



Characterising the links between the trade in donkey skins for traditional Chinese medicine and timber of conservation concern

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ABSTRACT

Trade in donkey skin for the production of E-Jiao, a Traditional Chinese Medicine, has been linked to the international wildlife trade, including the timber trade. We investigated timber species available in the donkey skin trade networks in business-to-business e-commerce websites in terms of species origins, supply, and demand. Using 340 product categories offered by 385 traders located in 55 countries we conducted a network analysis centred on trade in donkey skins. We identified over 60 tree species of 54 genera and 22 families, most of the species of conservation concern were native to Africa, including four hongmu species, which are high-value tree species identified by the National Rosewood Standard in China. We found 24 tree species of global conservation concern included in the donkey skin product network; these are designated by CITES in Appendices and/or by the IUCN as threatened or near-threatened. The presence of both donkey skins and timber species of conservation concern indicates a need for heightened surveillance and transparent reporting of the donkey skin trade. Furthermore, this points to a fresh avenue for monitoring the trade of timber, particularly for those species that are linked to the donkey skin product network.

1. Introduction

International wildlife trade is a significant threat to a great number of species, and trade-related threats take diverse forms (Lenzen et al., 2012; Marsh et al., 2022; Morton et al., 2021; Scheffers et al., 2019). While not all wildlife trade is negative, poorly or unregulated trade has the potential for substantial negative impacts on a wide range of plant and animal species (Fukushima et al., 2020; Macdonald et al., 2021). Among the various uses of traded animals and plants, traditional medicine has been increasingly highlighted as a potential threat to biodiversity (Byard, 2016; Cheung et al., 2021; Mills and Mainka, 1995). Donkeys (*Equus asinus*) are used in

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Traditional Chinese Medicine (TCM) where their skins are used to produce E-Jiao, a health and beauty product that can cost up to 750 USD/kg in China (Dong E E Jiao, 2020). China is the largest consumer of E-Jiao with an estimated 5600 tons consumed in 2016, with a corresponding market value of nearly 4 billion USD (Jing, 2017).

The high level of E-Jiao consumption in China drives a high and increasing demand for donkey skins on the international market. Donkey skin for E-Jiao is taken from both domestic and feral donkeys. Although donkey farming is growing in certain regions, such as China where donkey meat and hides are highly valued, the donkey's lengthy reproductive cycle poses challenges and requires substantial investments of time and money. As the result, a gap exists between domestic supply and demand in China. Consequently, companies have turned to sourcing donkey skins from outside of China, primarily from African countries where donkeys are mainly used for work and transportation. Many of the donkeys sourced from African countries are feral, but the increasing demand and rising prices for donkey skins has caused unsustainable harvesting. Now, the high international value of their skins has incentivised the theft of donkeys from communities which rely on them for the labour they provide. This escalating incidence of donkey theft can push affected households into even greater poverty (Brooke, 2019), jeopardize the livelihoods of these vulnerable communities (Maichomo et al., 2019). Moreover, the international trade in donkey skins is often poorly regulated, with different sets of rules governing donkey skin exports in different countries (Su et al., 2022; The Donkey Sanctuary, 2019). A number of countries have responded by implementing regulations or complete bans on the trade of donkey skins. From 2015–2020, at least 19 countries across three continents have taken various measures against the donkey skin trade, including bans, restrictions on slaughter, and strict prohibitions on donkey skin exports. Notably, eBay enacted a ban on the sale of E-Jiao products in 2017, while the World Veterinary Association has called for a cessation of the skin trade. These actions highlight the global recognition of the issues associated with the donkey skin trade (The Donkey Sanctuary, 2019). In countries where the trade is legal, there are often illegal practices associated with the sourcing, transport, and slaughter of donkeys, which undermine efforts by national governments to protect their donkey herds. Despite the implementation of regulations and bans, concerns remain regarding their effectiveness in addressing the underlying issues related to sustainability and animal welfare. Furthermore, the trade is also linked to concerns about environmental contamination and biosecurity risk (The Donkey Sanctuary, 2022, 2019). Recent findings by Su et al. (2022) provide evidence that the online trade in donkey skins is closely associated with wildlife trade, including the timber trade. In this study, we aim to extend these results by investigating the connection between the online trade in donkey skins and specific timber and wood products that are also in high demand within the Chinese market.

