TOWARDS LEGAL, SUSTAINABLE AND EQUITABLE WILDLIFE TRADE

EDITED BY: Tien Ming Lee, Amy Hinsley, Miguel Pinedo Vasquez and Yan Zeng

PUBLISHED IN: Frontiers in Ecology and Evolution

frontiers Research Topics

frontiers

ISSN 1664-8714
ISBN 978-2-88974-188-5
DOI 10.3389/978-2-88974-188-5

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TOWARDS LEGAL, SUSTAINABLE AND EQUITABLE WILDLIFE TRADE

Topic Editors:
Tien Ming Lee, Sun Yat-sen University, China
Amy Hinsley, University of Oxford, United Kingdom
Miguel Pinedo Vasquez, International Research Institute for Climate and Society (IRI), United States
Yan Zeng, Institute of Zoology, Chinese Academy of Sciences (CAS), China

Citation: Lee, T. M., Hinsley, A., Vasquez, M. P., Zeng, Y., eds. (2022). Towards Legal, Sustainable and Equitable Wildlife Trade. Lausanne: Frontiers Media SA. doi: 10.3389/978-2-88974-188-5

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frontiers in Ecology and Evolution

ORIGINAL RESEARCH
published: 23 October 2020
doi: 10.3389/fevo.2020.604921

Korean 'Housewives' and 'Hipsters' Are Not Driving a New Illicit Plant Trade: Complicating Consumer Motivations Behind an Emergent Wildlife Trade in *Dudleya farinosa*

*Jared D. Margulies**

Department of Geography, University of Alabama, Tuscaloosa, AL, United States

Illegal trade in wild plants receives less scientific and policy attention than illegal trade in wild animals and animal-derived products. One exception to this generalizable trend is the recent emergence of an illegal trade in the California succulent species *Dudleya farinosa*. US officials and mainstream media reporting on these incidents suggest the final destination of these plants is succulent consumer markets in South Korea and other East Asian countries. It is believed that this illegal trade emerged in response to sudden and widespread consumer demand for succulents due to: (1) the increasing popularity of succulent plants in mainstream South Korean and East Asian cultures writ large; and (2) the preferential valuing of 'wild' versus cultivated plants by succulent consumers. Based on findings from content analysis of media reports and in-depth qualitative interviews in California and South Korea, I argue instead for a more nuanced perspective of the drivers of this emergent trade, with the primary motivational desire for these plants coming from a selective and highly skilled community of succulent enthusiasts, rather than mainstream plant consumer groups. In presenting these findings I demonstrate the importance of in-depth, critical qualitative research for exploring the emergence of particular trades in wildlife in order to inform more sustainable and legal trades. I clarify the primary drivers of this new trade in *Dudleya farinosa* as an illegal but logical response to the economics and temporalities of plant trade. I offer suggestions on how these findings can inform more sustainable solutions to the illicit extraction of wild plants in meeting consumer demand.

Keywords: conservation social science, plant trade, illegal wildlife trade (IWT), succulents, poaching, California, South Korea

OPEN ACCESS

Edited by:
Tien Ming Lee,
Sun Yat-sen University, China

Reviewed by:
Laura Thomas-Walters,
University of Stirling, United Kingdom
David L. Roberts,
University of Kent, United Kingdom

Correspondence:
Jared D. Margulies
jdmargulies@ua.edu

Specialty section:
This article was submitted to Conservation and Restoration Ecology, a section of the journal Frontiers in Ecology and Evolution

Received: *10 September 2020*
Accepted: *29 September 2020*
Published: *23 October 2020*

Citation:
Margulies JD (2020) Korean 'Housewives' and 'Hipsters' Are Not Driving a New Illicit Plant Trade: Complicating Consumer Motivations Behind an Emergent Wildlife Trade in Dudleya farinosa. Front. Ecol. Evol. 8:604921. doi: 10.3389/fevo.2020.604921

INTRODUCTION

There is proportionally limited scientific research on illegal trades in plants compared to animals (Wyatt, 2013; Lavorgna et al., 2018; Margulies et al., 2019a). Within the plant kingdom, research on known existing illicit trades beyond timber is patchy, and limited to only few taxa, such as orchids (Phelps and Webb, 2015; Hinsley et al., 2016, 2017; de Boer et al., 2017). Despite the high volume of international illegal trade in many cactus and succulent plant species, there remains very little published scientific research on their illegal trade (but see Sajeva et al., 2007; Goettsch et al., 2015; Lavorgna and Sajeva, 2020). In general, international illegal trades in succulent plants, such as cacti and cycads, among other succulents, exist when a plant's trade is restricted or regulated under the Convention on International Trade in Endangered Wild Fauna and Flora (CITES), or when they are acquired in an illegal manner (such as cases involving trespassing and illegal extraction). The primary value of illegally traded succulents is in their aesthetic qualities valued by plant collectors (Sajeva et al., 2007; Goettsch et al., 2015). There is very little empirical data on how succulent trades function, or what motivates consumer choices in collecting or purchasing plants traded illegally, including the scale, scope, and foundational drivers behind these trades (Hinsley et al., 2016; Lavorgna et al., 2018; Wyatt et al., 2020).

It is perhaps unsurprising that illegal plant trade rarely features prominently in high-level fora on illegal wildlife trade (IWT) or in IWT funding programs, given the longstanding taxonomic biases that persist within biodiversity conservation efforts toward charismatic megafauna in efforts to combat wildlife trafficking (Fukushima et al., 2020; Massé and Margulies, 2020; Massé et al., 2020). Another consequence of this general inattention to plants is that despite the long-standing awareness within conservation circles of global illegal succulent trades, these trades have historically received scant attention from media and press outlets. This is beginning to change, however, and a variety of recent incidents of succulent poaching have received widespread media attention. The unusual limelight cast on these incidents is likely a result of both the increasing global popularity of succulents amongst mainstream consumers, alongside the headline-grabbing potential of unusual stories about 'succulent smugglers,' 'plant poachers,' or 'cactus rustlers.' One example of illegal succulent trade receiving widespread international attention involves the theft of the succulent species *Dudleya farinosa* from within its habitat range in California, United States. *D. farinosa* also goes by the common names of powdery liveforever, bluff lettuce, sea lettuce, or *siempreviva*s (**Figure 1**). Based on research conducted in 2018–2019, in this article I offer a critique of many of the explanations and justifications offered in media reporting on the emergent trade in *D. farinosa*. In particular, I draw the title of this article from the frequent use of "housewives" and "hipsters" as general coded categories of mass-consumer markets many articles suggested were responsible for the rapid rise in this illegal trade.

