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Su, S., Macdonald, E.A., Beseng, M. [orcid.org/0000-0003-1761-3068](https://orcid.org/0000-0003-1761-3068) et al. (2 more authors) (2022) The link between wildlife trade and the global donkey skin product network. *Conservation Science and Practice*, 4 (6). e12676. ISSN 2578-4854

<https://doi.org/10.1111/csp2.12676>

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# The link between wildlife trade and the global donkey skin product network

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## Abstract

Unsustainable global wildlife trade impacts biodiversity and threatens national and global security, but many aspects of this trade remain opaque. Our study is a novel investigation of the alleged links between the trade in wildlife products and in donkey skins. The global donkey skin trade is a newly prevalent and lucrative business, largely driven by Chinese demand for E-Jiao, a traditional medicine derived from donkey skins. Records of donkey skins being seized alongside other wildlife products lead us to hypothesize that there is a link between these two trades. We identified all donkey skin dealers on seven business-to-business e-commerce websites and obtained 14,949 data points. These were used in a network analysis to demonstrate the structure of the network and reveal the connection between the products, including wild animal and plant products offered alongside donkey skins. We identified at least 13 groups of CITES-listed species in the densely connected donkey skin product network, demonstrated an association between the online trade in wildlife products and donkey skins, and discuss the implications of this overlap—including the potential to shed light on potential novel trade pathways in legal and illegal domestic animal and wildlife trade.

## KEYWORDS

CITES, donkey hide trade, e-commerce, E-jiao, network analysis, online wildlife trade, traditional Chinese medicine

## 1 | INTRODUCTION

Globally, wildlife is the basis of a multi-billion dollar trade, much of which is legal but an illegal component funds one of the most lucrative sectors of international crime (Avis, 2017; Engler & Parry-Jones, 2007; Nellemann

et al., 2016). Scheffers et al. (2019) estimated that at least 20% of vertebrate species are affected by wildlife trade, and while sustainable use is theoretically possible, the over-exploitation of wildlife is a primary driver of global biodiversity loss (Bongaarts, 2019; Hoffmann et al., 2010; Maxwell et al., 2016). Wildlife trade contributes to the decline of charismatic species such as tigers (*Panthera tigris*; O'Kelly et al., 2012), rhinoceros (Rhinocerotidae; Haas & Ferreira, 2016), pangolins (Manidae; Heinrich

Shan Su and Ewan A. Macdonald contributed equally to this study and shared first authorship.

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et al., 2017), and parrots (Psittaciformes; Tella & Hiraldo, 2014), but importantly also involves huge numbers of less conspicuous species (García-Díaz & Cassey, 2014; Simberloff, 1986; Su et al., 2015; Vall-Llosera & Su, 2018). Many less charismatic species are not specifically listed by name in existing legislation thus their trade is technically legal, however, these legal trades still have the potential to remain enormously damaging (Macdonald et al., 2021; Marshall et al., 2020).

In wildlife trade, as in illegal trade more generally (Thomaz, 2020), traders deal in a diversity of products (Costa, 2019; EIA, 2017; Thomaz, 2020), and these products are often transported under the guise of, or concealed within a set of, legal products (Chatham House, 2018; EIA, 2018). There is increasing evidence that wildlife products are being traded alongside donkey skins (as documented in media and NGO reports; de Greef, 2017; The Donkey Sanctuary, 2019).

Animals and their parts are traded for a variety of reasons, including as pets, food, religious or cultural symbols, ornaments, or traditional medicines (Blackburn et al., 2009; Su et al., 2014). Among traditional Chinese medicines and health supplements, E-Jiao has recently experienced a resurgence, becoming one of the most popular. E-Jiao is derived from donkey (*Equus asinus*) skins and has been credited with medical value and tonic effects (Liu et al., 2014; Tian et al., 2017). The recent explosion in popular demand for E-Jiao has resulted in an enormous global trade in donkey skins and a highly profitable business. High-end E-Jiao retails at more than £550 per kg (Dong-E-E-Jiao, 2020). To meet the demand for E-Jiao, an estimated 4.8 million donkeys are required for slaughter annually (The Donkey Sanctuary, 2019). However, the supply of donkeys within China is currently unable to keep up with the demand (Bennett & Pfuderer, 2019, 2020), this has led E-Jiao manufacturers to source donkey skins on the international market.

The Convention on International Trade in Endangered Species (CITES) aims to protect against over-exploitation of wildlife species via international trade, and regulates some of the most intensely traded species. The donkeys used to supply the E-Jiao industry are either domesticated or feral varieties, meaning that they are neither considered as wildlife nor fall under any CITES listing. The trade in domestic and feral donkeys has been linked to political, economic, and conservation problems globally (Bornman, 2017; Brooke, 2019; Lesté-Lasserre, 2019; The Donkey Sanctuary, 2017). The trade in donkeys is associated with increasing reports of donkeys being stolen from nomadic and other vulnerable African communities, which risks pushing the affected households into even greater poverty (Brooke, 2019). Little is known about the precise operational detail of these thefts but media and NGO reports suggest

that the perpetrators may have links to organized crime and may also be involved in the smuggling of other illegal products including cigarettes, alcohol, and wildlife (Nkala, 2020). Stolen donkeys may sometimes be transported to abattoirs or are slaughtered in the bush (Al-Dostor, 2016) and the associated lack of regulation raises concerns for animal welfare and potentially an increased risk of product contamination and the emergence of zoonotic diseases (The Donkey Sanctuary, 2019). Furthermore, a growing body of co-seizure records raises concern that the trade in donkey skins is associated with the trade in other wildlife products, including the illegal trade of CITES-listed species (Grobler, 2019; NSPCA, 2017). Here, we focus on the last of these issues; the connections between the donkey skin trade and the trade in wildlife products (including both CITES and non-CITES species).