In many countries, timber and non-timber forest products play a crucial role in local economies. However, unsustainable harvesting practices can lead to negative impacts both directly to the community, as well as indirectly through its contributions to deforestation, wildlife loss, habitat degradation, and the reduced natural productivity of ecosystems and agriculture (Aguiar et al., 2012; Mayer, 2005; Nepstad et al., 1999). China is one of the major consumers of tropical timber and hongmu (rosewood), a category of precious woods with cultural significance used for high-end furniture (Huang and Sun, 2013; ITTO, 2021; Richards et al., 2022; Treanor, 2015). The National Rosewood Standard of China classifies the heartwood of 29 species from five genera (*Pterocarpus*, *Dalbergia*, *Diospyros*, *Millettia*, and *Senna*) as hongmu (GB/T 18107–2017) (National Standards of the People's Republic of China, 2017). However, non-listed species from the five genera can also be traded as hongmu, subject to specific conditions. This allows sellers to meet the demand for precious wood by searching for alternatives from different regions or species. In 2014, China's rosewood imports had grown by 12.5 times since 2000, reaching nearly 2 million m³ (Treanor, 2015). As of 2020, over 83% of China's rosewood imports came from Africa, and the proportion of hongmu species among all hardwood logs imported from West Africa increased from 34% in 2011 to 77% in 2020 (Richards et al., 2022).

In international trade, illegal products are often traded alongside legal product, and there are also various forms of interconnections among illegal products (Boakye, 2015; Chatham House, 2018; Environmental Investigation Agency, 2016; Esmail et al., 2020; INTERPOL, 2019; World Bank Group, 2019). Examples include the trade of caviar alongside weapons (Musing et al., 2019) and the link between legal timber and illegal drugs (Devlin, 2016). These connections manifest in diverse ways, such as the sharing of shipments, utilization of established transportation routes, exploitation of legal trade as a cover for illegal trade, and the operation of multiple trade lines by the same trade group (Van Uhm et al., 2021). Cultural demands play an important role in shaping regional trends in wildlife trafficking and markets, particularly the demand in China and across Asia for traditional medicines (Van Uhm et al., 2021). In some cases, wildlife trade occurs in conjunction with other trade. For example, pangolin scales used in traditional Chinese medicine were found to be smuggled alongside methamphetamine into China (Jacobs et al., 2019). Additionally, there have been records of large-scale smuggling of 17 tonnes of donkey skins and 1 tonne of shark fins, falsely declared as salt, in Hong Kong (Customs and Excise Department, 2020). Just as in legal markets, illegal traders seek to maximize profits and minimize costs by optimizing their supply chains. Thus, once a trade route is established, traders may seek to maximise the return on their investment by using it to funnel multiple products and product types. Given the increasing demand in China for both E-Jiao and precious timber, we posited that valuable timber species, including hongmu and substitute products, originating from African countries, may be interconnected within the donkey skin trade network, driven by their shared high demand in China.

The global timber trade is a vast network of commerce, with an annual value of hundreds of billions of dollars (FAO and UNEP, 2020; Nellemann et al., 2016). However, illegal logging activities are estimated to account for a significant portion of global timber production, ranging from 15% to 30%, with a monetary value ranging from \$51–152 billion in 2019 (INTERPOL, 2019). Despite the implementation of legal restrictions, illegal exports of CITES-listed species still occur (EIA, 2019). Furthermore, the legal timber trade is often associated with illegal logging, which together contribute to deforestation, wildlife declines, and wildlife crime, resulting in significant economic losses for many countries (Arcilla et al., 2015; EIA, 2021; Esmail et al., 2020; Macdonald et al., 2021). Inconsistencies and loopholes in laws between countries pose a challenge to regulating this trade (UNODC, 2020).

To address these issues and to combat illicit activities in the timber trade, researchers and governments have made significant efforts to understand the dynamics of the trade and the species involved. It is likely that the trade networks for donkey skins and

precious timber from African countries are associated, as they both share a common demand and may be destined for the same market. In our study, we aim to document the timber species involved in the donkey skin product network. This will provide a new perspective on the investigation of this trade, despite it being a small portion of the much larger global timber trade. Understanding the trade network can also potentially help to improve forest management, law enforcement and the conservation of species.