Legal, regulated mechanisms exist for the purchase, sale, and international trade of cultivated *D. farinosa*. No species of the *Dudleya* genus is currently listed on the appendices of CITES, the primary international agreement regulating trade in wildlife. Two species of *Dudleya—D. stolonifera* and *D. traskiae*—were previously listed on CITES appendices (first Appendix I, then downgraded to Appendix II) due to their limited habitat range, threatened status, and previous concerns about illegal trade at the time of their listing in 1983. However, these species were later delisted from CITES during the Sixteenth meeting of the Conference of the Parties in 2013 as it was believed they did not face any threat from international trade (Convention on International Trade in Endangered Species of Wild Fauna and Flora, 2013). Although IUCN Red List assessments have not been carried out for any member of the *Dudleya* genus, a number of *Dudleya* species are listed on California State and/or the US Federal list of endangered species, but *D. farinosa* is not (California Natural Diversity Database [CNDDB], 2020). Because it is not a threatened or endangered plant, *D. farinosa* is also not protected by the U.S. Lacey Act which prohibits the import, export, transport, and sale via interstate or international commerce of CITES-listed plants or those protected by State endangered species laws. Unlike some threatened or endangered *Dudleya* species, *D. farinosa* has a wide distribution range. *D. farinosa* is a coastal dwelling species inhabiting a narrow ecotone along steep coastal bluffs ranging from southern Oregon in the North to Santa Barbara, CA in the South (McCabe, 2012). It is therefore important to clarify that because *D. farinosa* is not a CITES-listed species nor listed as threatened or endangered by state or federal authorities, what makes its trade illegal refers specifically to the ways in which it was either (a) illegally acquired (e.g., taken without permission from private or public lands), and/or (b) traded in a manner that violated US or international shipping regulations (e.g., failing to be shipped with necessary phytosanitary permits, false filing with the postal service, etc.).

The available legal channels for international trade in *D. farinosa* make the existence of an illegal international trade all the more surprising, as in theory there are legal markets by which consumers desiring *D. farinosa* can obtain them. With this in mind, inductive qualitative research was conducted in order to pursue the following core research questions: (1) why did an illegal trade in *D. farinosa* emerge? (2) Who were the primary consumers for poached *D. farinosa*? (3) What motivated consumer desire for these plants? The motivations behind trade in wildlife products are typically complex and multifaceted, and can be difficult to fully characterize through quantitative methods alone (e.g., Zhu, 2020). Rarely do simple narratives effectively capture the complex social motivations mediating choices actors make in engaging in criminal behaviors that impact wildlife, or the preferences of consumers for legal or illegal wildlife products (Hübschle, 2017; Wong, 2019; Hinsley and 't Sas-Rolfes, 2020; Zhu and Zhu, 2020). Based on in-depth qualitative research in both California and South Korea on the recent rise of an illegal *D. farinosa* trade, this article complicates simplistic narratives circulating in both mainstream media outlets as well as amongst law enforcement organizations and plant conservation communities about the consumer motivations driving *D. farinosa* poaching from California. Further, in presenting evidence for the motivations behind this trade, this article holds a mirror to commonplace narratives of wildlife consumption patterns in East Asia rooted in blunt stereotypes of Asian consumer habits and global patterns of wildlife trade that are persistent within both the conservation and wildlife trade sectors (Margulies et al., 2019b). While there are a variety of valuable and important methodologies available for researching drivers of IWT and consumer preferences for particular wildlife products, this article demonstrates the critical value of qualitative research early on in the study of IWTs. Qualitative research can reveal important context and nuance related to consumer motivational behavior, which in turn can help inform the development of legal, alternative, and more sustainable trades.

FIGURE 1 | Dudleya farinosa, near Eureka, CA, United States. Photograph by the author.

MATERIALS AND METHODS

I employed semi-structured qualitative interviews as well as qualitative media content analysis and document collection (such as court cases, depositions, etc.) adopting a methodology that Ballvé (2020) recently described as 'investigative ethnography.' Investigative ethnography represents a blended research approach combining the interest in fact-finding and use of public records related to incidents of wrongdoing familiar to investigative journalism, with the contextual and interpretivist work of ethnography as thick description (Ballvé, 2020). In this sense I was both interested in some of the basic questions a rigorous journalist might pursue in uncovering the 'true' nature of this illicit trade, while at the same time I approached these questions through the inductive lens of ethnographic inquiry. An ethnographic perspective demands a critical stance toward ideas of the neutral positionality as a researcher, as a researcher, and an equally critical stance towards the idea of an objective or singular 'truth' about the drivers and mechanisms underlying this emergent illicit trade (Ballvé, 2020).

While analyzing interviews, court records, news reports, and documents represents a form of research triangulation via comparison useful for understanding what is known about the supply side dimensions of this illicit trade, I employed qualitative interviews in South Korea to generate a fuller appreciation of the nuances and complexities around the drivers of demand for *D. farinosa* and what motivates succulent enthusiasts to acquire them. This approach relied on developing theoretical saturation related to themes of consumer motivation employing the use of constant comparison as an iterative technique to ensure that data was analyzed and compared throughout the research process in order to inform further research and theory generation (Glaser, 1965; Maxwell, 2012; Fram, 2013). Inductive theoretical codes emergent from this process were applied to interview transcripts and managed within the qualitative data analysis software NVivo (QSR International). This inductive research approach was more appropriate to this study of *D. farinosa* trade than other research methods such as larger consumer-oriented surveys for several reasons (e.g., Doughty et al., 2019). First, there was no baseline data from which to support a survey tool or other statistically robust form of measurement. Second, the market for *D. farinosa* is highly dispersed and selective, as well as international (not just confined to South Korea), making survey implementation with targeted consumers extremely difficult due to access and privacy concerns. Third, while there is an uneven appreciation of the illicit status of wild-harvested *D. farinosa* in Korea, it made the subject a possibly sensitive topic that could not be easily broached; it required longer-form interviews with research subjects before the subject of illicit acquisition could be discussed, if at all (Dang Vu et al., 2020). Fourth, the goal of this research was to develop a generalizable understanding of a suite of motivations and desires within succulent consumer groups, rather than testing a particular variable against a set of dependent variables.