Domesticated and feral donkeys are closely related to the African wild ass (*Equus africanus*), a critically endangered and CITES Appendix 1 listed species (IUCN, 2014). While hunting for food and medicinal purposes are listed as the primary threats to African wild ass, these are predominantly for local consumption. The extreme rarity of the African wild ass (20–200 mature individuals) likely precludes their systematic use in the E-Jiao trade, and while it is possible for their skins to enter the trade opportunistically we are unaware of any documented cases at present. Even so, the precarious conservation status of African wild ass is such that the potential links with the E-Jiao trade warrant ongoing monitoring.

Trade in a multiplicity of illegal products is often strongly connected, a process known as “parallel trafficking” (Ayling, 2013; Clifton & Rastogi, 2016; Elliott, 2012; Haas & Ferreira, 2015). Illegal wildlife trade is a form of transnational organized crime (Costa, 2019), which rarely functions in isolation and often occurs in highly mobile trade networks (Heinrich et al., 2017) extending over several countries (Warchol, 2004). For example, there is evidence of links between caviar and weapons trafficking (van Uhm, 2018), and abalone (*Haliotis spp.*) and the drug trade (de Greef, 2016). Previous investigations based on seizures and on-site surveys have shown hints of the association between the trade in donkey skins and of CITES-listed species, for example, the lion (*Panthera leo*) skin (NSPCA, 2017) and tiger skin (Bornman, 2017). Although parallel trade has been documented for several wildlife species (Grobler, 2019; van Uhm & Siegel, 2016) this is an area of important policy relevance that is currently under explored.

The international trade in donkey skins is legally complex, with China permitting the import of skins of non-edible *Equus spp.* (including donkeys) from 23 countries across Africa, Australasia, Central Asia, Europe, and America (General Administration of Customs of the

People's Republic of China, 2019). However, an increasing number of countries (including those with existing trade relationships with China) are enacting domestic legislation with varying levels of severity to restrict the slaughter and trade in donkeys and their derivative products (The Donkey Sanctuary, 2019). Even so, it is thought that donkeys and their skins are often traded illegally by exceeding quotas or by transiting donkeys, alive or as products, across borders from countries where the trade is restricted into countries where the trade is legal, thus allowing traders to claim the legal origin of their products (Dawson, 2017; Nkala, 2017, 2019). This complex landscape of legal agreements and cross border trades, combined with the often dubious provenance of many of the donkeys that enter the trade (e.g., animals that have been stolen or illegally traded; Brooke, 2019; Maichomo et al., 2019) creates a legal ambiguity surrounding the trade in donkey skins which may in turn attract criminals seeking to profit from illegal activities or seeking to obscure their activities behind a legal façade. To those involved, the illegal trade in wildlife is simply a business enterprise (Albanese, 2011; Paoli, 2002). The nature of illegal markets, the risks of betrayal, and the potential failure of cooperation limit the size and structure of the market (Albanese & Reichel, 2014; Paoli, 2002), which may result in a complex, durable, and flexible trafficking systems (Costa, 2019).

Therefore, in this context, our goal is to provide the first empirical exploration of a link between the trade in donkey skins and wider wildlife trade. However, the legal complexity of both the wildlife trade and the trade in donkey skins means that it will be beyond the scope of this study to assess the legality of trades in this context, and we will confine our results to the associations between these trades.

There is a growing interest in online wildlife trade (Hinsley et al., 2016; Miller et al., 2019; Patel et al., 2015; Wu, 2007; Yin et al., 2020), a medium that is challenging for investigators because it changes rapidly (Nijman & Stoner, 2014). In the case of donkey skins, seizure records can also provide indications of the scale and route of the illegal trade, but probably represent a biased subset of less than 10% of the traffic (Rosen & Smith, 2010). In addition to seizure records, we therefore examine data scraped from online trade websites where vendors are known to sell donkey skins.

Our key questions are whether there is an association between the online trade in donkey skins and the wider wildlife trade; and if so, how the two sets of products interact in the network.

In general, we can assume that vendors (online or otherwise) make decisions about the most appropriate product assortment to maximize their profits (Balderston, 1956),

improve customer retention (Borle et al., 2005), and to compete in an increasingly visible and searchable internet-dominated market (Cachon et al., 2008). As such, their decisions about which products to sell will be reflective of the competitive nature of their markets, the condition of their supply chains (which they might or might not have in common), as well as the demand pressures from their customers. These decisions made manifest in their product listings, form an informative basis with which to elicit market structure, commodity relationships, and more. We used a network analysis to explore the structure of the network as a whole, relational patterns between products, the geographic hotspots for the trade, and to assess the association between the wildlife and donkey skins in the product network.