2. Methods

2.1. Data collection

To describe the links between online-based trade in donkey skins and timber, and to identify tree species traded within the donkey skin product networks, we first adapted data collected in [Su et al. \(2022\)](#) and then collected new data to inform our focus on timber products in this study. The original online trade data were compiled using Mozenda data extraction software ([Mozenda, Inc, 2021](#)) between January and April in 2020 from seven business-to-business e-commerce platforms (B2Bs) where donkey skins were available for sale ([Su et al., 2022](#)). On each site, all instances of “donkey skins” in both English and Mandarin were searched in order to identify all traders who offered donkey skins as part of their product offerings. English was selected because it is often used in international online trade and because it was the default language on all of the platforms analysed in this study. Mandarin was also selected because China is the dominant consumer country of donkey skin products ([Su et al., 2022](#)). For traders who offered donkey skins, [Su et al. \(2022\)](#) collected data on the complete list of all other products that sellers offered for sale on the platform during that time period. In total, the database included 385 sellers located in 55 countries and comprised 302 product categories from 14,949 data points offered by sellers who traded donkey skins ([Su et al., 2022](#)). We took the information provided by traders at face value, given that this information was provided to potential business partners; stated locations of trading companies may refer to either their legal registration or physical locations.

The raw dataset of products contained many similar products along with the same products listed under slightly different names or descriptions. It was therefore necessary to categorise the raw products into similar product categories. For example, a product title might include “spices, chili, pepper and bay” or “tilapia, shrimp and other seafood”. We sorted products systematically, removing all brand names and adjectives, such as “fine” or “beautiful”. Products were then renamed based on the information given in the advertised product name and grouped into categories such as product-industry, product-type, product-usage or product-source material. Examples of product categories include: agricultural machinery, engine oil, and used oil. Other examples, based on common product categories in supermarkets include: dairy, meat, seafood, fruit, spices, vegetables, beverages and beauty products. In some cases, if a sub-group was characterised by potential conservation concerns, such as sea cucumber or crocodile skin, then it was extracted from the wider seafood or fashion categories, and categorised by species or genus ([Su et al., 2022](#)).

In the original [Su et al. \(2022\)](#) analysis, the primary focus was on the link between donkey skins and wildlife products, and thus timber products were grouped into coarse timber product categories. The current study aims to better understand the particular links with the timber trade, therefore we explore this particular set of products in more detail.

For this study, we obtained timber product information from the advertised primary product names and the product details listed as part of each listing. We investigated each of the advertised timber products via their URL link obtained from the B2B platforms. The URL links led to further product information, in which additional timber species were sometimes listed for sale in addition to the primary products. We compiled information on all available timber species for sale in the same post. Traded timber species advertised on e-commerce websites generally used country-specific product names, which we standardised following the Association Technique Internationale des Bois Tropicaux ([ATIBT, 2016](#)). Whenever possible, we identified traded timbers to species. However, in some cases, advertised product names may refer to several species of a genus. For example, “mahogany” can refer to genuine mahogany (*Swietenia* spp.), African mahogany (*Khaya* spp.) or “bastard” mahogany (*Carapa* spp.). In these cases, we classified species to genus and family level following the APG IV classification system ([Markus, 2017](#)) via The Plant List ([The Plant List, 2013](#)). We classified all rosewoods as genus *Dalbergia* unless specified otherwise. Consequently, the estimated number of species represents the minimum count of potential species. Eighteen timber species could not be identified to taxonomic species, genus or family level from the given image or description, these were categorised as “unidentified timber.” Full details of our classification are given in [supplementary material A](#).

With the great number and diversity of products identified in the donkey skin product network, it is challenging to follow strictly a standardised assortment method. This means that the reported links between some product categories might be different if we had used a different classification system (e.g. treating each post as a unique product). However, this bias is largely confined to the non-wildlife and non-timber products that occurred within the network since it was possible to use a consistent taxonomic classification system for wildlife and timber products (to genus or species level). The primary interest of this study is in the relationships between these well-defined product categories, and consequently, the potential biases arising from the product categorisations are likely to be of secondary concern.

