E. (2019). Assessing the minimum sampling effort required to reliably monitor wild meat trade in urban markets. Frontiers in Ecology and Evolution, 7, 180.

McEvoy, J. F., Connette, G., Huang, Q., Soe, P., Pyone, K. H. H., Valitutto, M., Htun, Y. L., Lin, A. N., Thant, A. L., Htun, W. Y., Paing, K. H., Swe, K. K., Aung, M., Min, S., Songer, M., & Leimgruber, P. (2019). Two sides of the same coin–Wildmeat consumption and illegal wildlife trade at the crossroads of Asia. Biological Conservation, 238, 108-197.

McFadden, M. S., Topham, P., & Harlow, P. S. (2017). A ticking time bomb: is the illegal pet trade a pathway for the establishment of corn snake (*Elaphe guttata*) populations in Australia? Australian Zoologist, 38(4), 499-504.

McKie, R. (2018). Jaguars killed for fangs to supply growing Chinese medicine trade. The Guardian, 4 March. Available at https://www.theguardian.com/environment/2018/mar/04/jaguars- killed-for-fangs-chinese-medicine-trade (accessed April 2018).

McMillan, S. E., Dingle, C., Allcock, J. A., & Bonebrake, T. C. (2021). Exotic animal cafes are increasingly home to threatened biodiversity. Conservation Letters, 14(1), e12760.

Melgarejo, A. R. (2009). Serpentes Peçonhentas do Brasil. In J. L. C. Cardoso, F. O. S. França, F. W. Wen, C. M. S. Malaque, V. H. Jr. (Eds.), Animais

peçonhentos no Brasil. Biologia, clínica e terapêutica dos acidentes (pp. 42-70). São Paulo: Sarvier.

Mikhailitchenko, A., Javalgi, R. R. G., Mikhailitchenko, G., & Laroche, M. (2009). Cross-cultural advertising communication: visual imagery, brand familiarity, and brand recall. Journal of Business Research, 62(10), 931-938.

Ministério da Saúde do Brasil. 2006. Sistema de informação de agravos de notificação – SINAN: Normas e Rotinas. Série A. Normas e Manuais Técnicos. Ministério da Saúde, Secretaria de Vigilância em Saúde, Departamento de Vigilância Epidemiológica. Brasília, Editora do Ministério da Saúde, 80 pp.

Miniwatts Marketing Group. 2020. Internet world stats: usage and population statistics. Available at: http://www.internetworldstats.com/stats.htm.

Miszczyk, M., Płonka, M., Stobiecki, T., Kronenbach-Dylong, D., Waleczek, K., & Weber, R. (2018). Official control of plant protection products in Poland: Detection of illegal products. Environmental Science and Pollution Research, 25(32), 31906-31916.

Mittermeier, R. A., Robles Gil, P., & Mittermeier, C. G. (1997). Megadiversity: Earth's biologically wealthiest nations. CEMEX, Mexico City, Mexico.

Mittermeier, R. A., Wilson, D. E. and Rylands, A. B. (2013) *Handbook of the mammals of the world: primates.* Lynx Edicions.

Moorhouse, T. P., Balaskas, M., D'Cruze, N. C., & Macdonald, D. W. (2017). Information could reduce consumer demand for exotic pets. *Conservation Letters*, *10*(3), 337-345.

Moorhouse, T. P., D'Cruze, N. C., & Macdonald, D. W. (2021). Information about zoonotic disease risks reduces desire to own exotic pets among global consumers. Frontiers in Ecology and Evolution, *9*, 37.

Morens, D. M., Daszak, P., Taubenberger, J. K. (2020). Escaping Pandora's box – another novel coronavirus. New England Journal of Medicine, 382(14), 1293-1295.

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

Mota, E. L. S., da Nóbrega Alves, R. R., & Dias, T. L. P. (2020). Fishing, trade, and local ecological knowledge of the marine gastropod, Cassis tuberosa–a target species of the international shell trade. Ethnobiology and Conservation, 9.

Moura, M. R. D., Costa, H. C., São-Pedro, V. D. A., Fernandes, V. D., & Feio, R. N. (2010). O relacionamento entre pessoas e serpentes no leste de Minas Gerais, sudeste do Brasil. Biota Neotropica, 10(4), 133-141.

Moyle, B. (2009). The black market in China for tiger products. Global Crime, 10, 124–143.

Mufunda, J., Ndambakuwa, Y., Munodawafa, D., & Kobie, A. (2016). Is a total ban on business and consumption of bushmeat a sustainable end game for Ebola outbreak in West Africa: but why now? Public Health Open Journal, 1, 4-7.

Musing, L., Suzuki, K., & Nekaris, K. A. I. (2015). Crossing international borders: the trade of slow lorises, *Nycticebus* spp., as pets in Japan. Asian Primates Journal, 5(1), 12-24.

Nascimento, C. A. R., Czaban, R. E., & Alves, R. R. N. (2015). Trends in illegal trade of wild birds in Amazonas state, Brazil. Tropical Conservation Science, 8(4), 1098-1113.

Nekaris, K. A. I., Campbell, N., Coggins, T. G., Rode, E. J., & Nijman, V. (2013). Tickled to death: analysing public perceptions of ‘cute’ videos of threatened species (slow lorises – *Nycticebus* spp.) on Web 2.0 Sites. PlosOne, 8(7), e69215.

Nekaris, K. A. I., Shepherd, C. R., Starr, C. R., & Nijman, V. (2010). Exploring cultural drivers for wildlife trade via an ethnoprimatological approach: a case study of slender and slow lorises (*Loris* and *Nycticebus*) in South and Southeast Asia. American Journal of Primatology, 72(10), 877-886.

Nguyen, M., & Willemsen, M. (2016). A rapid assessment of e-commerce wildlife trade in Viet Nam. TRAFFIC Bulletin, 28(2), 53-55.

Ni, Q., Wang, Y., Weldon, A., Xie, M., Xu, H., Yao, Y., Zhang, M., Li, Y., Li, Y., Zeng, B., & Nekaris, K. A. I. (2018). Conservation implications of primate trade

in China over 18 years based on web news reports of confiscations. PeerJ, 6, e6069.

Nijman, V. (2010). An overview of international wildlife trade from Southeast Asia. Biodiversity and Conservation, 19(4), 1101-1114.

Nijman, V. (2021a). Illegal and legal wildlife trade spreads zoonotic diseases. Trends in Parasitology 37: 359-360.

Nijman, V. (2021b). Zoos consenting to the illegal wildlife trade–the earless monitor lizard as a case study. Nature Conservation, 44, 69.

Nijman, V., & Lee, P. B. (2016). Trade in nautilus and other large marine molluscs as ornaments and decorations in Bali, Indonesia. Raffles Bulletin of Zoology, 64, 368-373.

Nijman, V., & Nekaris, K. A. I. (2017). The Harry Potter effect: The rise in trade of owls as pets in Java and Bali, Indonesia. Global Ecology and Conservation, 11, 84-94.

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

Nijman, V., & Shepherd, C. R. (2015). Trade in tigers and other wild cats in Mong La and Tachilek, Myanmar–a tale of two border towns. Biological Conservation, 182, 1–7.

Nijman, V., Morcatty, T., Smith, J. H., Atoussi, S., Shepherd, C. R., Siriwat, P., Nekaris, K. A. I., & Bergin, D. (2019). Illegal wildlife trade—surveying open animal markets and online platforms to understand the poaching of wild cats. Biodiversity, 20, 58–61.

Nijman, V., Morcatty, T., Smith, J. H., Atoussi, S., Shepherd, C. R., Siriwat, P., Nekaris, K. A. I., & Bergin, D. (2019). Illegal wildlife trade – surveying open animal markets and online platforms to understand the poaching of wild cats. Biodiversity, 20(1), 58-61.

Nijman, V., & Shepherd, C. R. (2009). Wildlife trade from ASEAN to the EU: Issues with the trade in captive-bred reptiles from Indonesia. TRAFFIC, Cambridge.

Nowell, K. (2000). Far from a cure: the tiger trade revisited. TRAFFIC International, Cambridge, United Kingdom.

Nuñez, A., & Aliaga-Rossel, E. (2017). Jaguar fangs trafficking by Chinese in Bolivia. CAT News, 65, 50–51.

Oksanen, J., Blanchet, F. G., Kindt, R., Legendre, P., Minchin, P. R., O'hara, R. B., & Oksanen, M. J. (2013). Package 'vegan'. Community ecology package, version, 2(9), 1-295.

Oliveira, E. S., Freitas Torres, D., & Alves, R. R. N. (2020). Wild animals seized in a state in Northeast Brazil: Where do they come from and where do they go? Environment, Development and Sustainability, 22(3), 2343-2363.

Oliveira, L. C., & Grelle, C. E. V. (2012). Introduced primate species of an Atlantic Forest region in Brazil: present and future implications for the native fauna. Tropical Conservation Science, 5(1), 112-120.

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

Ordaz-Németh, I., Arandjelovic, M., Boesch, L., Gatiso, T., Grimes, T., Kuehl, H., Lormie, M., Stephens, C., Tweh, C. & Junker, J. (2017). The socio-economic drivers of bushmeat consumption during the West African Ebola crisis. PLoS Neglected Tropical Diseases, 11 (3), e0005450.

Pagano, I. S., de Sousa, A. E. A. B., Wagner, P. G. C., & da Costa Ramos, R. T. (2010). Aves depositadas no Centro de Triagem de Animais Silvestres do IBAMA na Paraíba: uma amostra do tráfico de aves silvestres no estado. Ornithologia, 3(2), 132-144.

Pappas, G., (2013). Socio-economic, industrial and cultural parameters of pig-borne infections. Clinical Microbiology and Infection, 19(7), 605-610.

Parrish, C. R., Holmes, E. C., Morens, D. M., Park, E. C., Burke, D. S., Calisher, C. H., Laughlin, C. A., Saif, L. J., & Daszak, P. (2008). Cross-species virus transmission and the emergence of new epidemic diseases. Microbiology and Molecular Biology Reviews, 72(3), 457-470.

Parry, N. (2020). COVID-19 and pets: When pandemic meets panic. Forensic Science International: Reports, 2, 100090.

Passas, N. (2003) Cross-border crime and the interface between legal and illegal actors. Security Journal 16(1): 19-37.

Paviolo, A., De Angelo, C., Ferraz, K. M., Morato, R. G., Pardo, J. M., Srbek-Araujo, A. C., Beisiegel, B. M., Lima, F., Sana, D., da Silva, M. X., Velázquez, M. C., Cullen, L., Crawshaw Jr, P., Jorge, M. L. S. P., Galetti, P. M., Di Bitetti, M. S., de Paula, R. C., Eizirik, E., Aide, T. M., Cruz, P., Perilli, M. L. L., Souza, A. S. M. C., Quiroga, V., Nakano, E., Pinto, F. R., Fernández, S., Costa, S., Moraes Jr, E. A., & Azevedo, F. (2016). A biodiversity hotspot losing its top predator: the challenge of jaguar conservation in the Atlantic Forest of South America. Scientific Reports, 6, 37147.

Pearson, R. M., Sievers, M., McClure, E. C., Turschwell, M. P., & Connolly, R. M. (2020). COVID-19 recovery can benefit biodiversity. Science, 368(6493), 838-839.

Phelps, J., Biggs, D., & Webb, E. L. (2016). Tools and terms for understanding illegal wildlife trade. Frontiers in Ecology and the Environment, 14(9), 479.

Phelps, J., Carrasco, L. R., & Webb, E. L. (2014). A framework for assessing supply-side wildlife conservation. Conservation Biology, 28, 244–257.

Phelps, J., Webb, E. L., Bickford, D., Nijman, V., & Sodhi, N. S. (2010). Boosting CITES. Science, 330(6012), 1752-1753.

Pires, S. F. (2012). The illegal parrot trade: a literature review. Global Crime, 13(3), 176-190.

Pires, S. F., & Clarke, R. V. (2011). Sequential Foraging, Itinerant Fences and Parrot Poaching in Bolivia. British Journal of Criminology, 51(2), 314–335.

Pires, Stephen F., Schneider, J. L., & Herrera, M. (2016). Organized crime or crime that is organized? The parrot trade in the neotropics. Trends in Organized Crime, 19(1), 4–20.