By centering and constraining our analysis on vendors who sold donkey skins, we will be able to provide a detailed assessment of the range of products that are associated with the donkey skin trade. The presence of wildlife products in this online trade network would demonstrate that donkey skins are at least sometimes traded alongside wildlife products, and the co-occurrence of both product sets in seizure records would provide evidence that these product sets also travel through the supply chain together. This study design allows us empirically to confirm or reject the claimed parallel trade between the trade in donkey skins and the wildlife trade, although further work will need to be done to establish the strength, importance, and drivers of these associations. To the extent that any interaction is illegal, or prejudicial to conservation, we discuss how it can be curbed.

## 2 | METHODS

### 2.1 | Data collection and management

We used R version 4.0.5 (R Core Team, 2021) and the web scraping tool Mozenda (Mozenda Inc, 2021) for data collection; and the R package stringr (Wickham & RStudio, 2019) and OpenRefine (Ham, 2013) for text processing and data management.

To explore the internet-based trade in donkey skins, we used Google Web Search to assemble a list of B2B (business-to-business) e-commerce platforms used by manufacturers, wholesalers, and distributors. In order to identify which of these platforms offered donkey skins for sale, we used their internal search engines to search for the term “donkey skins” in both English and Mandarin. These languages were selected because English is often used as a lingua franca for international online trade and is a default language on all of the platforms surveyed, and Mandarin is widely spoken and understood in China, the

dominant consumer of donkey skin products. These searches allowed us to identify seven B2B websites that sold donkey skins for analysis. The web traffic analysis company [www.alexa.com](http://www.alexa.com) estimates that the total number of external sites that link to these e-Commerce platforms is 5986 (Alexa Internet Inc, 2021, accessed in September 2021).

On each of the selected e-commerce platforms, we used internal search engines to identify all merchants offering “donkey skins” as part of their product portfolios. We did this by identifying all search results for products that represented actual donkey skins for sale, and then collected profile data relevant to each seller. For each of the donkey-skin traders across these platforms, we collected their trading company name and its given location. The merchants were located in over 55 countries, however, it was worth noting that this location information may be tied to their legal status rather than true operating footprint. In this study, we took this information at face value, since it was the location they were providing to potential business partners, however, this uncertainty about the true operating footprint of these traders means that interpretation of these location data should be treated cautiously. Once all merchants offering donkey skins had been identified, we then collected information on all other products that they offered for sale. We removed duplicated data where the same product was offered by the same merchant. Across all merchants, a total of 14,949 data points (10,487 products) were offered alongside donkey skins. We categorized these products by product features, and where relevant, species. The pet trade is one of the most important drivers of biodiversity loss (Bush et al., 2014; Lockwood et al., 2019), therefore, we categorized species often traded as pets into pet animal groups. Among the animal products of conservation concern, we categorized cheetahs (*Acinonyx jubatus*), lions, and tigers as big cats; Asian arowana (*Scleropages formosus*) and leopardi stingray (*Potamotrygon leopoldi*) as pet fish; the eggs of falcons (*falco spp.*) and gray parrots (*Psittacus erithacus*) as eggs of pet birds. We excluded less than 0.0005% of products as a consequence of being unable to identify them from the names or images advertised on the webpages.

Because e-commerce websites do not require vendors to provide information about the origin of their products, we were unable to verify the claimed provenance of the wildlife-related products in our database, and the claimed CITES status (wild-caught or captive-bred) of traded species is often incorrectly reported (Poole & Shepherd, 2017; Shepherd et al., 2012). We therefore classed all CITES-listed species, and species of conservation concern as wildlife, irrespective of the declared source.

To reveal which wildlife products shared a history of seizures with donkey skins, we obtained records of customs seizures involving donkey skins from publicly available online news reports and official custom press releases from 1990 to 2020 to aggregate information on which products were co-seized along with donkey skins. In addition to news and customs reports, we also obtained trade records from the Environmental Investigation Agency (EIA) (2020), these including seizure records on rhino horn (707 seizures, ranging from 2006 to 2020), Asian big cats (*Panthera spp.*, 2102, 1990–2020), pangolin (1250, 2006–2020), and elephant tusk (*Elephantidae*, 2656, 2012–2019) from 2006 to 2019. Seizure data are often skewed with certain animal groups receiving more publicity than others, however, the purpose of this study is to present empirical evidence for the parallel trade and trafficking of donkey skins with wildlife products. The inherently biased nature of this seizure database limits our ability to analyze the scale and causal associations between these trades, but these data do provide confirmatory evidence of a link between these two trades.

## 2.2 | Data analyses

We used R version 4.0.5 (R Core Team, 2021) and Gephi 0.9.2 (Bastian et al., 2009; Heymann, 2018) for analyses; R packages ggplot2 (Wickham, 2016) for data visualization.

We note that the data collected from the B2B platforms and their member firms amount to individual-level product assortment information. The assortment decisions of businesses illuminate specific choices made by the vendors, reflecting the expectation that a given final assortment would be profit-maximizing (Balderston, 1956). The logic is fairly simple; adding products that are expected to sell, giving priority to those with higher profit margin and larger volumes, and removing products that require too much effort relative to their profit contribution. Importantly, these decisions are conditional on each merchant's knowledge of their marketplace. As such, the co-offering of products by merchants is necessarily non-random, and reflects the reality of that marketplace (Balderston, 1956). As such, any persistent relationship among products across all merchants highlights underlying similar market processes.

In order to examine the relationship between donkey skins and other products, we constructed a product network based on the co-occurrence of donkeys with all other products sold by merchants on B2B websites, following the standard procedure (Borgatti & Halgin, 2011) described as follows.