I conducted (N = 15) in-depth semi-structured interviews ranging from 45 min to 2.5 h in California with relevant commercial succulent growers, California Department of Fish and Wildlife staff, and conservationists with known expertise or particular insight into the *D. farinosa* trade using a snowball sampling protocol. In Korea I similarly conducted in-depth semi-structured interviews with key commercial succulent growers and succulent enthusiasts and experts (N = 12) as well two small group interviews with Korean government agency officials with expertise or regulatory purview over Korean wildlife trade regulations (1) and the Korean succulent industry (1). Because I was focusing on key expert/specialist perspectives and insights, this snowball-sampling protocol was most appropriate as it enabled experts to identify other important experts and specialists that they felt would be informative for this research. In both South Korea and in the United States, I suspended recruitment for additional interviewees once experts continued to identify the same individuals I had already either contacted or interviewed. In South Korea, initial contacts were identified by conducting online research on specialist and large scale commercial greenhouses focusing on succulent plants in Korea, with particular emphasis on specialist dealers who specifically advertised possessing and selling *D. farinosa.* During both sets of interviews a basic interview guide comprised of 20 questions was utilized, broken down by questions on (1) the general popularity and growth of the Korean/US succulent industry and consumer market; (2) questions related to plant conservation, trade and law enforcement/regulatory issues; and (3) more specific questions about the *Dudleya* genus and consumer demand. In South Korea I also visited numerous commercial succulent nurseries and wholesalers in order to assess the presence or absence of *D. farinosa* as a means of triangulating interview responses about their availability, as well as to take detailed notes on which species of succulents appeared most popular with Korean succulent consumers based on stocking patterns. Further, this research was informed by 2 years of in-depth qualitative research on the global illicit succulent trade writ large, including more than 85 in-depth interviews with succulent consumers and enthusiasts, law enforcement officials, succulent dealers, and succulent smugglers.

I compiled a set of online English language (N = 15) as well as Korean language news articles (N = 14) reporting on the emergence of the *Dudleya* trade using a simple Boolean search strategy run through the Google search engine ["dudleya farinosa" AND ("theft" OR "poaching" OR "illegal")]. I excluded informal forum threads (via sites like reddit.com) and personal blog posts from my analysis. While there were many more news articles available than those I compiled, many smaller and regional newspapers and online news sites recycled the same quotes and material from previously published articles. It was not my aim to conduct a systematic media content analysis, but instead focus on key themes emergent in the most widely circulated and read articles published by major news outlets on the subject. I applied Thomas-Walters et al.'s (2020a) framework for understanding the motivations behind the use of wildlife products as a coding system for media content analysis (Altheide and Schneider, 2012). Articles were coded with a total of 5 primary codes and 15 secondary codes (**Figure 2**). I suspended content analysis once I had analyzed enough articles that no new major motivational behavior narratives emerged (point of theoretical saturation). The same codebook was applied *post hoc* to transcribed interviews conducted with Korean succulent dealers and consumers as a secondary round of coding.

RESULTS AND DISCUSSION

A New Illegal Trade

Beginning in late 2017, California's Department of Fish and Wildlife (CDFW) became aware of a growing problem of *D. farinosa* poaching by foreign nationals in multiple, unrelated incidents. The first reported incident in December 2017 was presumed by CDFW to be an isolated matter, and CDFW was alerted to the issue by a citizen who was suspicious of a man attempting to ship a large number of packages from a small post office in Mendocino, California. The citizen observed dirt falling out of the packages and was concerned it was an issue of abalone poaching, a problem common to the area, and therefore contacted the CalTip hotline, a citizen reporting line to alert them of her suspicions (CDFW Interview, January 18, 2019). A month later, the same officer who followed up on this incident observed behavior he suspected indicated abalone poaching near the town of Point Arena, California. Instead, he discovered a man harvesting *D. farinosa.* In March of 2018, the same officer apprehended two Korean foreign nationals stealing 850 *D. farinosa* from private property. The men also had in their possession the names of a variety of international succulent commercial operations.

> This wasn't their first rodeo. These guys were global plant poachers. If you looked at their paperwork, it was all vendors, and vendors' purchase lists" (CDFW interview, January 18, 2019).

At this point, CDFW realized this was no longer a matter of just one or two isolated incidents, but small groups of people