Polisar, J., Davies, C., Morcatty, TQ., Silva, M., Zhang, S., Duchez, K.., Madrid, J., Lambert, A.E., Gallegos, A., Delgado, M., Nguyen, H., Wallace, R.,

Arias, M., Nijman, V., Ramnarace, J., Pennell, R., Novelo, Y., Rumiz, D., Rivero, K., Murillo, Y., Nunez, M., Kretser, H.E., & Reuter, A. In review. Multi-lingual multi-platform investigations of online trade in jaguar parts. PlosOne (under review).

Poston Jr, D. L., & Wong, J. H. (2016). The Chinese diaspora: the current distribution of the overseas Chinese population. Chinese Journal of Sociology, 2, 348–373.

Quevans, N., Falcón, N., & Elías, R. (2013). Fauna silvestre y productos derivados decomisados durante el período 2000-2007, Lima–Perú. Salud y Tecnología Veterinaria, 1, 14-18.

Raab, J., & Milward, H. B. (2003). Dark networks as problems. Journal of Public Administration Research and Theory, 13, 413–439.

Rassy, D., & Smith, R. D. (2013). The economic impact of H1N1 on Mexico's tourist and pork sectors. Health Economics, 22(7), 824-834.

Raven, P. H., Gereau, R. E., Phillipson, P. B., Chatelain, C., Jenkins, C. N., & Ulloa, C. U. (2020). The distribution of biodiversity richness in the tropics. Science Advances, 6(37), eabc6228.

Redford KH, Robinson JG (1991) Subsistence and commercial uses of wildlife in Latin America. In: Robinson JG, Redford KH (eds) Neotropical wildlife use and conservation. University of Chicago, Chicago, pp 6–23

Reed, K. D., Melski, J. W., Graham, M. B., Regnery, R. L., Sotir, M. J., Wegner, M. V., Kazmierczak, J. J., Stratman, E. J., Li, Y., Fairley, J. A., Swain, G. R., Olson, V. A., Sargent, E. K., Kehl, S. C., Frace, M. A., Kline, R., Foldy, S. L., Davis, J. P., & Damon, I. K. (2004). The detection of monkeypox in humans in the Western Hemisphere. New England Journal of Medicine, 350(4), 342-350.

Reeve, R. (2002). Policing international trade in endangered species: the CITES treaty and compliance. London, UK: The Royal Institute of International Affairs and Earthscan Publications Ltd.

Regueira, R. F. S., & Bernard, E. (2012). Wildlife sinks: Quantifying the impact of illegal bird trade in street markets in Brazil. Biological Conservation, 149(1), 16-22.

RENCTAS. (2001). 1º Relatório nacional sobre o tráfico da fauna silvestre. Brasília: Rede Nacional Contra o Tráfico de Animais Silvestres, 108 p.

Reuter, A., Maffei, L., Polisar, J., & Radachowsky, J. (2018). Jaguar hunting and trafficking in Mesoamerica, recent observations. WCS, New York.

Reuter, P., & O'Regan, D. (2017). Smuggling wildlife in the Americas: scale methods and links to other organised crimes. Global Crime, 18(2), 77-99.

Robinson, J. E., Griffiths, R. A., St. John, F. A. V., & Roberts, D. L. (2015). Dynamics of the global trade in live reptiles: Shifting trends in production and consequences for sustainability. Biological Conservation, 184, 42-50.

Roe, D. (2008). Trading Nature. A report, with case studies, on the contribution of wildlife trade management to sustainable livelihoods and the Millennium Development Goals. TRAFFIC International and WWF International, Bonn, 86 p. Available at https://www.traffic.org/publications/reports/trading-nature-the-contribution-of-wildlife-trade-management-to-sustainable-livelihoods-and-the-millennium-development-goals/ (accessed June 2021).

Roe, D., Dickman, A., Kock, R., Milner-Gulland, E. J., Rihoy, E., & t'Sas-Rolfes, M. (2020). Beyond banning wildlife trade: COVID-19, conservation and development. World Development, 136, 105-121.

Roldán-Clarà, B., Lopez-Medellín, X., Espejel, I., & Arellano, E. (2014). Literature review of the use of birds as pets in Latin-America, with a detailed perspective on Mexico. Ethnobiology and Conservation, 3.

Rosen, G. E., & Smith, K. F. (2010). Summarizing the evidence on the international trade in illegal wildlife. EcoHealth, 7(1), 24-32.

Saif, S., Russell, A. M., Nodie, S. I., Inskip, C., Lahann, P., Barlow, A., Greenwood Barlow, C., Islam, M. A., & MacMillan, D. C. (2016). Local usage of tiger parts and its role in tiger killing in the Bangladesh Sundarbans. Human Dimensions of Wildlife, 21, 95–110.

Sánchez-Mercado, A., Asmüssen, M., Rodríguez, J. P., Moran, L., Cardozo-Urdaneta, A., & Morales, L. I. (2020). Illegal trade of the Psittacidae in Venezuela. Oryx, 54(1), 77-83.

Schaper, A., Desel, H., Ebbecke, M., de Haro, L., Deters, M., Hentschel, H., Hermanns-Clausen, M., & Langer, C. (2009). Bites and stings by exotic pets in Europe: An 11 year analysis of 404 cases from Northeastern Germany and Southeastern France. Clinical Toxicology, 47(1), 39-43.

Scheffers, B. R., Oliveira, B. F., Lamb, I., & Edwards, D. P. (2019). Global wildlife trade across the tree of life. Science, 366(6461), 71-76.

Schloenhardt, A., & Ege, G. (2021). Wildlife Trafficking: Criminological, International and Criminal Law Perspectives. In: Grafl, C., Stempkowksi, M., Beclin, K., Haider, I (Eds.). "Sag, wie hast du's mit der Kriminologie?" – Die Kriminologie im Gespräch mit ihren Nachbardisziplinen, Forum Verlag Godesberg, Germany.

Shanee, N. (2012). Trends in local wildlife hunting, trade and control in the tropical Andes biodiversity hotspot, northeastern Peru. Endangered Species Research, 19, 177–186.

Shanee, N., Mendoza, A. P., & Shanee, S. (2017). Diagnostic overview of the illegal trade in primates and law enforcement in Peru. American Journal of Primatology, 79(11), e22516.

Shepherd, C. R., Leupen, B. T., Siriwat, P., & Nijman, V. (2020). International wildlife trade, avian influenza, organised crime and the effectiveness of CITES: The Chinese hwamei as a case study. Global Ecology and Conservation, 23, e01185.

Siers, S. R., Savidge, J. A., & Reed, R. N. (2017). Ontogenetic and ecological variation in invasion risk of Brown Treesnakes (*Boiga irregularis*) on Guam. Management of Biological Invasions, 8(4), 469–483.

Silva, A. M., Bernarde, P. S., & de Abreu, L. C. (2015). Accidents with poisonous animals in Brazil by age and sex. Journal of Human Growth and Development, 25(1), 54-62.

Silva, E. M., & Bernard, E. (2016). Inefficiency in the fight against wildlife crime in Brazil. Oryx, 50(3), 468-473.

Silva, J. L., Fonseca, W. L., Silva, A. M., Amaral, G. L. G., Ortega, G. P., de Souza Oliveira, A., Correa, R. R., Oliveira, I., Monteiro, W. M., & Bernarde, P. S.

(2020). Venomous snakes and people in a floodplain forest in the Western Brazilian Amazon: Potential risks for snakebites. Toxicon, 187, 232-244.

Siriwat, P., & Nijman, V. (2018a) Using online media-sourced seizure data to assess the illegal wildlife trade in Siamese rosewood. Environmental Conservation, 45(4), 352-360.

Siriwat, P., & Nijman, V. (2018b). Illegal pet trade on social media as an emerging impediment to the conservation of Asian otters species. Journal of Asia-Pacific Biodiversity, 11(4), 469-475.

Siriwat, P., & Nijman, V. (2020). Wildlife trade shifts from brick-and-mortar markets to virtual marketplaces: A case study of birds of prey trade in Thailand. Journal of Asia-Pacific Biodiversity, 13(3), 454-46.

Siriwat, P., Nekaris, K. A. I., & Nijman, V. (2019). The role of the anthropogenic Allee effect in the exotic pet trade on Facebook™ in Thailand. Journal for Nature Conservation, 51, 125726.

Skinner, G. W. (2017). Change and persistence in Chinese culture overseas: a comparison of Thailand and Java. Pages 53–67 in Reid A, editor. The Chinese diaspora in the Pacific. Routledge, London.

Smith, K. F., Behrens, M., Schloegel, L. M., Marano, N., Burgiel, S., & Daszak, P. (2009). Reducing the risks of the wildlife trade. Science, 324(5927), 594-595.

Soulsbury, C. D., Iossa, G., Kennell, S., & Harris, S. (2009). The Welfare and Suitability of Primates Kept as Pets. Journal of Applied Animal Welfare Science, 12(1), 1-20.

Souviron-Priego, L., Muñoz, A. R., Olivero, J., Vargas, J. M., Fa, J. E. (2018). The legal international wildlife trade favours invasive species establishment: the monk and ring-necked parakeets in Spain. Ardeola, 65(2), 233-246.

Souza, V. L., Santos, T. M., Peña, A. P., Luz, V. L. F., & Reis, I. J. (2007). Caracterização dos répteis descartados por mantenedores particulares e entregues ao centro de conservação e manejo de répteis e anfíbios–RAN. Revista de Biologia Neotropical/Journal of Neotropical Biology, 4(2), 149-160.

Stasinopoulos, D. M, & Rigby, R. A. (2007). Generalized additive models for location, scale and shape (GAMLSS) in R. Journal of Statistical Software, 23, 1–46.

Stoner, S. (2014). Tigers: exploring the threat from illegal online trade. TRAFFIC Bulletin, 26(1), 26-30.

Stringham, O. C., Toomes, A., Kanishka, A. M., Mitchell, L., Heinrich, S., Ross, J. V., & Cassey, P. (2020). A guide to using the Internet to monitor and quantify the wildlife trade. Conservation Biology, DOI: 10.1111/cobi.13675.

Strutton, D., S. J. Vittel and L. E. Pelton: 1994, 'How Consumers may Justify Inappropriate Behavior in Market Settings: An Application on the Techniques of Neutralization', Journal of Business Research 30(3), 254– 260.

Sung, Y. H. & Fong, J. (2018). Assessing consumer trends and illegal activity by monitoring the online wildlife trade. Biological Conservatio, 227, 219-225.

Suriname Mirror. 2018. China's vraag naar jaguar hoektanden bedreigt deze beschermde diersoort in Latijns-Amerika. Suriname Mirror. Feb 28. Available at http://jaguar-in-suriname.blogspot.com/2018/02/chinas-vraag-naar-jaguar-hoektanden.html (acessed March 2018).

Sutherland, W. J., Adams, W. M., Aronson, R. B., Aveling, R., Blackburn, T. M., Broad, S., Ceballos, G., Côté, I. M., Cowling, R. M., Da Fonseca, G. A. B., Dinerstein, E., Ferraro, P. J., Fleishman, E., Gascon, C., Hunter Jr., M., Hutton, J., Kareiva, P., Kuria, A., Macdonald, D. W., Mackinnon, K., Madgwick, F. J., Mascia, M. B., McNeely, J., Milner-Gulland, E. J., Moon, S., Morley, C. G., Nelson, S., Osborn, D., Pai, M., Parsons, E. C. M., Peck, L. S., Possingham, H., Prior, S. V., Pullin, A. S., Rands, M. R. W., Ranganathan, J., Redford, K. H, Rodriguez, J. P., Seymour, F., Sobel, J., Sodhi, N. S., Stott, A., Vance-Borland, K., & Watkinson, A. R. . (2009). One hundred questions of importance to the conservation of global biological diversity. Conservation Biology, 23(3), 557-567.

Symes, W. S., McGrath, F. L., Rao, M., & Carrasco, L. R. (2018). The gravity of wildlife trade. Biological Conservation, 218, 268-276.

‘t Sas-Rolfes, M. T., Moyle, B. J., & Stiles, D. (2014). The complex policy issue of elephant ivory stockpile management. Pachyderm, 55, 62-77.