To establish which products are co offered by traders within the “donkey skin product network”, we first structured the data collected from the B2B merchants as a bipartite merchant-by-product affiliation matrix (MP matrix),

which contains a set of binary relationships between the merchant and product, where the elements of the matrix denote the number of products (of a category) being sold by each specific merchant. We then multiplied this MP affiliation matrix by its transpose (product-by-merchant matrix), to create the product-by-product adjacency matrix (PP matrix), whose elements represent a continuous measure that captures the strength of relationships between products. In a product network, the strength of a connection conveys information about the relationships between sets of products, for example, strong links might suggest supply chain similarity (vendors might source some sets of products from the same supplier such that certain related products are often found together), demand-side similarity (customers might frequently purchase certain products together, or may commonly transition from one product to another), or may be the result of some other process. It is therefore difficult to specify directional causality in the linkage, and as such, we remain agnostic on this interpretation and the associated underlying mechanism. Rather, we will report the strength of associations between products and return below to a discussion of the implications of these possible mechanisms, given an empirically observed product relationship.

Of note, as the data collection was conditional on the merchant offering donkey skins, the resulting network will have donkey skins as the center-most and most highly connected product. This is known as the donkey skin ego-network of products, and results in a view of the constellation of products that were most directly related to donkey skins, as well as capturing the relational structure exhibited among these diverse ancillary products.

In order to demonstrate the structural composition of the undirected network, our network analyses derived the following metrics from network measurements based on the PP matrix obtained in the previous step.

For network structure, we calculated the following metrics:

1. *Network diameter*: The donkey skin product network comprises “nodes” representing each of the products, and “edges” which convey information about the links between products (nodes). The network diameter is a measure of how quickly one can move from one product to any other in the network (Winship et al., 1996), and is well known as the “six degrees of separation” concept (Watts, 2004). Network diameter measures the longest distance of all calculated shortest paths in a network, and theoretically ranges from 1 to  $N-1$ , where  $N$  is equal to the total number of the products (nodes). The diameter value of a network indicates the number of intermediaries needed to connect to any other product. A diameter of 2 was expected by construction, since our sampling design dictated that all products would be connected to donkey skins. This means that no two items in the donkey product ego network were more than two “steps” away from each other. A theoretical browsing customer could therefore start on any product at random (i.e., drones) and arrive at any illegal product after viewing one intermediary product (in this case, donkey skins, the product at the center of the network). There is therefore a strong possibility that naïve customers might easily “stumble” across wildlife products while browsing for some other product—a process similar to social discovery (Zhang et al., 2017).
2. *Degree and average degree*: The degree is a measure of the number of connections (edges) between products (nodes), providing a measure of the relative importance of each node in a network. Products that are connected to many other products will have a high degree and are thus most likely to lead to the social discovery of other products. The average degree is the average number of edges per product, calculated by using  $(2E/N)$ , where  $E$  is the total number of edges, and  $N$  is the total number of nodes in the network.
3. *Density*: A complete graph is a graph in which every pair of products (nodes) is connected through a direct link (edge). Such a network would have a density equal to 1, meaning the network has all possible edges. The density measures how close the network is to being complete, derived by using the number of edges ( $E$ ) divided by the total number of possible edges in a network (total possible edges =  $N[N - 1]/2$ ). In this case, a high-density value for the network would suggest that each trader sells similarly diverse assortments of products (i.e., most products are seen alongside all other products, indicating that traders are generalists who cater for a mass market rather than focusing on a particular niche or specialized set of products).
4. *Modularity*: We adapted the Louvain method based on modularity optimization (Blondel et al., 2008) with resolution based on Lambiotte et al. (2015) to explore our network communities. The modularity represents the extent to which the network is divided into distinct clusters. A high modularity score would represent a network in which the nodes within clusters are closely connected but have sparse connections to nodes in different clusters (Newman, 2006). A modularity of zero would suggest that the selection of products in a cluster is likely to occur at random.

For network connectivity, we computed the following metrics:

1. *Betweenness centrality*: betweenness centrality is a measure of the centrality of a node in the network

based on the shortest paths between nodes. There is always the shortest path linking any pair of nodes, and it may involve more than one edge, the betweenness centrality of a node is measured as the number of shortest paths, between other pairs of nodes, that pass through that node. This value can reveal the importance of a product in the network and in this case a high betweenness centrality would suggest that a product is connected with a wide basket of other products.

2. *Average clustering coefficient*: clustering coefficient is a measure of the extent to which nodes within a network are connected (Watts & Strogatz, 1998). Values are calculated for each node and range from 0 to 1. Similar to the previously noted Density measure, the average clustering coefficient captures the local interconnectivity of a node among its immediate neighbors (whereas density captures this interconnectivity at the level of the whole network). In a product network, high local clustering implies high levels of similarity, akin to homophily.
3. *Average path length*: the average path length is the average length of the shortest paths between all pairs of nodes in a network. This gives an overall measure of how efficiently connected the network is. In general, this is a measure of how efficiently information might flow through a network (a short average path length would represent an efficient network), but in the case of a product network, this value captures the diversity in the assortment of products across the various traders.