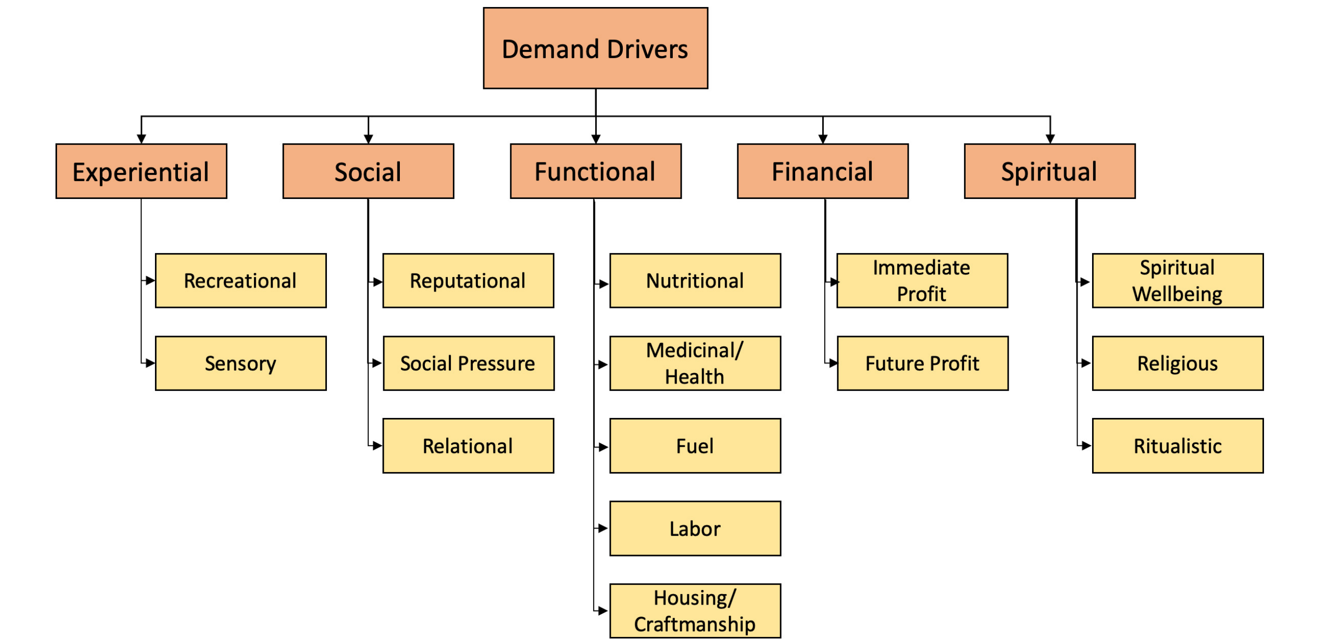

FIGURE 2 | Framework for the motivations behind the use of wildlife products adapted from Thomas-Walters et al. (2020a).

taking increasingly large volumes of plants (CDFW Interview, January 16, 2019).

Between 2017–2108, there were at least six known incidents of attempts by foreign nationals to harvest and/or ship wild grown *D. farinosa* from California. The size and scope of these incidents varied, ranging from single actors being caught with approximately 50 plants, to repeated incidents of several actors arrested, working in coordination to ship thousands of individual wild-harvested plants in shipments believed by CDFW to be worth in excess of 1,000,000 USD (CDFW Interview, January 16, 2019; court documents). However, expert interviewees and court documents reveal that other incidents of illegal *Dudleya* poaching and international shipments had likely occurred during at least the past several years, though perhaps smaller in scale or magnitude (*Dudleya* expert interview, January 22, 2019). Further, the problem of *Dudleya* poaching is not exclusively restricted to California or the *farinosa* species, as a major incident in May in Baja California, Mexico demonstrated, involving the interception of several thousand poached *Dudleya pachyphytum* from Isla de Cedros off the Baja coast (Investigaciones Zeta, 2018).

Motivations for Acquiring *Dudleya farinosa* Expressed in Media Reports

While media articles offered a variety of explanations for the sudden emergence of illicit *D. farinosa* trade, to date there has been no academic research on the subject, an important step toward developing meaningful responses and sustainable solutions grounded in empirical data. **Table 1** summarizes (a) consumer motivations for *D. farinosa* described in online media articles; and (b) consumer motivations described by Korean experts in the succulent consumer market and collecting community. I conducted content analysis of a total of 18 news articles in both English and Korean (10 English, 9 Korean), the latter facilitated by working with research assistants fluent in Korean. Due to the limited number of relevant articles (many articles, particularly in Korean, were repetitive of previously published articles), I do not quantify the frequency of each code's occurrence; instead **Table 1** describes a range of the most frequently referenced motivations for consumer desire in order to fully characterize the suite of perceived possibilities for *D. farinosa* consumer interest. This framework is useful as a form of *consumer* demand categorization; it does not, in contrast, focus on supply side dimensions, such as the profit motive for those illegally acquiring *D. farinosa* and their subsequent sale to consumers or wholesalers. Here, the focus is on why a consumer demand exists in the first place for *D. farinosa* driving their illicit acquisition. I provide examples of these understandings of motivation categorized in **Table 1** by code category in **Table 2**.

Most news articles gave multiple reasons for consumer motivational use of *D. farinosa*. For instance, multiple Korean news sites either closely reproduced and/or repeated the following statement:

> Like cactus, Dudleya is a plant that contains water in its leaves and stems to live in a dry climate. It's also in the limelight as an investment tool in South Korea for its air purifying effect and home decoration use.
>
> 두들레야는 선인장처럼 건조한 기후에 살기 위해 잎과 줄기에 수분을 함유한 식물로 공기정화와 인테리어 효과가 있어 국내에서 재테크 수단으로도 각광 받고 있습니다.

In this frequently occurring statement, the coded motivational categories are: Experiential-Sensory (home-decoration);

TABLE 1 | Motivations for acquiring *Dudleya farinosa* by consumers as described in (a) new media reporting on this trade and (b) interviewed Korean succulent dealers and collectors.

	Motivations				
Narrative Group	**Experiential**	**Social**	**Functional**	**Financial**	**Spiritual**
News Media Outlets	Recreational and Sensory	Reputational	Medicinal	Future Profit	Spiritual well being
Korean Succulent Dealers and Collectors	Recreational and Sensory	Relational	—	—	—

Motivational framework adopted from Thomas-Walters et al. (2020a).

TABLE 2 | Examples of excerpts of news articles coded by sub-categories from the applied framework of Thomas-Walters et al. (2020a).