‘t Sas-Rolfes, M., Challender, D. W., Hinsley, A., Veríssimo, D., & Milner-Gulland, E. J. (2019). Illegal wildlife trade: Scale, processes, and governance. Annual Review of Environment and Resources, 44, 201-228.

Taha, F. A. (2007). How highly pathogenic avian influenza (H5N1) has affected world poultry-meat trade. *AgEcon Search,* LDP-M-159-02. doi:

Taipei Times. 2018. Jaguars killed for fangs to supply China. Taipei Times. Mar 5. Available at: http://www.taipeitimes.com/News/world/archives/2018/03/05/2003688718 (accessed March 2018).

Tapley, B., Griffiths, R. A., & Bride, I. (2011). Dynamics of the trade in reptiles and amphibians within the United Kingdom over a ten-year period. The Herpetological Journal, 21(1), 27-34.

Tappe, D., & Büttner, D. W. (2009). Diagnosis of human visceral pentastomiasis. PLoS Neglected Tropical Disesases, 3(2), e320.

Tella, J. L., & Hiraldo, F. (2014). Illegal and legal parrot trade shows a long-term, cross-cultural preference for the most attractive species increasing their risk of extinction. PLoS One, 9(9), e107546.

Tensen, L. (2016). Under what circumstances can wildlife farming benefit species conservation? Global Ecology and Conservation, 6, 286-298.

Thomas-Walters, L., Veríssimo, D., Gadsby, E., Roberts, D. & Smith, R.J. (2020). Taking a more nuanced look at behavior change for demand reduction in the illegal wildlife trade. Conservation Science and Practice, 2(9), e248.

Thumsová, B., González-Miras, E., Faulkner, S. C., & Bosch, J. (2021). Rapid spread of a virulent amphibian pathogen in nature. Biological Invasions, DOI: 10.1007/s10530-021-02571-y.

Thung, P. H. (2020). Why education about zoonotic diseases is not reducing hunting, a view from rural Borneo, POKOK: Using anthropology to mitigate orangutan killing and human-orangutan conflict in Borneo. Available at: https://pokokborneo.wordpress.com/blog/

Titeca, K. (2019). Illegal ivory trade as transnational organized crime? An empirical study into ivory traders in Uganda. The British Journal of Criminology, 59(1), 24-44.

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

Toivonen, T., Heikinheimo, V., Fink, C., Hausmann, A., Hiippala, T., Järv, O., Tenkanen, H., & Di Minin, E. (2019). Social media data for conservation science: A methodological overview. Biological Conservation, 233, 298–315.

Toland, E., Warwick, C., & Arena, P. C. (2012). Pet hate: Exotic pet-keeping is on the rise despite decades of initiatives aimed at reducing the trade of exotic and rare animals. Three experts argue that urgent action is needed to protect both animals and ecosystems. Biologist, 59(3), 14-18

Toomes, A., Stringham, O. C., Mitchell, L., Ross, J. V., & Cassey, P. (2020). Australia's wish list of exotic pets: biosecurity and conservation implications of desired alien and illegal pet species. NeoBiota, 60, 43. doi:

TRAFFIC. (2020). Viet Nam issues ban on wildlife imports & announces closure of illegal wildlife markets. Retrieved from https://www.traffic.org/news/viet-nam-issues-ban- on-wildlife-imports-announces-closure-of-illegal-wildlife-markets/

TRAFFIC, WWF and IFAW. (2020). Offline and in the Wild: A Progress Report of the Coalition to End Wildlife Trafficking Online. Washington, DC. Available at: https://www.worldwildlife.org/pages/coalition-to-end-wildlife-trafficking-online

Transparency International. (2018). Corruption perception index 2018. Transparency International, Berlin. Available at https://www.transparency.org/cpi2018 (accessed April 2019).

Twinamatsiko, et al. (2014). Linking conservation, equity and poverty alleviation: understanding profiles and motivations of resource users and local perceptions of governance at Bwindi Impenetrable National Park, Uganda. IIED Research Report, London.

UNDP Panthera CI WCS and WWF (2018) *Jaguar 2030 High Level Forum Summary Report*. New York: United Nations.

UNEP-WCMC (2019) CITES trade statistics derived from the CITES Trade Database UNEP World Conservation Monitoring Centre, Cambridge.

UNODC Commission on Crime Prevention and Criminal Justice. (2002). Progress made in the implementation of Economic and Social Council resolution 2001/12 on illicit trafficking in protected species of wild flora and fauna. United Nations Economic and Social Council Vienna. Available at https://www.unodc.org/documents/commissions/CCPCJ/CCPCJ_Sessions/CCPCJ_11/E-CN15-2002-07/E-CN15-2002-7_E.pdf (accessed 10 May 2021)

UNODC, 2020. World Wildlife Crime Report, 2020. Trafficking in Protected Species. https://www.unodc.org/documents/data-and-analysis/wildlife/2020/World_Wildlife_Report_2020_9July.pdf (accessed 10 May 2021)

Valença-Montenegro, M.M., Bezerra, B.M., Ruiz-Miranda, C.R., Pereira, D.G., Miranda, J.M.D., Bicca-Marques, J.C., Oliveira, L., da Cruz, M.A.O.M., Valle, R.R. & Mittermeier, R.A. 2021. *Callithrix jacchus* (amended version of 2018 assessment). The IUCN Red List of Threatened Species 2021: e.T41518A191705043.

Valenta, J., Stach, Z., & Michalek, P. (2014). Exotic snake bites in the Czech Republic—Epidemiological and clinical aspects during 15-year period (1999–2013). Clinical Toxicology, 52(4), 258-264.

Valle, R.R., Ruiz-Miranda, C.R., Pereira, D.G., Rímoli, J., Bicca-Marques, J.C., Jerusalinsky, L., Valença-Montenegro, M.M. & Mittermeier, R.A. 2021. *Callithrix penicillata* (amended version of 2018 assessment). The IUCN Red List of Threatened Species 2021: e.T41519A191705321.

Van Ooyen-Houben, M., Bieleman, B., & Korf, D. J. (2014). Coffeeshops, toeristen en lokale markt: evaluatie van het Besloten club-en Ingezetenencriterium voor coffeeshops. Cahier WODC, (2014-12).

van Uhm, D. (2016): Illegal Wildlife Trade to the EU and Harms to the World. In: Spapens, T./White, R./Huisman, W. (eds): Environmental Crime in

Transnational Context: Global Issues in Green Enforcement and Criminology. London: Routledge, pp. 43–66.

Van Uhm, D. P. (2016). The Illegal Wildlife Trade: Inside the World of Poachers, Smugglers and Traders. Vol. 15, Springer.

van Vliet, N., Mesa, M. P. Q., Cruz-Antia, D., de Aquino, L. J. N., Moreno, J., & Nasi, R. (2014). The uncovered volumes of bushmeat commercialized in the Amazonian trifrontier between Colombia, Peru & Brazil. Ethnobiology and Conservation, 3.

van Vliet, N., Moreno, J., Gomez, J., L'haridon, L., de Aquino, L. N., Sandrin, F., & Nasi, R. (2018). Current levels, recent historical trends, and drivers of wildmeat trade in the Amazon Tri-Frontier region between Colombia, Peru, and Brazil. Academic Press, Ethnozoology, 215-231.

Verheij P. 2019. An assessment of wildlife poaching and trafficking in Bolivia and Suriname. International Union for Conservation of Nature, Gland, Switzerland.

Veríssimo, D. & Wan, A (2019) Characterizing efforts to reduce consumer demand for wildlife products. Conservation Biology, 33 (3), 623-633.

Wang, H, Shao, J., Luo, X., Chuai, Z., Xu, S., Geng, M. & Gao, Z. (2020) Wildlife consumption ban is insufficient. Science, 367(6485), 1435-1435.

Warrell, D. A. (2009). Commissioned article: management of exotic snakebites. QJM: An International Journal of Medicine, 102(9), 593-601.

Warrick, B. J., Boyer, L. V., & Seifert, S. A. (2014). Non-native (exotic) snake envenomations in the US, 2005–2011. Toxins, 6(10), 2899-2911.

Warwick, C., & Steedman, C. (2012). Injuries, envenomations and stings from exotic pets. Journal of the Royal Society of Medicine, 105(7), 296-299.

We are social and Hootsuite (2021). Digital 2021 April Global Statshot Report. Available on: https://wearesocial.com/uk/blog/2021/04/60-percent-of-the-worlds-population-is-now-online (Last access on: 8 Jun 2021).

Webster, R. G. (2004). Wet markets—a continuing source of severe acute respiratory syndrome and influenza? The Lancet, 363(9404), 234-236.

White, R. (2013). Environmental crime and problem-solving courts. Crime, law and social change, 59(3), 267-278.

WHO – World Health Organization, Regional Office for South-East Asia. (2014). A brief guide to emerging infectious diseases and zoonoses. WHO Regional Office for South-East Asia. https://apps.who.int/iris/handle/10665/204722

Wilk, V., Soutar, G. N., & Harrigan, P. (2017). Tackling social media data analysis: Comparing and contrasting QSR NVivo and Leximancer. *Qualitative Market Research*, 22(2), 94-113.

Wilkinson, D., & Thelwall, M. (2011). Researching personal information on the public web: Methods and ethics. Social Science Computer Review, 29(4), 387-401.

Williams, D. J., Faiz, M. A., Abela-Ridder, B., Ainsworth, S., Bulfone, T. C., Nickerson, A. D., Habib, A. G., Junghanss, T., Fan, H. W., Turner, M., Harrison, R. A., & Warrel, D. A. (2019). Strategy for a globally coordinated response to a priority neglected tropical disease: Snakebite Envenoming. PLoS Neglected Tropical Diseases, 13(2), e0007059.

Williams, V. L., Coals, P. G., de Bruyn, M., Naude, V. N., Dalton, D. L., & Kotzé, A. (2021). Monitoring compliance of CITES lion bone exports from South Africa. PlosOne, 16(4), e0249306.

Williams, V. L., Loveridge, A. J., Newton, D. J., & Macdonald, D. W. (2017). Questionnaire survey of the pan-African trade in lion body parts. PlosOne, 12, e0187060.

Williams, V. L., Newton, D. J., Loveridge, A. J., & Macdonald, D. W. (2015). Bones of contention: an assessment of the South African trade in African lion Panthera leo bones and other body parts. Joint Report. TRAFFIC, Cambridge, United Kingdom, and WildCRU, Oxford.

Wise, T., Zbozinek, T.D., Michelini, G., Hagan, C.C., & Mobbs, D. (2020). Changes in risk perception and self-reported protective behaviour during the first week of the COVID-19 pandemic in the United States. Royal Society Open Science, 7(9).

Wong, O. F., Hin-Tat, F., Shing-Kit-Tommy, L., Ka-Keung, L., Chak-Wah, K., & Simpson, I. D. (2009). A preliminary survey of Hong Kong snake shops and the potential snake bite risks for the healthcare system. Transactions of the Royal Society of Tropical Medicine and Hygiene, 103(9), 931-936.

Wong, R. W. (2015). The organization of the illegal tiger parts trade in China. British Journal of Criminology, 56, 995–1013.

Woo, P. C., Lau, S. K., & Yuen, K. Y. (2006). Infectious diseases emerging from Chinese wet markets: zoonotic origins of severe respiratory viral infections. Current Opinion in Infectious Diseases, 19(5), 401-407.

World Bank. 2019. GDP per capita, PPP, 2019. World Development Indicators. The World Bank Group, Washington, D.C. Available at https://data.worldbank.org/indicator/NY.GDP.PCAP.PP.KD (accessed August 2019).

World Health Organization. (2019). Snakebite envenoming: a strategy for prevention and control.

WTO (World Trade Organization). 2019. DATA portal. WTO, Geneva. Available at: https://data.wto.org/ (accessed April 2019).

Wyatt, T. (2009). Exploring the organization of Russia Far East's illegal wildlife trade: two case studies of the illegal fur and illegal falcon trades. Global Crime, 10, 144–154.

Wyatt, T., Johnson, K., Hunter, L., George, R., & Gunter, R. (2018). Corruption and wildlife trafficking: three case studies involving Asia. Asian Journal of Criminology, 13(1), 35-55.