### 3 | RESULTS

We identified 382 companies trading donkey skins; these were engaged in trading a diversity of other commodities that we consolidated into 302 product categories. A total of 29 products related to species of potential conservation concern (sorted into 23 product categories see Table 1) were available for sale in the network. Then, 19% of these traders sold some kind of wildlife products. These included CITES-listed animals and their products, such as Asian Arowana, cheetah, crocodile skin, elephant tusks, falcon eggs, gray parrot eggs, lion skins, conch shells from Bahamas, leopoldi stingray, pangolin scales, rhino horns, seahorses, and tiger skins. In total, we recorded at least 13 groups of CITES-listed species in the donkey skin product network (Table 1).

The diameter value of the “donkey skin product network” was 2, with average path at 1.59. The density value was at 0.409 and the average number of edges per product category was 128.84 (average degree based on

302 nodes and 19,456 edges). We found the averaging clustering coefficient of the network was 0.81, meaning more than 80% of all possible graph triangles were completed, indicating a high-density network. As noted previously, this offers strong evidence for an important role of mass and diversified (versus niche or specialized) traders in the donkey and wildlife trade. Ninety product categories had betweenness centrality at 0. Apart from donkey skins, the five product categories with the highest degree were nuts and seeds, unprocessed fruit, edible oil and fat, meat, and paper. The five product categories with the highest betweenness centrality (apart from donkey skins) were unprocessed fruits, nuts and seeds, animal hides, beans, and edible oil and fat. Among the wildlife products of conservation concern, sea cucumber had the highest degree at 230, directly linked to 230 other products, and big cats had the lowest degree at 36. For those products that served as a transition point between other products, sea cucumber had the highest betweenness centrality at 230.27 and stingray skins had the lowest betweenness centrality at 0.29. There were 11 wildlife product categories with betweenness centrality at zero, meaning that no shortest paths (between pairs of other products) pass through these products.

A network is considered complete when every pair of distinct nodes is connected by a distinct edge, in the case of the donkey skin product network, this would require every distinct product to be sold alongside every other product in the network. In other words, a complete network would be one in which all traders sell an identical basket of goods. Based on the nature of our network in which 382 separate vendors are making independent decisions about the assortment of products that they sell, we would not expect a complete network. Indeed, the global network (the overall network) was incomplete with a density (the measure of such completeness) of only 0.409. However, interestingly, it was still very dense locally, with a clustering coefficient of 0.81. This means that while traders sell different baskets of goods, there are certain groups of products that are often traded together making it extremely easy for consumers to navigate from product to product; this is consistent with the low average path length between products. The high clustering value pointed to a structural similarity across the vendors, and therefore a structural similarity to these products (e.g., either sourced or sold together).

Our analyses identified five sub-communities (modularity = 0.057) in the network structure of the donkey product network, containing 153, 79, 50, 20, and 13 product categories (nodes). These clusters of products seemed to fit the following broad descriptions: agriculture products with seafood ( $n = 153$ , denoted by C1), more than 50% of the product categories found in this cluster were

**TABLE 1** The wildlife products identified in the sub-communities (C1–C5) of the donkey skin product network and their CITES status

| Types of wildlife product and donkey skin ( <i>n</i> = 24) | Product name ( <i>n</i> = 29)   | Products with seizure history with donkey skins | CITES-listed species | C1 ( <i>n</i> = 153) | C2 ( <i>n</i> = 79) | C3 ( <i>n</i> = 50) | C5 ( <i>n</i> = 13) |
|--|---------------------------------|---|----------------------|----------------------|---------------------|---------------------|---------------------|
| Big cats   | Tiger                           | x   | x                    |                      | x                   |                     |                     |
| Big cats   | Cheetah                         |   | x                    |                      | x                   |                     |                     |
| Big cats   | Lion                            |   | x                    |                      | x                   |                     |                     |
| Conch shell from Bahamas                                   | Conch shell from Bahamas        |   | x                    | x                    |                     |                     |                     |
| Crocodile skin   | Crocodile skin                  |   | x                    |                      | x                   |                     |                     |
| Eggs of pet birds  | Falcon eggs                     |   | x                    |                      | x                   |                     |                     |
| Eggs of pet birds  | Gray parrot eggs                |   | x                    |                      | x                   |                     |                     |
| Elephant   | Elephant tusks                  | x   | x                    |                      | x                   |                     |                     |
| Pangolin scales  | Pangolin scales                 | x   | x                    |                      | x                   |                     |                     |
| Pet fish   | Asian Arowana                   |   | x                    | x                    |                     |                     |                     |
| Pet fish   | Leopoldi Stingray               |   | x                    | x                    |                     |                     |                     |
| Rhino horn   | Rhino horn                      |   |                      |                      | x                   |                     |                     |
| Abalone  | Abalone                         | x   |                      | x                    |                     |                     |                     |
| Animal horns   | Animal horn antler velvet skull |   |                      | x                    |                     |                     |                     |
| Bird nest  | Bird nest                       |   |                      | x                    |                     |                     |                     |
| Caviar   | Caviar                          |   |                      |                      | x                   |                     |                     |
| Coral  | Coral                           |   |                      |                      | x                   |                     |                     |
| Cordyceps  | Cordyceps                       |   |                      | x                    |                     |                     |                     |
| Donkey skin  | Donkey skin                     |   |                      |                      | x                   |                     |                     |
| Dried goliath beetles                                      | Dried goliath beetles           |   |                      | x                    |                     |                     |                     |
| Fish maw   | Fish maw                        | x   |                      | x                    |                     |                     |                     |
| Frog skin  | Frog skin                       |   |                      |                      | x                   |                     |                     |
| Live reptile   | Live reptile                    |   |                      | x                    |                     |                     |                     |
| NA   | Shark fin <sup>a</sup>          | x   |                      |                      |                     |                     |                     |
| Scorpion   | Scorpion                        |   |                      | x                    |                     |                     |                     |
| Sea cucumber   | Sea cucumber                    | x   |                      |                      |                     |                     | x                   |
| Seahorse   | Seahorse                        |   | x                    |                      | x                   |                     |                     |
| Stingray skin  | Stingray skin                   |   |                      |                      | x                   |                     |                     |
| Tortoise skin  | Tortoise skin                   |   |                      |                      |                     | x                   |                     |

Note: The table excludes community C4 because it contained no wildlife products.