	Category description	Excerpts from news media reporting
Experiential-Recreational	Motivated by the desire for leisure or pursuit of a pastime or hobby.	"In the Asian country [South Korea], tending succulents had become a favorite pastime across generations, popular with everyone from harassed housewives to Generation-Z hipsters. And with all things Korean – from fashion and music to food and soap operas – grabbing the popular imagination in China, the world's most populous nation had caught a massive dose of dudleya fever." (Lanyon, 2018)
Experiential-Sensory	Motivated by the desire to please the senses, including aesthetic, olfactory, and tactile.	"Native Dudleya plants from coastal habitats in Northern California are particularly valuable in Asia due to their unique physical features, including the color and shape of their leaves." (Garcia, 2019) "Those plants had survived in their natural habitats for decades through rain and wind. That's what makes them beautiful. You can't grow succulents like them with artificial measures." (Horowitz-Ghazi, 2018)
Social-Reputational	Motivated by the desire to give others a certain impression, or to benefit socially; or to gain currency in a business transaction, or highlight social standing or wealth.	"Right now these plants are a boom in Korea, China and Japan. It's huge among domestic housewives. It's a status thing," (McCormick, 2018). "I think things like this can quickly become a symbol of the middle class for the generation 30 and under [in China], it's important for them to show that they are the generation that got the privilege of buying things." (McCormick, 2018) "They want to have the plant that isn't native to where they are or the plant that people see via social media. . .In this situation, a plant has become so popular that the idea that someone does not have it makes people go the extra mile." (Garcia, 2019)
Functional - Medicinal	Motivated by the desire to treat an illness or promote wellness (i.e., curative/preventative).	Like cactus, Dudleya is a plant that contains water in its leaves and stems to live in a dry climate. It's also in the limelight as an investment tool in South Korea for its air purifying effect and home decoration use. (Three Koreans arrested, 2018)
Financial- Future Profit	Motivated by the desire for future profit or an investment strategy.	"In South Korea and China, Dudleya is traded for $40–50 per head. Growing its seedlings and trading them at high prices is used as an investment tool." (Han, 2018).
Spiritual-Spiritual Well Being	Motivated by the desire to improve one's fortune in this life or any others.	"The squat plants boast a geometric beauty reminiscent to some of the blossom of a lotus flower." (Lake County News, 2018).

Functional-Medicinal (air purification); and Financial-Future Profit (investment tool). Motivations highlighted in other articles included speculation that within China and Korea in particular, there was pressure to acquire a *D. farinosa* in order to demonstrate economic security to others through the purchase of a non-essential popular item (Social-Reputational), in particular one that requires skills of caretaking (McCormick, 2018). Others suggested that *D. farinosoa's* shape was reminiscent of the shape of a lotus flower (Spiritual-Spiritual well-being), an auspicious spiritual and religious symbol in many East Asian cultures that is especially associated with Buddhism (Ward, 1952).

The diversity of explanations for consumer motivation for *Dudleya farinosa* presented in media articles mirror the diversity of beliefs and opinions expressed by CDFW staff as well as commercial succulent dealers and members of the California plant conservation community I interviewed. In part this is because many of the perspectives offered in media articles came from CDFW staff or noted succulent market and/or *D. farinosa* experts in California. Thus, there was a recirculation of themes between a relatively small group of identified key experts and the motivational narratives described in media articles.

A consistent consumer motivation narrative focused on the status of poached *D. farinosa* as wild-origin plants (and thus seen as more rare or exotic), coupled with the rise of a growing mass consumer market in East Asia:

> *There are people who will place a higher value on anything that is difficult to attain. Let's take the recreational sturgeon fishery. Sturgeon are barely populous enough to sustain a recreational fishery. It's a very highly regulated fishery and because they are so difficult to attain, poachers want them more than ever so the value goes up. With Dudleya, the fact that they are difficult to attain and illegal to attain then people just want them more. (CDFW Interview, January 16, 2019).*
> *There is a giant rising middle class in China and in South Korea, they have more disposable income, and want to beautify their houses, and this [Dudleya farinosa] has become the fad, to have these cute little plants in their house. And so. . .there's the rise of more people having disposable income. And I think, it's like wild versus farmed salmon, having the place that it is from, the natural thing, there's kind of like a, 'this came from this place.' (District Attorney's Office Interview, January 18, 2019).*

While most interviewees expressed the speculative nature of these theories, there was nevertheless general consistency across media articles and interviewers about the primary motivations behind the rise of consumer demand for *D. farinosa*. As one media article put it, consumer motivation could be understood as stemming from a rapidly growing "fever" among "housewives" and "hipsters" (i.e., mass consumer market) for succulents in Korea and China in general (Lanyon, 2018), with wild-harvested *D. farinosa* plants possessing greater value and monetary worth due to their exotic provenance and having wild-origin characteristics (especially in color, form, and size) compared to cultivated plants. This framing of "housewives" and "hipsters" being the driving consumer market behind this trade was echoed by several other media articles, suggesting that the emergent trade in *D. farinosa* was the unfortunate result of the craze for other mass-market succulents in large sectors of the overall population (e.g., Horowitz-Ghazi, 2018; McCormick, 2018; Goodyear, 2019). In this context, "housewives" and "hipsters" are codes for particular consumer market sectors—namely, married women whose primary activities may be domestic responsibilities ("housewives"), and a growing market of plant enthusiasts within the 'millennial' and 'Gen-Z' generations ("hipsters").

Contrasting Narratives of Motivations for *Dudleya farinosa* Demand

The primary consumer motivations described by Korean succulent dealers and commercial operators were narrower in scope and also different than those described in popular press outlets, as was the characterization of who the primary consumers of *D. farinosa* were. In particular, Korean dealers emphasized that *D. farinosa* was not a widely popular succulent plant amongst mainstream consumers (i.e., "housewives" and "hipsters") and that it was specifically desired by specialized and typically more experienced collectors. Like many countries, succulents are currently immensely popular in South Korea, but interviewees made clear there is little relationship between the overall popularity of succulents and those desiring to possess *D. farinosa*. In addition to the consistency of this perspective across all succulent experts and purveyors of *D. farinosa* I interviewed in South Korea, after visiting three of the largest succulent plant markets in Seoul open to retail customers, I was only able to find one vendor selling any *D. farinosa*. This vendor said that they do not normally stock them due to lack of demand, though they can acquire them when requested (Succulent Vendor Interview, October 11, 2019). Other interviewed commercial market dealers affirmed that they did not normally stock *D. farinosa* because it was not widely desired by consumers, and its overall desirability is declining. Rather than finding *D. farinosa* at general household plant and succulent consumer markets, *D. farinosa* were primarily only available from a select number of specialist succulent growing operations, which are also the primary vendors selling *D. farinosa* online in South Korea for an international market.

Interviews with commercial succulent dealers and botanical experts in both California and South Korea confirmed that *D. farinosa* would be difficult to keep alive under the conditions available in most consumer homes or outside, where freezing temperatures would kill plants in winter. *D. farinosa* are easily killed or damaged by overwatering, and in the wild they grow on cliffsides; thus, experts suggested that growing them in vertical pots could result in root rot and eventual death if not carefully maintained. Succulent dealers in South Korea confirmed that *D. farinosa* is not a plant for beginner growers, but requires advanced levels of care and was predominantly sought out by specialist collectors who maintain large collections of plants, oftentimes renting space in professionally maintained greenhouses where they keep their collections and visit them (Succulent Greenhouse Operator and Vendor Interview, October 20, 2019).