2.2. Data management and analyses

We used R version 4.0.5 ([R Core Team, 2021](#)), R package *stringr* ([Wickham and RStudio, 2019](#)), OpenRefine ([Ham, 2013](#)), and Gephi 0.9.2 ([Bastian et al., 2009](#); [Heymann, 2018](#)) for text processing, data management, and analyses.

2.3. Donkey skin product network construction

To explore the donkey skin product network, we created a product adjacency matrix for all products available in the donkey skin product network, including donkey, timber, wildlife and other products. To achieve this, we first compiled a merchant-by-product adjacency matrix (denoted as MP matrix), in which the cell value showed the numbers of products in the given category offered by each merchant. We multiplied the MP matrix by its transposed matrix to obtain a product-to-product matrix (PP matrix), in which the values represent the strengths of the relationship between product categories.

We describe the relationships between products in the donkey skin product network using three specific network measurements: diameter, degree and density. Diameter is akin to the “six degrees of separation” concept (Watts, 2004), and is defined as a measure of how quickly one could move from one product to another product in the network (Winship et al., 1996). Because this network is based on a search of all traders who sell donkey skins, the network has a diameter of two by construction. This means that every product in the network is connected to every other product in the network by no more than two steps (links), or one intermediary. For example, within the network, a customer could start by browsing for any product at random (i.e., used cooking oil) and reach any other product, including illegal ones, after viewing one intermediary product, specifically via donkey skin. Degree is defined as a measure of the relative importance of each node in a network, where a high degree indicates that this node is connected to a high number of other products. Density is described along a gradient in which a complete network has a density value equal to 1, in which every possible pair of products is connected by a direct link.

We also explored network connectivity using two additional parameters: betweenness centrality and average clustering coefficient. Betweenness centrality is a measure of the centrality of a node in the network, revealing the importance of a product in the network based on the shortest path between nodes. A high betweenness centrality would suggest that a product is connected with a wide basket of other products. Average clustering coefficient is a measure of the degree to which nodes are connected in a network. It describes the local interconnectivity between immediate neighbours, compared to the density measurement which captures this interconnectivity at the level of the whole network. High local clustering indicates high levels of similarity in a product network.

3. Results

As reported in (Su et al., 2022), we documented a total of 385 donkey skin traders; of these 28 (listed in 10 countries) also offered timber products. This new analysis reveals that these traders offered a total of over 60 timber products across 54 genera and 22 families. Among the 60 timber products, we were able to identify 35 to species level, of which more than 80% of these species were native to Africa. We identified 24 timber products derived from species of conservation concern, with 19 products being identified at the species level (Table 1), among these, 17 are distributed throughout sub-Saharan Africa, with populations found in various countries

Table 1

Timber species of conservation concern detected in the donkey skin product network (n = 24) and their conservation status. All species in genus *Aquilaria*, *Dalbergia* and *Swietenia* are CITES-listed; as are all three species called bubinga in the genus *Guibourtia*.