<sup>a</sup>Shark fins were documented as being seized alongside donkey skins but were not found in the donkey skin product network.

associated with either the agriculture or seafood industries. Agriculture products (*n* = 79, C2), more than 56% of the product categories in this cluster were associated with the agriculture sector. Logs and timber (*n* = 50, C3), composed of at least 60% log and timber products. Health food supplements (*n* = 20, C4) consisting of 75% health food supplements. C5 cluster seemed to consist of a

miscellany of other products the majority of which (86%) fell under the broad categories of beauty products, household goods, personal care, and personal protective equipment (PPE) products (*n* = 13).

Sub-community analysis described the relevant structure of smaller components of the overall network. Specifically leveraging standard clustering ideas to isolate



parts of the network that shared a higher degree of similarity from those that were more distinct. The five distinct communities in this study are divided largely (although not necessarily exclusively) across product categories, such as agriculture or timber. Importantly, this analysis grouped the products into subcommunities without explicit information about the product labels. Therefore, the fact that categories of products were clustered together served as evidence of an underlying structure and similarity between products in groups (e.g., timber moved with other timber products, and customers who searched for PPE might browse multiple PPE alternatives). As additional validation, the top 10% most connected (highest degree) products were split across the three largest groups, suggesting that the modularity calculation and clustering processes underlying subcommunity identification were not simply identifying homophily (e.g., all popular products grouped together).

Importantly, wildlife products were mostly situated within the two largest sub-communities (C1 and C2, Table 1). Donkey skins themselves were grouped in the second-largest community (C2). This C2 sub-community was closely connected and mostly contained products relating to agriculture, but it also contained numerous wildlife products including big cats (tiger, lion, and cheetah), caviar, coral, crocodile skins, elephant tusks, frog skins, pangolin scales, parrot, and falcon eggs, rhino horns, seahorse, and stingray skins; 10 of the above animal groups were CITES-listed. This co-location into the same sub-community strongly suggested that these items share some underlying similarities that would favor their co-commercialization.

Furthermore, much like the whole-network, C2 was densely connected, with an average clustering coefficient of 0.77 (compared to a value of 1 for a fully connected network), a diameter of 2, and a similarly short average path length of 1.56, suggesting that even within this sub-community, navigating from donkey skins to a species of conservation concern is, in practice, extremely easy.

Records of products being seized together provided evidence that they were at least sometimes shipped together as well as being co-offered by the merchants. From published news reports, the following four wildlife products had been seized alongside donkey skins: abalone, fish maw, sea cucumber, and shark fins. Donkey skins also have been found to have been seized alongside elephant tusks, pangolin scales, and tiger skins. Of these, elephant tusk, tiger skin, and pangolin scales were CITES-listed; abalone was listed under EU Wildlife Trade Regulations. However, even legal trade of species that were not CITES-listed can have major impacts on wild populations (Marshall et al., 2020). Other products co-seized with donkey skins included liqueur and pet food.