Despite the frequent speculations expressed by CDFW officials, California conservationists, and succulent experts about Asian consumers valuing poached *D. farinosa* because of their wild origins, the growers I interviewed in South Korea who sold and/or possessed *D. farinosa* were nearly exclusively interested in their aesthetic qualities. Their status as 'wild origin' plants did not elevate their value nor desirability for most customers (Succulent Vendor and Collector Interview, October 13, 2019). While some interviewees had a general awareness of where they came from (California), price was determined by the size and quality of plant, as well as supply and demand. On the question of why *D. farinosa* were believed to be so desirous in East Asia, one dealer replied, "this isn't about Chinese collectors or Japanese collectors or Korean collectors, this is about individual collectors and what they want" (Succulent Vendor Interview, October 11 2019).

Although their origin as 'wild' plants did not matter to collectors, the age and size of *D. farinosa* plants did—larger plants were more valuable than smaller plants. But it is important to distinguish between large plants and 'wild' plants in how they accrue in value. In South Korea, most of the visibly wild origin plants I saw (identifiable by signs of pest damage, growth patterns, weathering, and size) were being maintained in commercial greenhouses and would not be put up for sale until they had grown sufficient new foliage and recovered from the stress of transport and their general environmental conditions in the wild to be seen as presentable show pieces, when they would fetch higher sale prices. The tell-tale signs of 'wildness' were seen by most dealers not as desirable qualities, but as imperfections which negatively affected their monetary worth (Succulent Online Vendor Interview, October 14, 2019). This difference is important, as it suggests both why *D. farinosa* poaching occurred—a limited supply of large plants in a growing East Asian as well as global market—as well as a simple solution to the problem by developing a sustainable trade in artificially cultivated plants abroad. I observed (and confirmed in interviews) that a number of specialized commercial growers in South Korea are now cultivating seed grown *D. farinosa*, but it takes time for these plants to develop into larger plants often sought by more passionate collectors. In fact, the reputation of South Korean succulent growers is so great that the demand for *D. farinosa* from China and other countries in the region is actually for *D. farinosa* (and other succulents) grown *in* Korea, rather than representing a demand for exotic, California-grown plants (Succulent Greenhouse Operator and Vendor Interview, October 13, 2019).

In summary, the principal thrust of what drove people to poach *Dudleya farinosa* plants relates to a disjuncture between the temporality of plants and the capacity to meet demand—*D. farinosa* grows slowly and, although desired by a specialist market, there was sufficient global demand to quickly deplete in-country cultivated supply. There was, several years ago, a surge in interest in *D. farinosa* in Korea, China, and Japan, among other places—including Europe—facilitated by social media platforms and the rapid dissemination in information as well as growth in desire for these plants amongst specialist collectors. Social media platforms and group messaging systems enable both the development of communities of interest and communication between group members, but also serve as platforms for both legal and illegal trade (Hinsley et al., 2016). In this way, there was not just Experiential-Recreational and Experiential-Sensory motivations for East Asian succulent growers to acquire *D. farinosa,* but also Social-Relational motivations. As increasing numbers of people within succulent communities acquired *D. farinosa,* there was interest by collectors to share in the experience of growing them within their enthusiast in-person and online communities. Thomas-Walters et al. (2020a, p. 5) define Social-Relational motivation as being "Motivated by the desire for companionship; or for closeness to a larger social group or cultural/national identity." Through popular group messaging applications, Instagram, and Facebook groups, there was motivation to share experience with others through raising *D. farinosa.* This, combined with the experiential and sensory enjoyment the plants provide collectors, represented the primary consumer motivations for acquiring *D. farinosa,* which mirror the primary motivations behind succulent collection and growing as a hobby writ large.

From the perspective of succulent dealers as opposed to consumers, while *D. farinosa* is not currently listed on the appendices of CITES restricting their trade, phytosanitary certificates and plant importation permits into Korea were described by dealers as very cost prohibitive and simply "too expensive" (Succulent Greenhouse Operator and Vendor Interview, October 13, 2019; US Commercial Greenhouse Manager Interview, February, 18, 2019). Within Korea there was a demand for *D. farinosa* and no readily available supply, and the cost of importation only further increased the cost of obtaining plants. Ironically, one of the reasons there was a limited supply of commercially (and legally) available *D. farinosa* within the US is that according to interviewed succulent commercial growers in the US, there has been a declining interest in the species amongst US succulent consumers. As one *Dudleya* expert commented, "at a time when they were stealing them out of the wild we couldn't sell them at our plant stalls for five bucks" (Dudleya Expert Interview, January 22, 2019). This created a profitable opportunity for the rise of an illicit market for imported *D. farinosa.* The fact that *D. farinosa* plants are now being legally sold by Korean growers to Chinese and other international customers relates to the reputation of Korean growers for high-quality plants. This suggests that efforts of artificial cultivation in South Korea should be able to successfully meet market demands in time, as it was not the provenance of their origin in California that made wild *D. farinosa* plants so desirable. At the time this research was conducted, all interviewed specialist retailers who sold *D. farinosa* said that prices for *D. farinosa* were dropping, and that many of the more spectacular plant prices seen online (and often referenced by CDFW officials when making estimates of their value) were only aspirational numbers to draw attention to the plants as stand-out specimens. This tactic was used both to start negotiating prices for prized plants with potential buyers, as well as to draw more general attention to a seller's overall collection (Succulent Greenhouse Operator and Vendor Interview, October 14, 2019).