Product name	English name	Family	Genus	Species	IUCN	CITES	Hongmu species
Kosso (Vène)	(West) African rosewood	Fabaceae	<i>Pterocarpus</i>	<i>Pterocarpus erinaceus</i>	EN	II	x
Blackwood (Grenadillo)	African blackwood	Leguminosae	<i>Dalbergia</i>	<i>Dalbergia melanoxylon</i>	NT	II	x
Ébène d'Afrique	African ebony	Ebenaceae	<i>Diospyros</i>	<i>Diospyros crassiflora</i>	VU		x
Wengé		Leguminosae	<i>Millettia</i>	<i>Millettia laurentii</i>	EN		x
Afromosia	African teak	Leguminosae	<i>Pericopsis</i>	<i>Pericopsis elata</i>	EN	II	
Padouk d'Afrique	Bloodwood	Fabaceae	<i>Pterocarpus</i>	<i>Pterocarpus tinctorius</i>	LC	II	
Agarwood		Thymelaeaceae	<i>Aquilaria</i>			II	
Rosewood		Leguminosae	<i>Dalbergia</i>			II	
Bubinga	African rosewood	Leguminosae	<i>Guibourtia</i>			II	
Mahogany	Mahogany	Meliaceae	<i>Swietenia</i>			II	
Mukulungu		Sapotaceae	<i>Autranella</i>	<i>Autranella congolensis</i>	EN		
Radiata pine	Monterey pine	Pinaceae	<i>Pinus</i>	<i>Pinus radiata</i>	EN		
Makoré		Sapotaceae	<i>Tieghemella</i>	<i>Tieghemella heckelii</i>	EN		
Okoumé	Gaboon	Burseraceae	<i>Aucoumea</i>	<i>Aucoumea klaineana</i>	VU		
Moabi	African pearwood	Sapotaceae	<i>Baillonella</i>	<i>Baillonella toxisperma</i>	VU		
Sapelli	Sapele	Meliaceae	<i>Entandrophragma</i>	<i>Entandrophragma cylindricum</i>	VU		
Kosipo	Kosipo mahogany	Meliaceae	<i>Entandrophragma</i>	<i>Entandrophragma candollei</i>	VU		
Sipo	Sipo mahogany	Meliaceae	<i>Entandrophragma</i>	<i>Entandrophragma utile</i>	VU		
Éyong	White sterculia	Malvaceae	<i>Eribroma</i>	<i>Eribroma oblonga</i>	VU		
Azobé	Red ironwood tree	Ochnaceae	<i>Lophira</i>	<i>Lophira alata</i>	VU		
Zingana	Zebrarwood	Leguminosae	<i>Microberlinia</i>	<i>Microberlinia brazzavillensis</i>	VU		
Bilinga	Opepe	Rubiaceae	<i>Nauclea</i>	<i>Nauclea diderrichii</i>	NT		
Imbuia	Brazilian olive wood	Lauraceae	<i>Ocotea</i>	<i>Ocotea porosa</i>	VU		
Abura			<i>fleroya</i>		VU		

including Angola (8 species), Benin (2), Burkina Faso (2), Botswana (1), Cameroon (16), Central African Republic (6), Chad (1), Congo (12), Côte d'Ivoire (10), Eritrea (1), Eswatini (1), Ethiopia (1), Equatorial Guinea (5), Gabon (14), Gambia (1), Ghana (9), Guinea (8), Guinea-Bissau (1), Kenya (1), Liberia (6), Malawi (2), Mali (2), Mauritania (1), Mozambique (2), Namibia (1), Niger (1), Nigeria (13), South Africa (1), Senegal (2), Sierra Leone (7), South Sudan (1), Sudan (1), Tanzania (2), The Democratic Republic of the Congo (12), Togo (4), Uganda (4), Zambia (2), and Zimbabwe (1); while 2 of which are originated from Mexico, the United States, and Brazil (IUCN, 2023).

There were 11 species classified by the IUCN as vulnerable (VU), two as near threatened (NT), and six as endangered (EN). At the genus level, we identified nine traded genera containing VU species, and six genera containing EN species. We found at least seven CITES-listed timber species within the donkey skin product network, including: African blackwood (*Dalbergia melanoxylon*), afrormosia (*Pericopsis elata*), kosso, padouk d'Afrique (*Pterocarpus tinctorius*), *Aquilaria* sp., *Dalbergia* sp., bubinga (*Guibourtia* sp.), and *Swietenia* sp. While we were unable to identify products from the latter four genera to species, it is important to note that all three species named bubinga are listed under CITES. Furthermore, all species of the genera *Aquilaria*, *Dalbergia* and *Swietenia* are CITES-listed. Therefore, it is possible that there may be additional CITES-listed species present if the unknown *Dalbergia* sp. differs from *D. melanoxylon* at the species level. At least four species from four genera were hongmu species. Additionally, we identified five of the CITES-listed tree species most commonly found in illegal trade (according to available illegal trade data identified by CITES (CITES, 2022a)) (Table 1). The majority of timber species of conservation concern identified in our study originated from Africa. Donkey skin sellers who also offered timber were registered in several countries in Africa, including Cameroon, Kenya, and South Africa, as well as countries outside of Africa, such as China, Hungary, Sri Lanka, Thailand, Ukraine, the United Kingdom, and the United States. It is likely that those sellers registered outside of Africa are primarily involved in import or re-export. Some e-commerce platforms also provide information on the origins of the products, such as sellers registered in China offering tree species that originated in Nigeria. The hongmu species identified in our study were provided by 11 sellers located in six countries, including Cameroon (3 sellers), Kenya (1), South Africa (2), Thailand (1), United Kingdom (1), Ukraine (1), and United States (2).