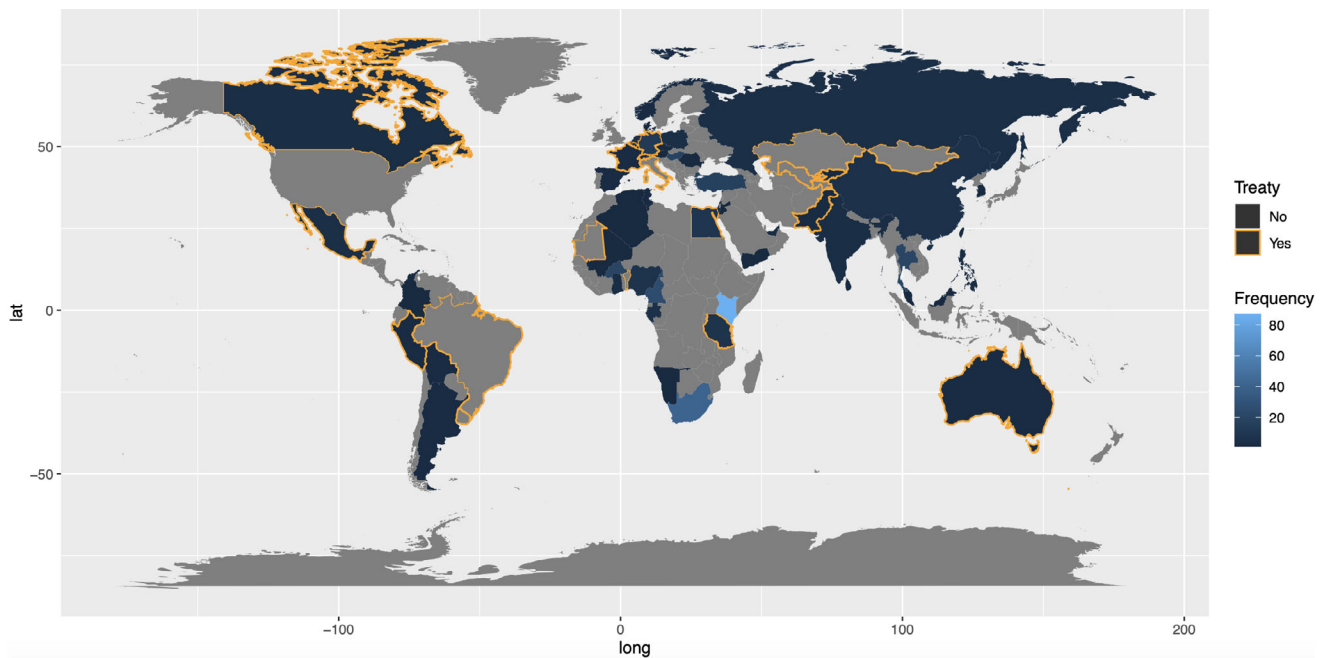
## 4 | DISCUSSION

### 4.1 | Legal ambiguity of the trade in donkey skins

High demand for E-Jiao in China is driving an international trade in donkey skins, and consequently, China represents the ultimate destination for the vast majority of donkey skins entering the market. Competition for donkey skins became acute in the early 21st century, when the two biggest E-Jiao enterprises, Dong-E-E-Jiao and Fupai, were licensed to import donkey skins from 17 and 15 countries in 2016 and 2015, respectively (Dong-E-E-Jiao, 2016; Fupai E-jiao, 2019).

Currently, China has treaties with 23 countries from which it can legally import donkey skins (General Administration of Customs of the People's Republic of China, 2019). Of these, Ghana, Nigeria, and Kenya have enacted domestic legislation banning the slaughter of donkeys and the export of their skins (The Donkey Sanctuary, 2019). Thus, we currently identify 20 countries that can legally export donkey skins to China; however, our analysis revealed traders listed in over 55 countries (Figure 1) In addition, some of the countries from which imports were permitted by China have introduced different levels of national restrictions for slaughter or/and trade of donkeys. It is important to note that this location information may not necessarily reflect the traders true operating footprint and more likely reflects the legal status of the companies—however, given the nature of this trade, the apparently opportunistic nature of the traders in our analysis, and the apparent lack of legal enforcement, we should not exclude the possibility that this geographic diversity hints at complex trade networks extending beyond the borders of the 20 countries with legal trade agreements.

The harmonized system of tariff codes is an internationally standardized classification system for international trade. Internationally traded items are assigned a multi-digit code in which subsequent pairs of digits denote increasing levels of resolution in the product description (e.g., the first two digits denote cereals, the next two digits denote rice, the next two denote how the rice has been milled). China classifies donkey skins as a distinct product category (HS 4101 20 20 91) separate from bovine or other equine skins, however, most trade databases, such as UN Comtrade Database, provide a truncated six-digit HS code (in this case, HS 4101 20) which also includes both bovine and equine skins. This six-digit code is also typically used by shipping and customs agencies. The lack of a distinct tariff code for donkey skins means that there is no easy mechanism for differentiating between consignments of donkey and other categories of skin. This hampers efforts to monitor



**FIGURE 1** The network analysis revealed traders listed in over 55 countries. The numbers of traders in each country ranges from 1 to 87. The map shows the frequency of traders detected in each country (blue hue). Countries from which E-Jiao producers can legally import donkeys and their skins are highlighted with orange borders. Currently, China allows E-Jiao producers to import donkey skins from a list of 23 countries with relevant trade agreements with China. Of these, three countries (GHA, NGA, and KEN) have enacted domestic bans on the donkey skin trade and so these have been excluded from the list of legal source countries

the trade and enforce existing regulations. Future research on the legality of the donkey skin trade will be valuable in devising appropriate policy solutions.

## 4.2 | The link of the wildlife and donkey skin trade

Combining the co-seizure records with information from B2B e-commerce websites, we have highlighted a clear association between the trade in donkey skins and the wider wildlife trade. The donkey skin product ego-network is densely connected; it needs only one single intermediary for one product (donkey skins) to connect to any other product in the network. This network structure emerges as a result of our study design focusing exclusively on traders who sold donkey skins. However, the existence of a variety of wildlife products, including those with a co-seizure history with donkey skins, indicates that these products were not only co-offered by the merchants but also shared, at least partially, their transportation routes. In addition, we identified products derived from at least 10 CITES-listed animal groups that had no record of being co-seized with donkey products. This hints at the possibility that the donkey skin trade may be associated with conservation-relevant species that has so far been recorded.

Our results reveal that donkey skins and wildlife products are both offered together and shipped together. We are not able to assess the provenance of the wildlife products offered for sale, however, many of the species discovered in our network are either IUCN or CITES-listed, requiring strict regulatory adherence to trade legally. Given the generally acknowledged lack of enforcement surrounding wildlife trade, it is not unreasonable to think that at least some of the wildlife products that we detected would fail to meet these criteria. The fact that these products are openly listed for sale alongside a diverse basket of other products raises concerning opportunities for the social discovery and legitimization of these products, two processes well documented in the wider business literature (Humphreys, 2010; Zhang et al., 2017). Thus, the existence of such links raises the possibility that a consumer who enters the market might accidentally stumble across, and possibly then purchase, wildlife products for sale even if that was not their original intention.