Xin, L., Yan-Yan, M., Ming, B., & Ming-San, M. (2017). From the traditional Chi- nese medicine with benefit viscera with viscera theory look mod- ern sterility infertility. 3rd annual international conference on modern education and social science (MESS 2017). DEStech Transactions on Social Science, Education and Human Science, 246–251.

Yabsley, M. J., Ellis, A. E., Cleveland, C. A., & Ruckdeschel, C. (2015). High prevalence of Porocephalus crotali infection on a Barrier Island (Cumberland

Island) off the coast of Georgia, with identification of novel intermediate hosts. Journal of Parasitology, 101(5), 603-607.

Yao, V. W. (2006). An economic analysis of counterfeit goods: The case of China. Business and Public Administration Studies, 1(1), 116-116.

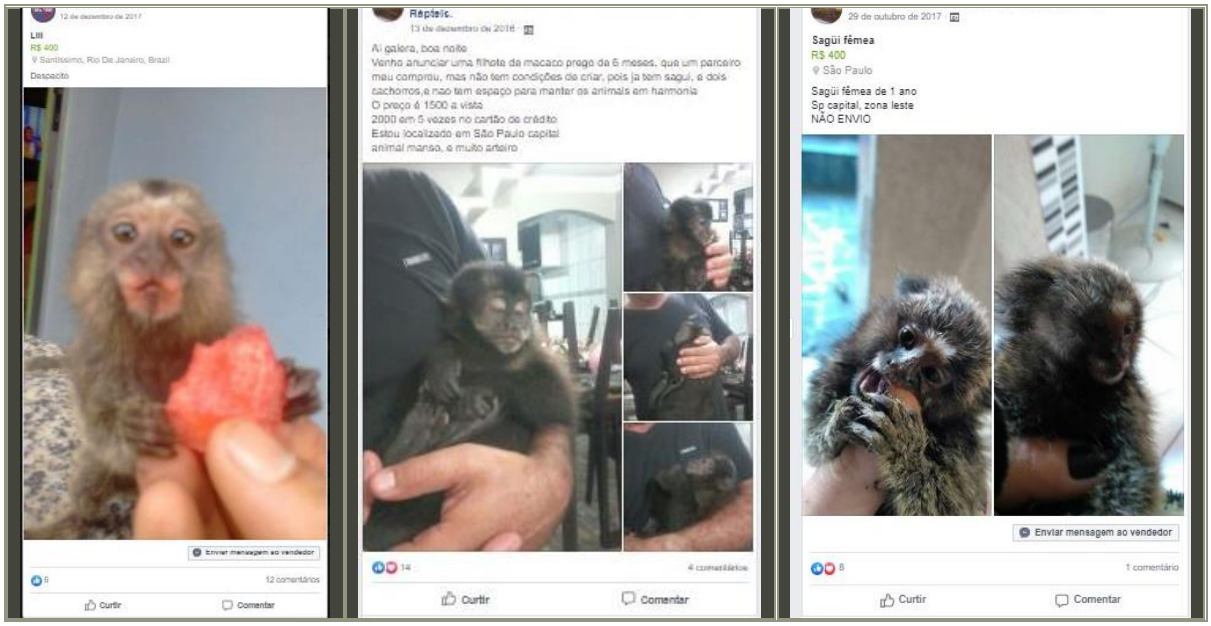
Ye, Z. W., Yuan, S., Yuen, K. S., Fung, S. Y., Chan, C. P., & Jin, D. Y. (2020). Zoonotic origins of human coronaviruses. International Journal of Biological Sciences, 16(10), 1686-1697.

Yeo, L. M., McCrea, R. S., & Roberts, D. L. (2017). A novel application of mark-recapture to examine behaviour associated with the online trade in elephant ivory. PeerJ, 5, e3048.

8. Appendices

8.1 Screenshots of advertisements offering wildlife for sale recorded

8.1.1 Online trade in primates in Brazil



8.1.2 Online trade in native and exotic venomous snakes in Brazil

8.1.3 Reference to COVID-19 pandemic in advertisments offering wild pets for sale in Brazil and Indonesia

8.2 List of additional scientific publications (not included in the PhD thesis) on wildlife trade and use produced in parallel with the PhD thesis

1. Fukushima, C. S.; Trichorate, P.; Toomes, A.; Stringham, O. C.; Rivera-Téllez, E.; Ripple, W. J.; Peters, G.; Orenstein, R. I.; **Morcatty, T. Q.;** … & Cardoso, P. (2021) Challenges and perspectives on tackling illegal or unsustainable wildlife trade. *Biological Conservation*, 109342. DOI: 10.1016/j.biocon.2021.109342
2. Cardoso, P.; Amponsah-Mensah, K.; Barreiros, J. P.; Bouhuys, J.; Cheung, H.; Davies, A.; Kumschick, S.; Longhorn, S. J.; Martínez-Muñoz, C. A.; **Morcatty, T. Q.;** Peters, G.; Ripple, W. J.; … & Fukushima, C. S. (2021) Scientists' warning to humanity on illegal or unsustainable wildlife trade. *Biological Conservation,* 109341. DOI: 10.1016/j.biocon.2021.109341
3. Mayor, P.; El Bizri, H. R.; **Morcatty, T. Q.**; Moya, K.; Bendayán, N.; Solis, S.; Vasconcelos Neto, C. F.; Kirkland, M.; Arevalo, O.; Fang, T. G.; Pérez-Peña, P. E.; Bodmer, R. E. (2021) Wild meat trade over the last 45 years in the Peruvian Amazon. *Conservation Biology*. DOI: 10.1111/cobi.13801
4. Chaves, W. A.; Valle, D.; Tavares, A. S.; **Morcatty, T. Q.;** Wilcove, D. S. (2021) Impacts of rural to urban migration, urbanization, and generational change on consumption of wild animals in the Amazon. *Conservation Biology*, 35(4), 1186-1197. DOI: 10.1111/cobi.13663
5. Nijman, V.; Campera, M.; Ardiansyah, A.; Balestri, M., … **Morcatty, T. Q.;** Nekaris, K. A. I. (2021). Large-Scale Trade in a Songbird That Is Extinct in the Wild. *Diversity*, 13(6), 238. 2021. DOI: 10.3390/d13060238
6. Svensson, M. S.; **Morcatty, T. Q.;** Nijman, V; Shepherd, C. (2021) Shedding Light on the Trade in Nocturnal Galagos. *Primate Conservation*, 35.
7. Lemos, L. P.; Loureiro, L. F.; **Morcatty, T. Q.;** Fa, J. E.; Vasconcelos Neto, C. F. A.; Jesus, A. S.; Silva, V. C.; Ramalho, M. L. O.; Mendes, A. M.; Valsecchi, J.; El Bizri, H. R. (2021) Social Correlates of and Reasons for Primate Meat Consumption in Central Amazonia. *International Journal of Primatology*, 1-23. DOI: 10.1007/s10764-021-00214-6
8. Ingram, D. J.; Coad, L.; Milner-Gulland, E. J.; Parry, L.; Wilkie, D.; Bakarr, M. I.; Benítez-López, A.; Bennett, E. L.; Bodmer, R.; Cowlishaw, G.; El Bizri, H. R.;

Eves, H. E.; Fa, J. E.; Golden, C. D.; Iponga, D. M.; Văn Minh, N.; **Morcatty, T. Q.; …** & Abernethy, K. (2021) Wild Meat Is Still on the Menu: Progress in Wild Meat Research, Policy, and Practice from 2002 to 2020. *Annual Review of Environment and Resources*, 46. DOI: 10.1146/annurev-environ-041020-063132

9. El Bizri, H. R.; **Morcatty, T. Q. (both first authors, listed in alphabetic order)**; Valsecchi, J.; Mayor, P.; Ribeiro, J. E. S.; Vasconcelos Neto, C. F. A.; Oliveira, J. S.; … & Nijman, V.; Fa, J. E. (2020) Urban wild meat consumption and trade in central Amazonia. *Conservation Biology*, 34, 438-448. DOI: 10.1111/cobi.13420
10. El Bizri, H. R; **Morcatty, T. Q.**; Ferreira, J. C.; Mayor, P.; Vasconcelos-Neto, C. F.; Valsecchi, J.; Nijman, V.; Fa, J. E. (2020) Social and biological correlates of wild meat consumption and trade by rural communities on the Jutaí River basin, central Amazonia. *Journal of Ethnobiology*, 40(2), 183-201. DOI: 10.2993/0278-0771-40.2.183
11. Nijman, V.; **Morcatty, T.**; Smith, J. H.; Atoussi, S.; Shepherd, C. R.; Siriwat, P.; Nekaris, K. A. I.; Bergin, D. (2019) Illegal wildlife trade - surveying open animal markets and online platforms to understand the poaching of wild cats. *Biodiversity*, 20, 58-61. DOI: 10.1080/14888386.2019.1568915
12. Mayor, P.; El Bizri, H. R.; **Morcatty, T. Q.**; Moya, K.; Solis, S.; Bodmer, R. E. (2019) Assessing the minimum sampling effort required to reliably monitor wild meat trade in urban markets. *Frontiers in Ecology and Evolution*, 7, 1-8. DOI: 10.3389/fevo.2019.00180
13. Nijman, V.; Ardiansyah, A.; Bergin, D.; Birot, H.; Brown, E.; Langgeng, A.; **Morcatty, T.**; Spaan, D.; Siriwat, P.; Imron, M. A.; Nekaris, K. A. I. (2019) Dynamics of illegal wildlife trade in Indonesian markets over two decades, illustrated by trade in Sunda Leopard Cats. *Biodiversity*, 20, 27-40. DOI: 10.1080/14888386.2019.1590236

8.3 Complete version of the scientific papers published related to the chapters of this PhD Thesis

Conservation Biology

Contributed Paper

Illegal trade in wild cats and its link to Chinese-led development in Central and South America

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Abstract: Seizures of hundreds of jaguar heads and canines in Central and South America from 2014 to 2018 resulted in worldwide media coverage suggesting that wildlife traffickers are trading jaguar body parts as substitutes for tiger parts to satisfy the demand for traditional Asian medicine. We compiled a data set of >1000 seized wild cats (jaguar [*Panthera onca*], puma [*Puma concolor*], and ocelot [*Leopardus pardalis*]) from 19 Central and South American countries and China. We ran generalized additive mixed models to detect trends in wild-cat seizures from 2012 to 2018 and assess the effects of socioeconomic factors of source countries and between those countries and China on the number of wild cats seized. Jaguar seizures increased over time, and most of the seized jaguar pieces were canines (1991 of 2117). Around 34% (32 of 93) of the jaguar-part seizure reports were linked with China, and these seizures contained 14-fold more individuals than those intended for domestic markets. Source countries with relatively high levels of corruption and Chinese private investment and low income per capita had 10–50 times more jaguar seizures than the remaining sampled countries. The number of Chinese residents in Central and South America was not significantly related to the number of jaguars seized. No socioeconomic factors influenced the seizures of puma and ocelots. Legal market chains may provide structure for the illegal chain; thus, the influx of illegal jaguar products is potentially a side effect of the economic partnership between Central and South American countries and China. Poverty and high levels of corruption in the source countries may motivate local people to engage in illegal activities and contribute to the growth of this trade. Supply-side interventions to curb this threat to Neotropical wild cats may include improved training for officials and promotion of governance and the value of protecting these animals to local people.