Analyses to describe the structure of the network showed high levels of connectivity, with an average clustering coefficient of 0.81, and high density. The average degree was 145.64 (nodes = 340; edges = 24,759), and graph density was 0.43. Since this network was centred on donkey skins, the network diameter was 2 by design, and, as expected, donkey skins had the highest degree value and betweenness centrality of all products in the network. Apart from donkey skin (betweenness centrality = 1610), the top five products, in terms of highest degree value (highest numbers of connections to other products) and the highest betweenness centrality values, were: 1) nuts and seeds (degree = 337; betweenness centrality = 874); 2) paper (330; 773), 3) meat (328; 733), 4) unprocessed fruit (327; 863), and 5) edible oil (327; 767). It is noteworthy that in comparison to the aforementioned product categories, timber products exhibit relatively lower centrality value. The top five timber products with the highest degree value also exhibited the highest betweenness centrality values; these were unidentified timber (236; 251), tali (221; 150), ayous (199; 117), padouk d'Afrique (203; 102) and bubinga (203; 102). Acajou (41; 0.1) had the lowest betweenness centrality among all the tree species in the network. There were 100 products with betweenness centrality at zero, including 29 timber products, meaning these products do not act as a node along the shortest path between any other pair of products.

4. Discussion

Our results reveal that timber products, including CITES-listed species and other species of conservation concern, are associated with the trade in donkey skins. These findings add to the evidence of links between the trade of donkey skins and wildlife products documented by Su et al. (2022). Donkey skin for use in E-Jiao is in high demand in China, and our finding that many timber species that are either CITES-listed or of conservation concern are associated with the donkey skin product network gives an indication of how trade in one high-value commodity may be linked with trade in many others. Although only a small proportion of the donkey skin sellers investigated in this study appeared to be involved in the timber trade, their product networks included at least 24 tree species of conservation concern and at least seven CITES-listed timber products (Table 1). The legality of specific products in the network we examined remains largely unknown, but involves numerous vulnerable and endangered species that are subject to strict regulation under CITES. Indeed, compliance with CITES permits does not guarantee legal trade (Poole and Shepherd, 2017; Shepherd et al., 2012). Knowledge of these connections between different trade networks can help governments and international institutions focus and enhance monitoring. This includes allocating resources more effectively to target species in key trade routes.

In this study, our focus was on the merchants engaged in trading donkey skins, as part of a larger body of research examining the connections and implications of the international trade. The main driver for importing donkey skin into China is E-Jiao production, but there may be potential applications beyond our current investigation. The donkey skin product network exhibited great diversity in terms of the range of products available for sale. Of the top five product categories with the highest centrality, four of them fall under the agriculture sector, while the other belongs to the paper category. While it is not possible to know the underlying drivers of these connections with certainty, several possibilities may explain the products with the highest betweenness centrality in the network. Firstly, these products may serve as key raw materials or ingredients in a diverse range of other products, thereby elevating their importance and potential to act as a bridge between other products. Secondly, these products may possess a high trade value, making them more likely to be involved in the network. Thirdly, there could be logistical or supply chain factors contributing to their connectivity with a large number of other products in the network. In comparison to the aforementioned product categories, timber products have a relatively lower value for centrality, suggesting that they may not be as crucial in maintaining the overall connectivity of the network. The high level of connectivity in this donkey skin trade network, with its diverse range of products, suggests that traders may be opportunists seeking to maximise profits (Balderston, 1956), retain customers (Borle et al., 2005), and enhance their

visibility in the market. Nonetheless, the stable and persistent relationships between the goods offered by sellers may also suggest further market links and dynamics that remain unexplored in the scientific literature and warrant future research. Understanding these networks, in turn, represents a challenge and an opportunity for governments to safeguard agricultural, forestry, and other natural resources by increasing monitoring and enforcing regulations.