## 4.3 | How donkey skin product network and wildlife trade network interacted

The donkey skin product network is a densely connected network, as is the wildlife product network with which it

intersects. The clustering of products in our dataset suggests that this intersection is established mainly through products in the agriculture industry, to which the donkey skins belong. More than 70% of the companies sell multiple products; on average, each product in the network is connected to 40% of the other products in the network. This suggests that the donkey network is likely to be highly coordinated. The low average path length, high average clustering coefficient value, and the high number of products (almost 30%) with betweenness centrality at 0, mean that many of the products are closely interconnected with either short or direct links. With an average path length of 1.59, we also know that consumers can, and do, move directly among products, often finding single steps to a potentially illegal wildlife product. This marks a strong opportunity for customers to be exposed to wildlife products, or to “stumble” upon them when searching for something else, a process similar to social discovery (Zhang et al., 2017). Our betweenness centrality measures illustrate the potential role of each product in facilitating this “jump” into a new product discovery. Sea cucumbers (with the highest betweenness centrality) function as a strong connector to other products, while stingray skin (with the lowest betweenness centrality) is far more likely to be a starting or ending point in a consumer journey. The large number of products offered, the diversity of product categories, and the structure and commonality of product assortment decisions by independent and diverse traders (existing in 55 countries) all suggest that these trade links are essentially opportunistic, with traders responding to the availability of products and suitable transportation pathways. Within this framework, the one-stop business model can create a legal network for illegal activities (EMS Foundation and Ban Animal Trading, 2018).

#### 4.4 | Sub-communities of the donkey skin product network: Donkey skins are particularly associated with CITES-listed species products

The donkey product ego-network is divided into sub-communities that are closely connected internally but with comparatively sparse connections between sub-communities (Girvan & Newman, 2002; Newman, 2006) and these sub-communities have been shown to have important real-world meaning (Newman, 2006). In the product network, we were able to identify five distinct clusters of products, dominated by products ranging from agriculture to PPE products. The traders in our network thus appear to be opportunistic generalists and the assortment of products offered for sale may reflect underlying market processes, or similarities between products, that lead to the emergence of these different clusters. For

instance, a merchant may stock items that their consumers frequently buy together (demand side similarity), they may source groups of items from the same supplier (supply side similarity) or there may be commonalities in the logistical requirements for storing or shipping of certain products (operational similarity). The co-occurrence of donkey skins with products derived from CITES-listed species in cluster C2 suggests a strong link between these particular products. It is currently unknown whether these associations are driven by demand side, supply side, or operational similarity and this is an important area for future research.

Our study suggests the donkey skin trade merits greater levels of interest and scrutiny from conservation practitioners and policy makers. This scrutiny is warranted by the negative economic and political impacts of the trade, the trade's legally ambiguous nature, the number of species of conservation concern associated with the trade, and the underlying social discovery of wildlife products within the donkey skin product network. Our study demonstrates that donkey skins are both offered and shipped together with a variety of wildlife products highlighting the possibility that the legally complex trade in donkey skins may provide a novel and poorly understood pathway for wildlife trade. The existence of wildlife products available for sale alongside donkey and other products creates the opportunity for social discovery of these products potentially stimulating demand for the wildlife trade. Network analysis of the clusters of products most commonly associated with wildlife suggests several potential hypotheses for the underlying drivers of these relationships. This raises concerns that the trade in donkey skins may provide an opportunity, conduit, and cover for the trade in wildlife products (and perhaps other illicit trade), or vice versa. However, more research is needed to understand better the causality of these links and develop policy solutions. In the meantime stronger monitoring and enforcement of the legally complex trade in donkey skins may have benefits for wildlife conservation, particularly if targeted at shipping and transportation hubs. Finally, our analyses also revealed the association between the donkey skin trade and the logging industry. Despite many similarities between the logging and wildlife trades, they are often considered and tackled separately. Better understanding this intersection between the donkey skin, wildlife, and timber trades will be an important focus for the future.

#### ACKNOWLEDGMENTS

Ewan A. Macdonald is supported by Saïd Business School's Future of Marketing Initiative. The Donkey Sanctuary recognized, through anecdotal and other initial evidence, that a link existed between IWT and the donkey skin trade and funded the independent assessment

described in this article. We thank Environmental Investigation Agency (EIA) for supplying the global database on seizure records.

## CONFLICT OF INTEREST

None of the authors have any competing interests, and the manuscript is not being considered for publication elsewhere.

## AUTHOR CONTRIBUTIONS

All authors made substantial contributions to the conception and methodology of the work. **Shan Su:** Investigation, Data Curation, Formal analysis, Visualization, Writing – Original Draft. **Ewan A. Macdonald:** Conceptualization, Investigation, Writing – Reviewing and Editing, Project administration, Funding acquisition. **Maurice Beseng:** Investigation, Writing – Reviewing and Editing. **Felipe Thomaz:** Writing – Reviewing and Editing, Supervision, Validation. **David W. Macdonald:** Writing – Reviewing and Editing, Supervision, Funding acquisition.

## DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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**How to cite this article:** Su, S., Macdonald, E. A., Beseng, M., Thomaz, F., & Macdonald, D. W. (2022). The link between wildlife trade and the global donkey skin product network. *Conservation Science and Practice*, e12676. <https://doi.org/10.1111/csp2.12676>