Keywords: jaguar fangs, *Panthera onca*, seizure, traditional Asian medicine, trafficking, wildlife trade

Mercado Ilegal de Felinos Silvestres y su Conexión al Desarrollo Encabezado por China en América Central y América del Sur

Resumen: La incautación de cientos de cabezas y colmillos de jaguar en América Central y América del Sur entre 2014 y 2018 resultó en una cobertura mediática mundial que sugirió que los traficantes de fauna están comerciando con partes de jaguar como sustituto de las partes de tigre para satisfacer la demanda de la medicina tradicional asiática. Recopilamos un conjunto de datos de más de mil felinos silvestres incautados (jaguar [*Panthera onca*], puma [*Puma concolor*], ocelote [*Leopardus pardalis*]) en 19 países de América Central y América del Sur y en China. Corrimos modelos aditivos mixtos generalizados para detectar las tendencias en las incautaciones de felinos silvestres entre 2012 y 2018 y para evaluar los efectos de los factores socioeconómicos de los países de origen y entre esos países y China sobre el número de felinos silvestres incautados. La incautación de

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artículos de jaguar incrementó con el tiempo y la mayoría de ellos fueron colmillos (1991 de 2117). Alrededor del 34% (32 de 93) de los reportes de incautación estuvieron vinculados a China y estas incautaciones tenían 14 veces más individuos que las incautaciones de artículos dirigidos al mercado doméstico. Los países de origen con niveles relativamente altos de corrupción y con inversión privada proveniente de China y con un bajo ingreso per cápita tuvieron de 10 a 50 veces más incautaciones de artículos de jaguar que los demás países muestreados. El número de residentes chinos en América Central y en América del Sur no tuvo una relación significativa con el número de jaguares incautados. Ningún factor socioeconómico influyó sobre las incautaciones de pumas y ocelotes. Las cadenas de mercado legales pueden proporcionar una estructura para la cadena ilegal; por lo tanto, la afluencia de productos ilegales de jaguar es potencialmente un efecto colateral de la colaboración económica entre China y los países de América Central y América del Sur. La pobreza y los altos niveles de corrupción en los países de origen pueden motivar a los habitantes locales a participar en actividades ilegales y a contribuir al crecimiento de este mercado. Las intervenciones del lado del suministro para disminuir esta amenaza para los felinos silvestres neotropicales pueden incluir mejoras al entrenamiento para los oficiales y el fomento entre los locatarios de la gestión y el valor de proteger a estos animales.

Palabras Clave: colmillos de jaguar, incautación, medicina tradicional asiática, mercado de fauna, tráfico, *Panthera onca*

摘要: 2014 至 2018 年间中南美洲缴获了数百个美洲豹头及犬齿, 引起了全球媒体的广泛关注。野生动物贩卖者可能正在试图将美洲豹作为虎的替代者, 以满足传统亚洲医药对后者器官的需求。我们从 19 个中南美洲国家及中国收集了超过 1000 起野生猫科动物缉获案件, 包含了美洲豹 (*Panthera onca*) 、美洲狮 (*Puma concolor*) 及虎猫 (*Leopardus pardalis*) 三个物种。通过广义可加混合模型, 我们揭示了2012至2018年上述国家野生猫科动物缉获频次的变化趋势, 并对来源国社会经济因素对此趋势的影响进行了评估。结果显示美洲豹的缉获数量呈上升态势, 其中大部分被缴获的器官为犬齿 (1991/2117) 。美洲豹器官的缉获报道中大约 34% (32/93) 与中国市场相关, 与其来源国市场相比, 涉及的个体数量超出 13 倍。在腐败严重、中国私人投资较多及人均收入较低的国家中, 美洲豹缉获案件数量超出其余国家 10 到 50 倍。中南美洲中国侨民的数量与美洲豹缉获数量之间无明显相关性, 同时也没有社会经济因素与美洲狮和虎猫的缉获数量直接相关。合法市场可以为非法贸易链条提供便利, 因此部分美洲豹制品的非法贸易可能是中南美洲国家与中国之间经贸往来的附带产物。部分国家的贫穷与腐败可能刺激当地民众参与非法贸易活动, 进而导致贸易量持续上升, 威胁新热带区野生猫科动物的生存。来源国可以通过对官员的进一步培训, 强化管理及提升当地民众的保护回报等方式加以控制和干预。

关键词: 美洲豹牙, 美洲豹 (*Panthera onca*), 查获, 亚洲传统医学, 走私, 野生动物贸易

Introduction

In 2018, a report claiming that wildlife traffickers in South America were possibly seeking jaguars to satisfy the demand for wild-cat body parts in Asia garnered worldwide attention (Fraser 2018). The story was prompted by the discovery of beheaded jaguars (*Panthera onca*) and ocelots (*Leopardus pardalis*) in Belize in 2017, the interception of almost 200 jaguar canines in Bolivia before shipment to China from 2014 to 2016, and the seizure of 120 jaguar canines in China, presumably in this same period. The article stimulated additional news on this trade (McKie 2018 [U.K.]; Hong Kong Animal News 2018 [China]) that reached a global audience.

Lions (*P. leo*), tigers (*P. tigris*), leopards (*P. pardus*), pumas (*Puma concolor*), and jaguars are threatened in part by international trade; this threat is most pronounced for tigers (Goodrich et al. 2015). Tiger parts, especially skins, teeth, meat, and bones, are in trade as decorations, jewelry, luxury food, and traditional medicine (Stoner 2014; Loginov & Loginova 2017). Much of the trade in tiger and lion body parts is driven by Chinese demand (Wong 2015) and, to a lesser degree, demand in other Asian countries (Nijman & Shepherd 2015; Saif et al. 2016). For instance, individual wild cats or their parts (teeth and claws) accounted for 31% of all mammal seizures in airports worldwide; China was the most recorded destination (Center for Advanced Defense Studies 2018).

Trade in tiger and lion parts has been reported (Wong 2015; Williams et al. 2017), whereas little is known about the intensity of the emerging trade in jaguars and other Neotropical wild cats or about the market forces driving this trade. Consumer theory suggests the quantity ultimately sold in a market will be that in which the marginal benefit for consumers meets the marginal costs for the supplier in aggregate. Therefore, several variables from the supply and demand sides may influence market dynamics of the wild-cat trade. On the demand side, particularly in Asia, culture plays a significant role in shaping consumers' desire for wild cats in traditional medicine, as meat, or for social status (Moyle 2009; Nijman & Shepherd 2015; Williams et al. 2017). Growth of the overall economy and a boom in the urban middle class in China has increased demand. The middle class increased from 4% to 68% of the population, and urban household

income has almost doubled in the past 20 years, which has allowed these consumers to purchase a wider range of items (Barton et al. 2013). The demand for a given product may also be influenced by availability and price of substitutes for that item. Scarcity, due to the crackdown on trafficking in tiger parts (Kirkpatrick & Emerton 2010), may have raised the price of tiger parts to a level where consumers will accept potentially cheaper substitutes from other big cats, including those not native to Asia (Kernam 2010; Fraser 2018).

The cost of obtaining wild cats in source countries also influences establishment of the supply chain and prices paid along it (Wyatt 2009). Bottlenecks in the supply chain occur when products are moved up and capital is moved down to the different intermediaries involved (Raab & Milward 2003). Local people are typically responsible for sourcing wildlife parts. Their labor costs depend on how easy it is to access wildlife, how much they could earn in alternative economic activities, and the risk of being caught by local law enforcement (Barret et al. 2011; Biggs et al. 2017; Cooney et al. 2017). Setting up networks for transporting illegal products is usually difficult. Because covert trade networks must be concealed, stakeholders cannot count on a legal system to resolve contractual disputes. Therefore, trust becomes a key factor in reducing transaction costs and results in the majority of supply-chain transactions being done among ethnically homogeneous groups, in effect "trusting their own" (Raab & Milward 2003). Supplying the Chinese demand for wild cats may be facilitated by the Chinese diaspora (Skinner 2017). Recently, the Chinese influx to Central and South America has been associated with specialized occupations generated by new investments from China in these countries (Poston Jr & Wong 2016; Verheij 2019).

The presence of networks and flows of legal goods and capital between the consumer and the supplying countries can help reduce costs of illegal trafficking in at least 2 ways. First, illegal networks may find opportunities to exploit synergies with established, legal networks. Second, a strong flow of legal goods and capital can mask illegal flow and lower the cost of hiding trade (Raab & Milward 2003; Wyatt 2009). Chinese investment in Asia (∼US$500 billion) and Africa (∼$450 billion) has been substantial in the last decade (American Enterprise Institute 2018). Although smaller, Chinese investment in Central and South America, particularly in Brazil and Peru, has increased 10-fold over the last decade (∼$200 billion over the same period) and foreshadows potential growth in investment in illegal wildlife trade in this region.

That Chinese investment and migration and an existing overseas community may lead to an increase in jaguar trade is plausible. Thus far, however, this link has not been demonstrated empirically. The secretive nature of illegal wildlife trade means that researchers often resort to using indirect indicators (e.g., Ni et al. [2018] used online reports of seizures). Lacking a comprehensive database on the quantity, prices, and supply-chain elements in the trade in wild cats from Central and South America to China, we used a data set on >1000 wild cat seizures reported from 2012 to 2018. We aimed to assess trends in wild-cat trade in Central and South America and the influence of the Chinese diaspora and the Chinese-led development on this market. We hypothesized that high availability of jaguars in natural areas, low gross national income (GNI) per capita, relatively weak law enforcement in source countries, large resident Chinese population and Chinese private investment in Central and South America, and high levels of legal exports from those countries to China contribute directly or indirectly to a low cost of supplying wild cats to the Chinese market that consequently increases illegal trade from the region. We also considered possible strategies to mitigate trade impacts on Neotropical wild cat populations.

Methods

Data Acquisition

We focused on 3 of the largest wild cats in the Americas, jaguar (body mass ∼130 kg), puma (∼80 kg), and ocelot (∼20 kg). We collected data on seizures of these cats from online news articles, technical reports, and police reports published from January 2012 to March 2018 (seizures may be over-reported after March 2018 due to the reporting by Fraser [2018]; thus, we restricted our search to the period prior to that report). We used the search terms *seizure*, *arrest*, and the species' common and scientific names to locate reports in all 19 Central and South American countries (hereafter southern America), excluding Caribbean Islands. In these reports, the only non-American country that was mentioned more than once was China (see Results); thus, we used the same search terms to locate online reports in China. The search terms were translated into the relevant languages (Portuguese for Brazil, Dutch for Suriname, English for Belize, Mandarin for China, and Spanish for all other countries).

For each search, we checked all reports from the first 10 results pages, which totaled at least 100 sites consulted per species per country (El Bizri et al. 2015). For each report, we recorded the number of individuals seized, body parts involved, and final destination (domestic or foreign country). When the number of individuals was not specifically mentioned, we conservatively estimated the minimum number of individual cats required to obtain the number of reported body parts (i.e., 4 canines, 1 skull, 1 skin, or any amount of meat was considered 1 independent individual).

For each country and each species, we tallied the number of seizure reports and individual cats seized and

calculated the percentage of the total seizure reports that had links to China. These links could refer to Chinese nationals or descendants living in or visiting southern America being implicated in the seizure; confiscated packages with China reported as the end destination; explicit mentioning of China as the destination of the confiscated goods; or seizures made in China with explicit links to southern American countries. We use *Chinese involvement*, but recognize that few and specific individuals may be involved in this illegal trade, not Chinese society as a whole. We also do not imply the Chinese government is complicit in this activity.

To assess the market structures and dynamics of the wild-cat trade in southern America, we used the following as proxies: source country GNI per capita from 2012 to 2018 as a proxy for opportunity cost of local labor; species' extent of occurrence as an indicator of the costs of obtaining specimens; source country corruption perception index score from 2012 to 2018 as a proxy for effectiveness of local law enforcement (range: 0, highly corrupt, to 100, very clean); Chinese population resident in the source country in 2015 as an indicator of the cost of establishing local networks; flow of legal exports from source country to China from 2012 to 2018 as a proxy for costs of establishing networks for transportation of goods; and flow of Chinese private investment in southern American countries from 2012 to 2018 as a proxy for costs of establishing networks for transportation of capital.

We obtained data on the extent of occurrence for each species in each country from the IUCN Red List (IUCN 2019), on the Chinese population in southern American countries from the Central Intelligence Agency (2016), and on the corruption perception index from Transparency International (2018). We extracted the GNI per capita for each country from World Development Indicators (World Bank 2019) and Chinese foreign private investment and exports to China from the World Trade Organization (WTO 2019). All monetary units are in U.S. dollars.

Data Analyses

We used descriptive statistics to present the number of reports and individuals and number and types of items recorded as seized per species. To assess the difference in the number of individuals seized per report between seizures where China was implicated and seizures supposedly supplying the domestic demand, we used a *t* test with unequal variance because the homoscedasticity between groups was not met. We applied Shapiro–Wilk's test to test normality and Levene's test for homogeneity of variances.