Based on the collected and presented evidence in this paper, it appears likely that the ongoing illicit trade in wild harvested *D. farinosa* is likely to diminish as commercial Korean succulent operators develop an increasing stock of *D. farinosa* of a desirable size that many international customers seek out. Based on interviews and market visits, other succulents, especially South African lithops and conophytum, are growing in popularity in South Korea and East Asia, which may represent a new concern. Notably, a Korean man who fled the United States to avoid charges for illegal *D. farinosa* harvesting was recently apprehended in South Africa (and extradited to the United States) with over 60,000 conophytum plants, some of which were believed to be over 250–300 years old (Hyman, 2020). Coordinated efforts between Korean government agencies such as the Cactus and Succulent Research Institute at the Gyeonggido Agricultural Research and Extension Services (GARES), international partners, and commercial growers to pre-emptively breed desirable and threatened lithops and conophytum plants might help to reduce the likely possibility of further illegal extraction of these increasingly popular plants.

CONCLUSION

Comparisons of consumer motivations given by US-based law enforcement as well as botanical experts and Korean succulent experts reveal how reporting on the *D. farinosa* thefts: (a) were often either inaccurate or incomplete; (b) played upon blunt stereotypes about East Asian wildlife consumers valuing rare and exotic wild-origin material; and (c) led to a circulation of inaccurate narratives that were recycled within other groups and social networks internationally. Both law enforcement and popular media articles made a variety of assumptions about the drivers of this emergent illegal trade based on limited data or evidence. These assumptions were further fueled by unverified hypotheses driven in part by stereotypes about what motivates wildlife consumption in East Asia (Margulies et al., 2019a; Dang and Nielsen, 2020). In the case of *Dudleya farinosa,* assumptions focused on their perceived value as rare, exotic, and wild-collected species, with both news reports and some interviewees in the United States making mention of rhino horn or elephant ivory trades as meaningful comparisons. The contrast in understandings of consumer demand for *D. farinosa* between Korean succulent experts and US-based law enforcement and succulent experts is especially striking. This contrast suggests the need for the incorporation of more in-depth qualitative research in the early stages of understanding consumer motivations in relation to forms of IWT, as well as continued skepticism when racialized tropes about IWT consumer motivations emerge in the context of IWT in East Asia.

Understanding the complexities and motivations of parties engaged in the purchasing of illicitly traded wildlife products is essential for informing effective, socially just and responsible interventions to effectively curtail IWT and promote sustainable wildlife trades (Wyatt, 2009; Duffy et al., 2016; Doughty et al., 2019; Thomas-Walters et al., 2020b). Echoing the sentiments of others, research into the underpinnings of the illicit trade in *D. farinosa* speaks to the greater need for deeper interdisciplinary conversation and engagement between criminologists, conservation scientists, geographers and anthropologists in IWT-related research in order to inform more sustainable plant trades (Blair et al., 2017; Boratto and Gibbs, 2019; Gore et al., 2019). Close attention to foundational drivers of illicit trades and consumer motivations are essential in order to develop holistic understandings of why trades exist and how they might be responded to in the form of mediating consumer behavior. As demonstrated by this study, qualitative research has an important role to play in understanding fundamental drivers of illegal trades in wildlife, a necessary step toward designing effective species conservation interventions and the promotion of sustainable trades.

DATA AVAILABILITY STATEMENT

The datasets presented in this article are not readily available because they represent interview transcripts that are not permitted to be shared with outside parties under the IRB/ethics approvals of this research. Requests to access the datasets should be directed to jdmargulies@ua.edu.

ETHICS STATEMENT

This study was reviewed and approved by the University of Sheffield and the University of Alabama under two different ethics protocols. From December 2017 to August 2019, this research was conducted under the ethical approval #016909 from the Department of Politics at the University of Sheffield, which is the appropriate authority to carry out reviews for the University Research Ethics Committee. It also underwent additional review by the European Research Council. From October 2019, this research was conducted under the IRB approvals of the University of Alabama #19-10-2891. Participants in the study provided either written or oral informed consent based on their preference before participating in this study, in accordance with appropriate national legislation and institutional requirements.

AUTHOR CONTRIBUTIONS

JM was responsible for the conceptualization, research, analysis, and writing of the manuscript.

FUNDING

This work was supported by the European Research Council Grant # 694995 (BIOSEC), as well as funding from the College of Arts and Sciences, University of Alabama.

ACKNOWLEDGMENTS

I owe my deepest gratitude and thanks to Dr. Jinah Kwon and Jaehyun Kim for their phenomenal and dedicated research assistance on the Dudleya trade in South Korea in 2019. Further Korean translation assistance was graciously provided by Heeyoung Kang. I wish to thank the two reviewers of this article and editor TL who provided helpful feedback and suggestions on a previous iteration of this article, and I am especially grateful to them for their very timely reviews. This article benefited from helpful feedback and comments during a presentation at the Third Annual State of Biodiversity Conference at the San Diego Natural History Museum in February, 2020. Lastly, I would like to thank the BIOSEC research community in the Department of Politics and International Relations at the University of Sheffield for their constant enthusiasm and collective support. Any mistakes and errors remain my own.

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Conflict of Interest: The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

frontiers in Ecology and Evolution

ORIGINAL RESEARCH
published: 15 December 2020
doi: 10.3389/fevo.2020.574161

Reducing Pangolin Demand by Understanding Motivations for Human Consumption in Guangdong, China

Fuhua Zhang†, Yishuang Yu†, Shibao Wu, Amna Mahmood, Jiaming Yu and Yue Min*

School of Life Science, South China Normal University, Guangzhou, China

Pangolins are some of the most trafficked mammals in the world. China is a major destination country for illegal wildlife trade and Guangdong Province is one of the areas of high domestic wildlife consumption. A willingness to consume lies at the root of the illegal wildlife trade. To understand the ideological roots of pangolin consumption, and to propose solutions, we conducted a consumption survey in 21 prefecture-level cities in Guangdong and have collected 1,957 valid questionnaires. In these questionnaires, 108 respondents (5.52%) who had consumed pangolin-related products, scales had been consumed by 61 respondents (3.12%), 58 respondents (2.96%) had consumed meat. We found that scale consumption was primarily motivated by disease treatment (80.43%). The main reason for meat consumption was accidental (44.83%), but among those who intentionally ate pangolin were motivated by curiosity (22.41%) or "showing off" (8.62%). Simultaneously, the respondents' future consumption willingness for medicinal purposes was more difficult to change than its use for other purposes. What's more, the public's insufficient understanding of the status of pangolins in China and weak legal awareness were potential reasons for pangolin consumption. In addition to classifying pangolins as Category I state-protected animals in China and strengthening penalties and enforcement, we recommend creating public awareness of the risk of zoonotic diseases, advocating for the use of alternative medicines in disease treatment and removing scales from ingredients in patented medicines, which will all act to reduce the demand for pangolins. We expect these actions to change public consumption behaviors and their collective understanding of pangolins, which improve pangolin protection efforts around the globe.