Traders often engage in selling a diverse range of products. However, the connections between the trade in donkey skins and other trades of conservation concern have been underreported until now. While it is expected that traders would offer a variety of products, identifying the specific selection of products by individual traders can provide valuable insights into the market dynamics driving their choices. Factors such as supply sources, demand considerations, and operational logistics may influence the assortment of products stocked by particular traders. For instance, traders may acquire multiple products from the same source, cater to specific buyer preferences, or expand their offerings based on available resources, such as cold storage facilities. The coexistence of seemingly unrelated products, like donkey skins and timber, prompts intriguing questions about the underlying reasons for their presence alongside each other. The interplay between product categories, transportation networks, and operational considerations adds complexity to the trading landscape. While it would be unexpected for a trader to exclusively sell donkey skins, the juxtaposition of these seemingly unrelated products invites further exploration into the factors driving their coexistence.

The donkey skin product network contains species that are used and traded as hongmu, such as kosso, African blackwood, and *ébène d'Afrique*; or as hongmu substitutes, such as bubinga and padouk d'Afrique. Despite only four of the 29 hongmu species being identified in the donkey skin product network, they represent a significant example of overexploited timber resources. The increasing regulation of the hongmu trade, and its rapid development, have led to the trade of less regulated species. Consequently, as substitutes become scarce or subject to regulations, traders seek alternative wood species with comparable properties and colour patterns from various sources to fulfil the demands and secure profits. Bubinga, for instance, although not officially classified as standard hongmu, closely resembles other hongmu species and has been imported into China, serving as an alternative option for hongmu furniture before being listed in CITES in 2017 (Cites, 2016). Similarly, kosso was initially considered a low end product, but has become widely traded as a substitute for high-value timber from southeast Asia before its listing by CITES in 2016 (Treanor, 2015; UNODC, 2020, 2016). Of the 16 countries where kosso is known to be native, 8 have implemented voluntary zero-export quotas for commercial trade, while the remaining 8 are currently under trade suspension (Cites, 2022b). These measures reflect the collective efforts to regulate and control the trade of kosso. Our data support the need for these interventions and the need to continue close monitoring of these trade patterns following the implementation of these strengthened regulations.

Cultural conventions and practical preferences also play a role in consumer choice for timber products, which can limit the availability of alternative timber options (Deblauwe, 2021). For example, *ébène d'Afrique* (true ebony) is preferred for certain high-end musical instruments, with African blackwood being the only culturally acceptable alternative (Deblauwe, 2021). However, the unsustainable exploitation of African blackwood (Jenkins et al., 2002) and its regulation under CITES have created situation where the lack of sustainable substitutes may lead traders to accelerate the exploitation of rare species like *ébène d'Afrique*, in anticipation of future trade restrictions (Courchamp et al., 2006; Hall et al., 2008). It is important to act to protect rare or declining species before they become highly endangered, as well as to identify which species are going to be the next targets for trade. Therefore, close monitoring of species that share similarities with hongmu, other regulated precious woods, and their substitutes, becomes imperative, allowing for the identification of potential alternative species. The donkey skin trade network involves timber species of conservation concern, hongmu, and its substitutes, and our findings offer valuable insights into market trends and present a novel avenue for monitoring highly sought-after species.

5. Conclusion

Our study on the trade of donkey skins for E-Jiao in China revealed the involvement of timber products, including CITES-listed species, species of conservation concern, and hongmu. Further exploration into the market links and dynamics may provide valuable insights into, and understanding of, the complexities of this trade network. By identifying timber species of conservation importance and exploring alternative substitute timber products within the donkey skin product network, our research provides valuable insights for government enforcement agencies in source countries. Governments should anticipate emerging trends and develop suitable policies encompassing a spectrum of measures, including restrictions and promoting sustainable practices, to minimise potential conservation impacts.

Ethical approval

Not applicable.

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CRedit authorship contribution statement

All authors whose names appear on the submission 1) made substantial contributions to the conception or design of the work; or the

acquisition, analysis, or interpretation of data; or the creation of new software used in the work; 2) drafted the work or revised it critically for important intellectual content; 3) approved the version to be published; and 4) agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: David Macdonald reports financial support was provided by The Donkey Sanctuary.

Data Availability

Data will be made available on request.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at [doi:10.1016/j.gecco.2023.e02598](https://doi.org/10.1016/j.gecco.2023.e02598).

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