To assess the influence of the socioeconomic variables on the number of individuals seized, we analyzed a balanced panel data in which the cross-sectional unit was country and the time dimension was year. To address the time and spatial nonindependence (repeated measures) of the response variable, we applied generalized linear (GLM) and additive (GAM) mixed models. For that, we used GAM for location, scale, and shape (GAMLSS) (Stasinopoulos & Rigby 2007). A GAMLSS, similar to GLMs and GAMs, consists of a semiparametric statistical approach for univariate regression analysis that fits linear or nonlinear trends for the independent variables. Because no wild cat seizures were reported in some years in some countries, we fitted distribution families that balance the frequency of 0 s in the count data (such as the zero-adjusted gamma), provided by the GAMLSS. Because the socioeconomic factors were relative to the countries and because we may not have captured all intrinsic factors within a country that may influence the trade, country was set as a fixed effect, and, accordingly, the within effects for each country were accounted for in the model.

We used GAMLSS as described above to assess the influence of all socioeconomic variables compiled (see "Data Collection") on the number of individuals seized per year for each species in southern American countries from 2012 to 2018. In economic theory, trade usually has a nonlinear relationship with scale. Initially trade undergoes an economy of scale (process optimization), followed by a diseconomy of scale (external constraints limit productivity gains). Thus, we expected a similar trend for jaguar trade; the number of traded animals reaches an upper limit, similar to an asymptotic curve. Therefore, for economic variables and extent of distribution, we tested the fit of nonlinear effects with a penalized cubic splines function (cs) in which the nonlinear model is selected over a linear model only if the increase in fit is substantial enough to overcome the penalty. We tested for temporal autocorrelation in the panel data with the autocorrelation function (Acf), and there was no significant autocorrelation in the data. We also tested for multicollinearity among independent variables with a pair-wise correlation conducted with the function ggpairs. We considered any relationship between 2 variables with $R \geq 0.60$ collinear. Chinese foreign investment, exports to China, and jaguar extent of occurrence were collinear; thus, they were not included in the same model. For model selection, we ran the models with jaguar extent of occurrence. After selecting the best model, we reran it, replacing this variable with the Chinese foreign investment and the exports to China variables to obtain the relationship for these factors. For each model, we provide the estimates and SEs for the intercept and coefficients of each variable.

In a second analysis, we used a longitudinal approach to assess the trend in the number of jaguar, puma, and ocelot individuals seized in southern America over the sampled period. We pooled data from all countries per year and applied GAMLSS. We selected the family of

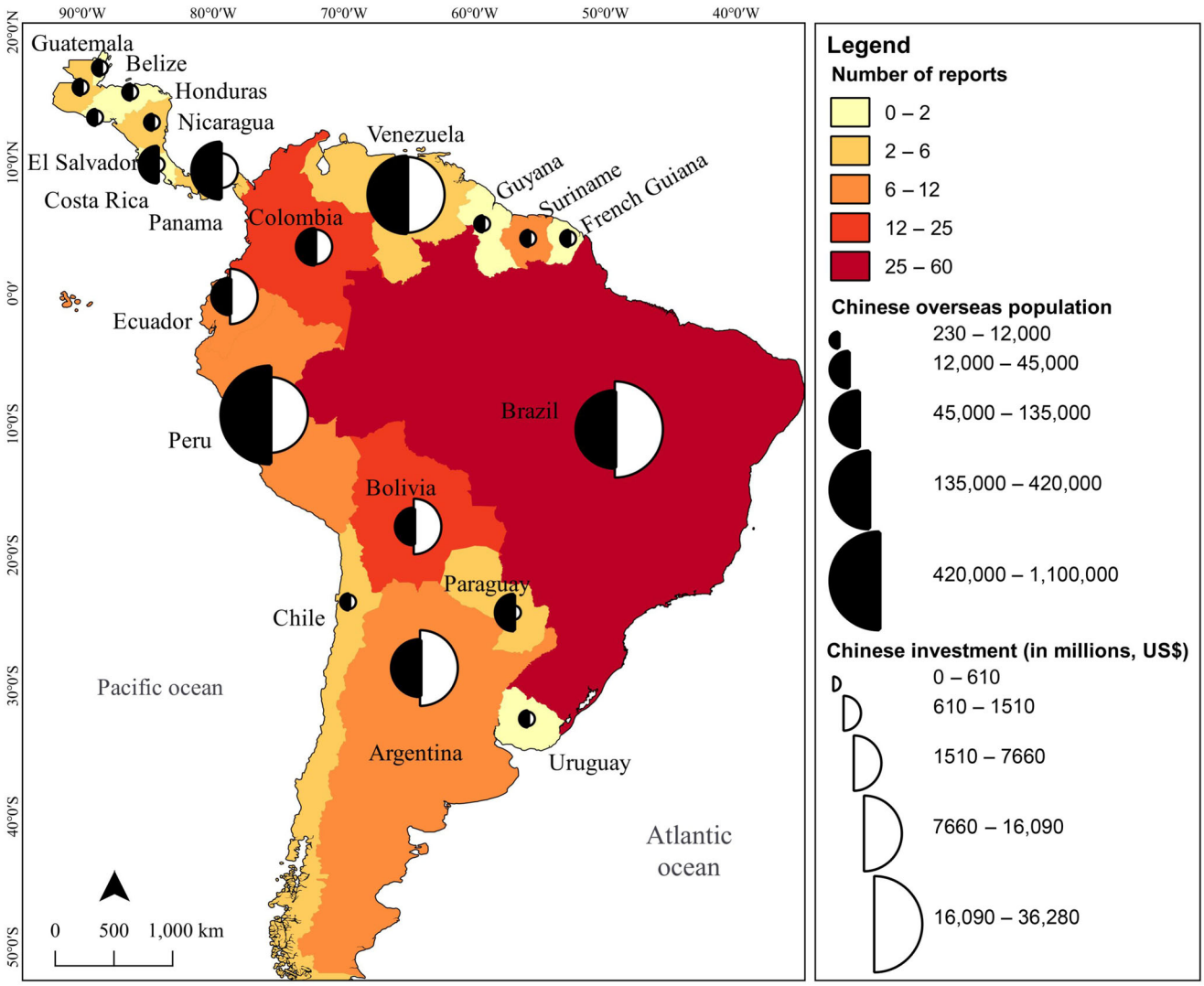

*Figure 1. In Central and South America, number of reports of seizures of jaguar (*Panthera onca*) parts, number of resident Chinese, and amount of the Chinese private investment from 2012 to 2018.*

distribution and final models based on the Akaike information criterion (AIC) for generalized models. Following the recommendations of Burnham and Anderson (2004), we considered models with good support and present in results all models with ΔAIC values <2 relative to the model with the smallest AIC (best-ranked model). We used gamlss, GGally, and Forecast R packages in R version 3.5.1 (http://www.R-project.org/) for statistical analyses and Quantum GIS 2.18.9 (https://quantum-gis.en.softonic.com/) to create the map and obtain species' extent of occurrence for each country.

Results

We found 489 reports of trade in jaguars, pumas, and ocelots in 171 unique events involving ≥1 species (93 included jaguars, 46 included pumas, and 59 included ocelots). These reports involved trade of at least 1038 individual cats (857 jaguars, 70 pumas, and 111 ocelots). Brazil had the most reports (n = 60, 35.1%), followed by Bolivia (n = 25, 14.7%), Colombia (n = 18, 10.6%), Peru (n = 12, 7.1%), and Suriname (n = 10, 5.9%) (Fig. 1 & Table 1). Two seizures of jaguars were reported in China (1.1%) that involved a minimum of 31 jaguars. For jaguars, most trade was in canines, followed by skins and heads. For pumas, most trade was in body parts (legs, claws, and tails), followed by whole bodies, and for ocelots, most trade was in live individuals (Table 2). When pooling all southern American countries, the number of jaguars seized annually (Fig. 2 & Table 3) and reports of jaguar seizures increased ~200-fold and 5-fold, respectively, over the assessed period (Fig. 2 & Table 3). Conversely, seizures of pumas or ocelots remained stable at a mean of 7 and 10 individuals seized annually (Table 3).

Table 1. Data on extent of occurrence of 3 wild cats in Central and South American countries and the socioeconomic factors tested in the generalized additive models for location, scale, and shape (GAMLSS).

	Extent of occurrence (in 1000 km²)				*Number of individuals*							
Country	*jaguar*	*puma*	*ocelot*	*Number of reports*	*jaguar*	*puma*	*ocelot*	*Corruption perception index*	*Gross national income per capita (US$)*	*Exports to China (millions US$)*	*Chinese investment (millions US$)*	*Resident Chinese population*
Argentina	44.1	2428.0	180.0	7	0	5	0	35.7	19,011	4641.333	3990	120,000
Belize	22.0	23.0	23.0	2	1	0	1	38.1	7828	0	0	1930
Bolivia	732.4	1098.6	978.6	25	482	1	13	33.1	6401	435.667	748	30,000
Brazil	4603.7	8515.8	8279.4	60	53	20	44	39.7	14,823	39,410	7236	400,000
Chile	0.0	378.1	0.0	5	1	5	1	69.4	22,122	17,568.33	770	10,000
Colombia	854.2	1138.9	1010.1	14	7	3	10	36.5	12,879	1797	200	25,000
Costa Rica	34.1	51.1	51.1	1	1	0	0	55.5	14,682	0	470	45,000
Ecuador	94.5	283.6	283.6	8	1	0	6	32.7	10,536	716.333	2157	30,000
El Salvador	0.0	21.0	0.0	2	0	0	2	36.9	6999	0	0	500
Guatemala	49.5	108.9	108.9	4	3	2	0	29.2	7235	0	700	1000
Guyana	215.0	215.0	215.0	0	0	0	0	31.8	7054	0	375	2919
Honduras	44.8	112.1	112.1	2	1	2	1	28.8	4279	0	350	530
Nicaragua	65.2	130.4	130.4	4	5	3	1	27.0	4788	0	530	12,000
Panama	37.7	37.7	75.4	3	3	0	0	37.2	20,728	0	503	135,000
Paraguay	203.4	406.8	406.8	4	5	0	0	26.9	11,071	26.333	0	40,000
Peru	642.6	1285.2	1285.2	12	12	5	19	36.7	12,093	9169.667	3346	1,100,000
Suriname	163.8	163.8	163.8	10	11	2	0	39.1	14,414	0	0	7885
Uruguay	0.0	22.0	0.0	0	0	0	0	71.8	19,945	1145.667	0	226
Venezuela	608.0	912.1	912.1	6	1	2	1	18.2	17,703	0	2713	420,000
China	0	0	0	2	31	0	0		–	–	–	–
Total	–	–	–	171	857	70	111	–	–	74,910.33	24,088	2,381,990

Table 2. Data on specimens of 3 wild cat species seized from 2012 to 2018 in Central and South American countries.

Species	*Number of specimens (no. reports)*	*Number of countries (%)*	*Number seized by type*						
			tooth	*skin*	*live animal*	*head or skull*	*body*	*other*[*]	*total*
Jaguar	857 (93)	15 (79)	1991	54	19	28	20	5	2117
Puma	70 (46)	11(58)	8	12	15	3	15	18	71
Ocelot	111 (59)	12 (63)	4	33	36	3	1	27	104
Total	1038 (171)	-	2003	99	70	34	36	50	2292

[*]*Legs, claws, tails, and meat.*

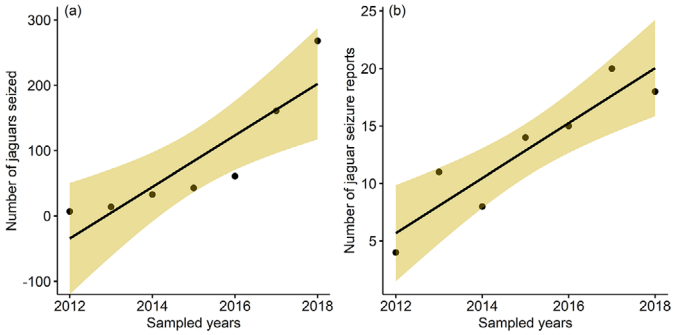

*Figure 2. Temporal trend in (a) number of individuals and (b) number of reports of jaguar parts (*Panthera onca*) seized in all Central and South American countries from 2012 to 2018 (shading, 95% CI). Statistical details related to these models are given in Table 3.*

Table 3. Details of the best-fit models using generalized additive models for location, scale, and shape (GAMLSS) for each response variable, for the temporal trend in the number of individuals seized, and for the relationship between the number of individuals seized per country and socioeconomic factors.

Response variables[a]	*Predictor variables*[b]	*Estimate*	*SE*	t	p	*Family*[c]	*ΔAIC*[d]
Temporal trend in seizures over the monitored period							
N reports of seized jaguars	intercept	−4808.8	768.8	−6.3	[e]	NOR	11.23
	year	2.39	0.38	6.3	< 0.001[e]		
Individual jaguars seized	intercept	−0.01	0.02	−43.2	0.01[e]	NOR	32.8
	year	3.94	0.91	43.3	0.01[e]		
Individual pumas seized (model 1)	intercept	1158.6	1316.2	0.9	0.42	NOR	1.27
	year	−0.57	0.65	−0.9	0.43		
Individual pumas seized (model 2)	intercept	7.14	1.37	5.2	< 0.001[e]	NOR	0
	(null model)	–	–	–	–		
Individual ocelots seized (model 1)	intercept	−3874.8	2344.5	−1.7	0.17	NOR	0.31
	Year	1.93	1.16	1.7	0.17		
Individual ocelots seized (model 2)	Intercept	11.29	2.7	4.11	0.01[e]	NOR	0
	(Null model)	–	–	–	–		
Socioeconomic factors related to the trade							
Individual jaguars seized	Intercept	2.23	0.384	5.8	< 0.001[e]	ZAGA	11.02
	cs(jaguar distribution)	0.004	0.00006	6.0	< 0.001[e]		
	cs(Chinese private investment)	0.0003	0.00002	13.3	< 0.001[e]		
	Corruption Perception Index	−0.413	0.010	−3.9	< 0.001[e]		
	Gross National Income per capita	−0.0009	0.0003	−3.2	0.002[e]		
	Exports to China	0.0002	0.0001	−1.0	0.31		
	Chinese population	−2.3e−08	3.2e−07	−0.07	0.94		
Individual pumas seized	Intercept	0.089	0.078	1.1	0.26	NOR	53.4
	puma distribution	0.0003	0.00004	7.9	< 0.001[e]		
Individual ocelots seized	Intercept	0.457	0.057	8.0	0.001[e]	ZAGA	6.0
	cs(ocelot distribution)	0.0002	0.00002	10.2	< 0.001[e]		

[a]*Link function log (ln).*
[b]*Nonlinear effect was fit with cubic splines (*cs*).*
[c]*Abbreviations: NOR, normal distribution; ZAGA, zero-adjusted gamma distribution.*
[d]*Difference between the selected model in relation to the second best-ranked model.*
[e]*Significant values (p < 0.05).*

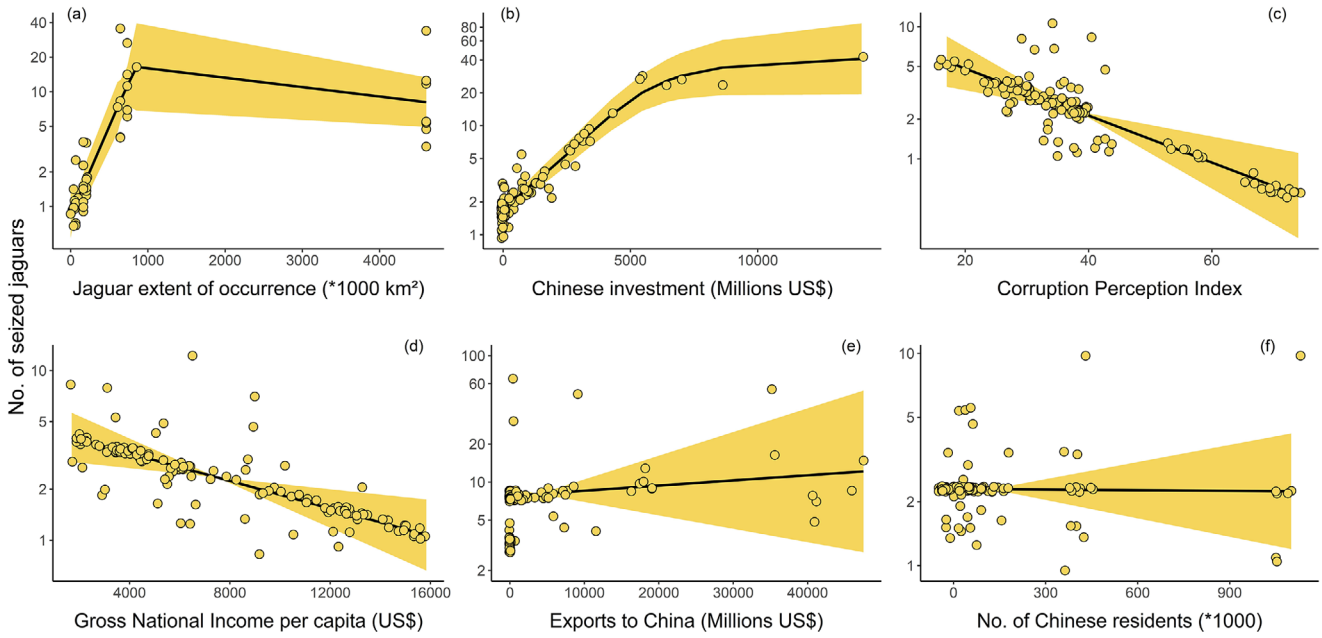

*Figure 3. Relationship between the number of jaguar (*Panthera onca*) parts reported as seized in 19 Central and South American countries (2012–2018, see Table 1) and the countries' attributes: (a) jaguar extent of occurrence, (b) Chinese private investment, (c) corruption perception index (0 = highly corrupt, 100 = very clean), (d) gross national income per capita, (e) value of goods exported to China, and (f) resident Chinese population (shaded area, 95% CI). Original values are plotted on a log-transformed (ln) y-axis. Statistical details related to these models are given in Table 3.*

Almost one-fifth (32 of 169) of the reports from southern America specifically referred to China; all 32 reports referred to jaguars. Seven reports referred to international trade without specifying a destination country, and 1 report referred specifically to Italy. Five of these 8 reports referred to jaguars. For the 6 countries with the most reports, 30% of the reports specifically referred to China as a destination country, ranging from a high of 76% for Bolivia (19 of 25) to a low of 6.5% for Brazil (4 of 61). Seizure reports where China was implicated, on average, involved more individual jaguars than reports that did not refer to international trade, which more likely referred to domestic trade (means of 28 vs. 2, respectively; $t = 6.45$, df $= 55$, $p < 0.001$).

For all cat species, the number of individuals seized was positively correlated with their extent of occurrence within each country (Table 3). Countries with a large number of jaguars seized had a relatively high amount of Chinese private investment and had relatively low corruption perception index scores and GNI per capita (Fig. 3d & Table 3). The amount of exports to China and the number of resident Chinese people were not significantly related to number of jaguars seized (Fig. 3e–f & Table 3). No variable other than extent of occurrence was retained in the best-fitted model for pumas and ocelots (Table 3).

Discussion

Long-term efforts to conserve populations of wild cats in southern America may be threatened by a new wave of trade for local and international consumption (Nuñez & Aliaga-Rossel 2017; Braczkowski et al. 2019; Verheij 2019). Our findings indicated a recent increase in trade in jaguars and significantly less and stable trade in pumas and ocelots over the 6-year study period.

Experts from Bolivia, Suriname, Belize, Costa Rica, Panama, and Honduras claim there may be Chinese or Asian involvement in trade in wild cats (Kernam 2010; Nuñez & Aliaga-Rossel 2017; Reuter et al. 2018). The marked proportion of analyzed reports on jaguar seizures that explicitly mentioned China as an end destination or had Chinese nationals implicated in the seizure supports the contention that jaguars may be hunted to meet demand in China or originated from the Chinese diaspora in southern America (Kernam 2010; Verheij 2019). Seizures linked to China contained significantly more jaguar individuals, meaning this demand may be more critical than the domestic demand and has great potential to reduce jaguar populations.

We found that some Chinese-related market forces associated with the supply side of the chain and socioeconomic factors from southern American countries were

related to variation in the numbers of jaguars seized. We confirmed the hypotheses that larger jaguar extent of occurrence and Chinese private investment in the countries are related to an increase in the trade in jaguars and that increases in the corruption perception index and GNI per capita are associated with lower trade rates. We did not confirm our hypotheses that exports to China and presence of Chinese residents contribute to the establishment of the jaguar market chain.

Transportation of product and capital is the key to success of any market chain (Wyatt 2009). The positive relationship between the number of jaguars seized and the amount of Chinese private investment may indicate that the legal market chain may provide structure for the illegal chain. Once the supply chain is built, it facilitates the trade in other illegal wildlife products. For instance, scales of African pangolins were initially traded to Asia for medicine, but afterward, sellers took advantage of the established chain to sell the species' meat, increasing hunting pressure (Challender et al. 2014).

High levels of rural poverty and corruption in developing countries may lead to the involvement of local people in illegal activities. The pursuit of financial improvement or social standing is one of the main motivations for poaching in rural communities (Cooney et al. 2017), and the lack of local governance and absence of institutions to properly manage the natural resources hinders long-term strategies for wildlife conservation (Barret et al. 2011). This is corroborated by the strong relationship we found between the corruption perception index and GNI per capita with the number of jaguars seized, which indicates the need to prioritize interventions on the supply side to generate potential reductions in jaguar trade in the region. Less corruption, and consequently more effective law enforcement, may increase in costs to people engaging in illegal activities by increasing the chances of successful prosecution with penalties (Cooney et al. 2017). Thus, as we expected, the combination of weak governance and limited sources of income in the rural areas of southern American countries, which contain vast tropical forests, may have promoted the establishment of hidden supply chains for jaguar trafficking in the region.

Because in our models the number of Chinese residents in the sampled countries did not have a significant effect, the Chinese connection to jaguar trade may be related to the more recent influx of Chinese people encouraged especially by new investments (Verheij 2019). New foreign visitors may still have fresh contacts with the Asian market and promote influxes of people and products. Conversely, long-established foreign descendants may have integrated into the local culture and lifestyle and may have less contact with people in their native country (Skinner 2017). Furthermore, as a high-end jewelry or decoration product, jaguar teeth may be more sought after by wealthy tourists or elites living in Asia than by working-class immigrants, as in the ivory market (Gao & Clark 2014).

The main driver of trade in tiger parts is the belief held by some Chinese that the species' bones contain medicinal attributes. With the demise of tigers, body parts of other big cats, including leopards and lions, are increasingly being used as substitutes (Williams et al. 2015). More recently, jaguars were specifically alluded to as a substitute species (Nuñez & Aliaga-Rossel 2017; Reuter et al. 2018; Verheij 2019). Tiger and lion canines may also be used occasionally for medicinal purposes, but this is less common (Xin et al. 2017). Because the trade we examined seems mostly to target jaguar canines, jaguars do not appear to be a replacement for tigers in the medicinal bone market (Fraser 2018). Some of the jaguar teeth seized were carved for the jewelry market, indicating that those jaguar canines may play a role in the Asian market as jewelry or amulets. Big cats are frequently associated with strength, and their body parts are used or kept by people for imbuing personal and spiritual power (Williams et al. 2017; Kelly 2018; Braczkowski et al. 2019). Decoration and collection markets for wildlife-derived products are often rarity driven (Phelps et al. 2014), and jaguar pieces may infuse novelty to this market. For instance, in the orchid trade, mass-market buyers choose species to buy based on quality and beauty, whereas collectors look for rare species, including wild-harvested specimens (Hinsley et al. 2015). Thus, jaguar canines are likely substituting for teeth of tiger, lion, and other cats (Nowell 2000; Nijman & Shepherd 2015; Williams et al. 2017). Further research efforts on the cross-price elasticity of demand for jaguar and Asian and African cat species are urgently needed to determine whether jaguars are market complements or substitutes for tigers or lions in the Asian market.

The influx of illegal jaguar products is likely a side effect of the economic partnership between southern American countries and China and the high corruption rates in the supply-side chain. Reducing bilateral economic relations is not a viable strategy. Increased surveillance and improved cooperation between countries trading with China are needed to curb this threat. For processed wildlife products, there is a higher probability of detecting or confiscating illegal items close to the source or in transit (Center for Advanced Defense Studies 2018). After teeth are carved or added to jewelry pieces, it may be difficult to recognize and identify the species from which they were obtained. Thus, at the end of the chain, these products could be easily laundered as a legal item (Wyatt 2009). Plausible interventions on the demand side include the development of awareness campaigns in China regarding the illegality of and conservation problems related to the item and changing consumer perceptions regarding the possession of the product (Hall et al. 2008).

Supply-side interventions include strategic alliances among southern American countries to amend the gaps in current legislation, increase border controls, and strengthen surveillance in the source countries. Community-level interventions that empower and engage local communities as active and motivated stakeholders in law enforcement are a cost-effective and often less corruptible alternative for low-income countries (Biggs et al. 2017; Cooney et al. 2017). Strategies that increase the income in rural areas and the value of the presence of the wildlife, through, for example, ecotourism and forest-product extraction, may offer incentives for people to not involve themselves in illegal activities (Biggs et al. 2017; Cooney et al. 2017).

The magnitude of the tooth jewelry market has not been estimated for wild cat species, especially because of the difficulty in accessing this illegal and restricted activity (Phelps et al. 2016; Nijman et al. 2019). The general jewelry market in China has grown in the last decades ($77 billion gross in 2012) (Hsu et al. 2014). We advocate for the establishment and improvement of comprehensive databases on hunting and trafficking of wild cats from southern American countries, improved training of officials so that they can recognize objects containing wildlife, and investment in research on wildlife trafficking. We did not explore demand-side factors of the jaguar market, and these drivers need further research.

Ours is the first large-scale assessment that shows the coverage and some drivers of the international trade in jaguars in southern America. We acknowledge the limitation posed by gathering data only from online sources in representing the real number of seizures and the actual number of individuals traded, especially considering the possible effects of distinct surveillance efforts among countries and the tendency to over-report seizures implicating international countries. Seizure reports and media items have been used frequently and are claimed to be among the few sources available through which to assess hidden markets in wildlife (Ni et al. 2018) or sensitive illegal behaviors, such as hunting (El Bizri et al. 2015). They can be an important source for a first diagnosis of trade in wild cats, especially considering the absence of an official seizure database in most of the involved countries and the high risk and difficulty of conducting market surveys and interviews with traffickers.

In addition to providing numbers and a perspective on the state-of-the-art and drivers of the jaguar trade in southern America, we sought to increase awareness of this emerging threat and to suggest priorities for new assessments. Besides wildlife trade, Neotropical wild cats are threatened throughout their distribution by habitat loss and fragmentation, road mortality, and conflicts with humans due to livestock predation (Paviolo et al. 2016; Verheij 2019). Unlike these other threats, trade in Neotropical cats is understudied (Kernam 2010; Reuter et al. 2018; Verheij 2019). Thus, understanding further features of this market, such as its magnitude and stakeholders involved, is crucial for developing strategies to address this threat and promote conservation of these threatened species.

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Literature Cited

American Enterprise Institute. 2018. China Global investment tracker. The American Enterprise Institute and the Heritage Foundation, Washington, D.C. Available from http://www.aei.org/china-global-investment-tracker/ (accessed March 2018).

Barrett CB, Travis AJ, Dasgupta P. 2011. On biodiversity conservation and poverty traps. Proceedings of the National Academy of Sciences of the United States of America **108:**13907–13912.

Barton D, Chen Y, Jin A. 2013. Mapping China's middle class. McKinsey Quarterly **3:**54–60.

Biggs D, Cooney R, Roe D, Dublin HT, Allan JR, Challender DW, Skinner D. 2017. Developing a theory of change for a community-based response to illegal wildlife trade. Conservation Biology **31:5–12.**

Braczkowski A, et al. 2019. The ayahuasca tourism boom: an undervalued demand driver for jaguar body parts? Conservation Science and Practice. **1**. https://doi.org/10.1111/csp2.126.

Burnham KP, Anderson DR. 2004. Multimodel inference: understanding AIC and BIC in model selection. Sociological Methods & Research **33:**261–304.

Center for Advanced Defense Studies (C4ADS). 2018. In plane sight: wildlife trafficking in the air transport sector. C4ADS and USAID-ROUTES, Washington, D.C.

Central Intelligence Agency (CIA). 2016. Profile guide in the world factbook. CIA, Washington, D.C. Available from https://www.cia.gov/library/publications/the-world-factbook/geos/br.html. (accessed March 2018).

Challender D, Waterman C, Baillie J. 2014. Scaling up pangolin conservation. IUCN SSC pangolin specialist group conservation action plan. Zoological Society of London.

Cooney R, et al. 2017. From poachers to protectors: engaging local communities in solutions to illegal wildlife trade. Conservation Letters **10:**367–374.

El Bizri H, Morcatty TQ, Lima J, Valsecchi J. 2015. The thrill of the chase: uncovering illegal sport hunting in Brazil through YouTube™ posts. Ecology and Society **20:**30.

Fraser B. 2018. China's lust for jaguar fangs imperils big cats. Nature News **555:**13–14.

Gao Y, Clark SG. 2014. Elephant ivory trade in China: trends and drivers. Biological Conservation **180:**23–30.

Goodrich J, et al. 2015. Panthera tigris. The IUCN Red List of threatened species 2015. International Union for Conservation of Nature, Gland, Switzerland. Available from http://doi.org/10.2305/IUCN.UK.2015-2.RLTS.T15955A50659951.en (accessed May 2019).

Hall RJ, Milner-Gulland EJ, Courchamp F. 2008. Endangering the endangered: the effects of perceived rarity on species exploitation. Conservation Letters **1:**75–81.

Hinsley A, Verissimo D, Roberts DL. 2015. Heterogeneity in consumer preferences for orchids in international trade and the potential for the use of market research methods to study demand for wildlife. Biological Conservation **190:**80–86.

Hong Kong Animal News. 2018. A British researcher points out that Chinese construction projects stimulate illegal wildlife hunting in South America — many jaguars have been killed in recent years (in Chinese). Hong Kong Animal News, 5 March. Available from http://www.hkanimalpost.com/2018/03/05/%E8%8B%B1%E7%0%94%E7%A9%B6/ (accessed April 2018).

Hsu T, Lucas A, Qiu Z, Li M, Yu Q. 2014. Exploring the Chinese gem and jewelry industry. Gems & Gemology **50:**2–29.

IUCN (International Union for Conservation of Nature). 2019. The IUCN Red List of threatened species. Version 2019-1. IUCN, Gland, Switzerland. Available from https://www.iucnredlist.org (accessed May 2019).

Kelly JR. 2018. Insights into the illegal trade of feline derivatives in Costa Rica. Global Ecology and Conservation **13:**e00381.

Kernam I. 2010. Exploitation of the jaguar, *Panthera onca* and other large forest cats in Suriname. WWF Guianas species conservation. World Wildlife Fund for Nature, Paramaribo.

Kirkpatrick RC, Emerton L. 2010. Killing tigers to save them: fallacies of the farming argument. Conservation Biology **24:**655–659.

Loginov O, Loginova I. 2017. Reverse side of Chinese medicine. International Journal of Environmental Studies **74:**915–919.

McKie R. 2018. Jaguars killed for fangs to supply growing Chinese medicine trade. The Guardian, 4 March. Available from https://www.theguardian.com/environment/2018/mar/04/jaguars-killed-for-fangs-chinese-medicine-trade (accessed April 2018).

Moyle B. 2009. The black market in China for tiger products. Global Crime **10:**124–143.

Ni Q, et al. 2018. Conservation implications of primate trade in China over 18 years based on web news reports of confiscations. PeerJ **6:**e6069. https://doi.org/10.7717/peerj.6069.

Nijman V, Morcatty T, Smith JH, Atoussi S, Shepherd CR, Siriwat P, Nekaris KAI, Bergin D. 2019. Illegal wildlife trade—surveying open animal markets and online platforms to understand the poaching of wild cats. Biodiversity **20:**58–61.

Nijman V, Shepherd CR. 2015. Trade in tigers and other wild cats in Mong La and Tachilek, Myanmar–a tale of two border towns. Biological Conservation **182:**1–7.

Nowell K. 2000. Far from a cure: the tiger trade revisited. TRAFFIC International, Cambridge, United Kingdom.

Nuñez A, Aliaga-Rossel E. 2017. Jaguar fangs trafficking by Chinese in Bolivia. CAT News **65:**50–51.

Paviolo A, et al. 2016. A biodiversity hotspot losing its top predator: the challenge of jaguar conservation in the Atlantic Forest of South America. Scientific Reports **6:**37147.

Phelps J, Biggs D, Webb EL. 2016. Tools and terms for understanding illegal wildlife trade. Frontiers in Ecology and the Environment **14:**479–489.

Phelps J, Carrasco LR, Webb EL. 2014. A framework for assessing supply-side wildlife conservation. Conservation Biology **28:**244–257.

Poston Jr DL, Wong JH. 2016. The Chinese diaspora: the current distribution of the overseas Chinese population. Chinese Journal of Sociology **2:**348–373.

Raab J, Milward HB. 2003. Dark networks as problems. Journal of Public Administration Research and Theory **13:**413–439.

Reuter A, Maffei L, Polisar J, Radachowsky J. 2018. Jaguar hunting and trafficking in Mesoamerica, recent observations. WCS, New York.

Saif S, Russell AM, Nodie SI, Inskip C, Lahann P, Barlow A, Greenwood Barlow C, Islam MdA, MacMillan DC. 2016. Local usage of tiger parts and its role in tiger killing in the Bangladesh Sundarbans. Human Dimensions of Wildlife **21:**95–110.

Skinner GW. 2017. Change and persistence in Chinese culture overseas: a comparison of Thailand and Java. Pages 53–67 in Reid A, editor. The Chinese diaspora in the Pacific. Routledge, London.

Stasinopoulos DM, Rigby RA. 2007. Generalized additive models for location, scale and shape (GAMLSS) in R. Journal of Statistical Software **23:**1–46.

Stoner S. 2014. Tigers: exploring the threat from illegal online trade. TRAFFIC Bulletin **26:**26.

Transparency International. 2018. Corruption perception index 2018. Transparency International, Berlin. Available from https://www.transparency.org/cpi2018 (accessed April 2019).

Verheij P. 2019. An assessment of wildlife poaching and trafficking in Bolivia and Suriname. International Union for Conservation of Nature, Gland, Switzerland.

Williams VL, Loveridge AJ, Newton DJ, Macdonald DW. 2017. Questionnaire survey of the pan-African trade in lion body parts. PLOS ONE, **12:**e0187060. https://doi.org/10.1371/journal.pone.0187060.

Williams VL, Newton DJ, Loveridge AJ, Macdonald DW. 2015. Bones of contention: an assessment of the South African trade in African lion *Panthera leo* bones and other body parts. Joint Report. TRAFFIC, Cambridge, United Kingdom, and WildCRU, Oxford.

Wong RW. 2015. The organization of the illegal tiger parts trade in China. British Journal of Criminology **56:**995–1013.

World Bank. 2019. GDP per capita, PPP, 2019. World Development Indicators. The World Bank Group, Washington, D.C. Available from https://data.worldbank.org/indicator/NY.GDP.PCAP.PP.KD (accessed August 2019).

WTO (World Trade Organization). 2019. DATA portal. WTO, Geneva. Available from https://data.wto.org/ (accessed April 2019).

Wyatt T. 2009. Exploring the organization of Russia Far East's illegal wildlife trade: two case studies of the illegal fur and illegal falcon trades. Global Crime **10:**144–154.

Xin L, Yan-Yan M, Ming B, Ming-San M. 2017. From the traditional Chinese medicine with benefit viscera with viscera theory look modern sterility infertility. Pages 246–251 in 3rd annual international conference on modern education and social science (MESS 2017). DEStech Transactions on Social Science, Education and Human Science https://doi.org/10.12783/dtssehs/mess2017/12122.

Morcatty , T.Q., Feddema, K., Nekaris, K.A.I., and Nijman, V. (2021) Online trade in wildlife and the lack of response to COVID-19, *Environmental Research* 193
doi: 10.1016/j.envres.2020.110439