Keywords: wildlife trade, pangolin, consumption willingness, species conservation, Guangdong province

OPEN ACCESS

Edited by:
Tien Ming Lee,
Sun Yat-sen University, China

Reviewed by:
Raymond Jansen,
Tshwane University of Technology, South Africa
Laura Thomas-Walters,
University of Stirling, United Kingdom

***Correspondence:**
Shibao Wu
wushibao@163.com

†These authors have contributed equally to this work

Specialty section:
This article was submitted to Conservation and Restoration Ecology,
a section of the journal Frontiers in Ecology and Evolution

Received: *19 June 2020*
Accepted: *24 November 2020*
Published: *15 December 2020*

Citation:
Zhang F, Yu Y, Wu S, Mahmood A, Yu J and Min Y (2020) Reducing Pangolin Demand by Understanding Motivations for Human Consumption in Guangdong, China. Front. Ecol. Evol. 8:574161. doi: 10.3389/fevo.2020.574161

INTRODUCTION

As economic globalization accelerates, the illegal wildlife trade expands (Chen, 2016). Although many different estimates of the worth of the illegal wildlife trade are cited in the literature, it has become one of the most profitable global illegal trades, with an annual value that can reach \$20 billion (Chen, 2016; t Sas-Rolfes et al., 2019). Illegal trade is now one of the greatest threats to biodiversity (Zhang et al., 2015; Maxwell et al., 2016).

Pangolins, a group comprising eight species in the family Manidae (Pholidota, Mammalia), are heavily trafficked primarily for their perceived medicinal and edible value or their use as symbols of wealth and status (Zhou et al., 2014; Shairp et al., 2016). Their scales are considered a rare and precious material in Chinese herbal medicine, and their meat is considered highly nutritious (Wu et al., 2002). Heinrich et al. (2016) estimated 809,723 whole pangolins to be involved in the trade for the period between 1977 and 2014. The trade in pangolins is now recognized as the most significant impediment to their conservation, for both Asian and African species (Chaber et al., 2010; Zhang et al., 2017a). In 2019, the International Union for Conservation of Nature (IUCN) Species Survival Commission (SSC) reassessed the status of all pangolin species and classified the Sunda pangolin (*Manis javanica*), Chinese pangolin (*Manis pentadactyla*), and Philippine pangolin (*Manis culionensis*) as Critically Endangered (CR) (Challender et al., 2019a,b; Schoppe et al., 2019). As of January 2017, all eight pangolin species were upgraded from Appendix II to Appendix I in the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), meaning that all international trade in wild-caught pangolins and their derivatives is prohibited (CITES, 2017).

Pangolins were once common in southern China, but their populations have been reduced by ∼90% since the 1960s due to over-harvesting (Wu et al., 2005; Zhang et al., 2008). Their low defense capacity, low birth rate, and poor survival lead to a slow population growth rate (Wang, 1998; Johnson, 2002). Thus, intensive harvesting and trafficking have caused dramatic reductions in the pangolin population. Habitat loss and fragmentation have also contributed to their decline. Since 2020, the management of wildlife resources has been strengthened, and penalties for trafficking have also been increased in China. On June 3, 2020, pangolins were upgraded from Category II to Category I state-protected animals in China.

Heinrich et al. (2017) stated that the illegal pangolin trade spanned 67 countries on six continents. China and the United States were the most common destinations, and China was the main destination for scales and whole individuals (Heinrich et al., 2016). China is implicated in many incidents reported in the media, as either a seizure or destination country (Challender et al., 2015; Heinrich et al., 2016). Guangdong Province is a key area for wildlife consumption in China and a major distribution center for pangolin smuggling and trade (Cheng et al., 2017; Guo et al., 2019). Over the 1960s, incomplete data from the Department of Medicinal Materials in Guangdong suggested that the annual capture of pangolin was more than 20,000 individuals (Wu et al., 2002), and Zhang et al. (2010) estimated exploitation in China to involve 150,000–160,000 pangolins annually around the 1960s. This likely increased through the 1990s as increased economic development led to a rise in the cost of and demand for pangolin scales and meat (Wu et al., 2005). Over time, the motivation for international trade in wild-caught specimens within their native ranges has shifted from obtaining a protein source to economic improvement (MacMillan and Nguyen, 2014; Nuwer and Bell, 2014). In the year following the prohibition of the pangolin trade in January 2017, at least six smuggling cases were uncovered in Guangdong, including 11.9 tons of scales seized in July 2017. This suggests that the trade and consumption of pangolins in Guangdong province remain prolific.

Ultimately, consumer demand is one of the root causes driving the illegal wildlife trade. Effective conservation of threatened species depends on a reduction in the use of these animals and their derived products by consumers (Schneider, 2008; Oldfield, 2014). Understanding consumer behavior and motivations is vital for the development of effective long-term campaigns that reduce wildlife consumption (Challender et al., 2014; Theng et al., 2018). Within China, efforts to reduce the consumption of native wild animals have focused on establishing a series of wildlife laws and regulatory systems. With the core value of wildlife protection, the People's Republic of China aims to gradually establish long-term mechanisms for wildlife protection through improved legislation and stronger law enforcement (Chen, 2016). However, these legal efforts have not been satisfactory when contrasted with the number of instances of illegal pangolin trade documented in China in recent years. If we can understand the motivations behind pangolin consumption, we can propose solutions to reduce consumer demand for this threatened species.

We aimed to first examine the level of public awareness of pangolins in Guangdong Province and to grasp the reasons for their consumption in this region. We wanted to make effective suggestions for protection and countermeasures against pangolin consumption to reduce the demand for their consumption. This was assessed using a questionnaire administered to the public in 21 prefecture-level cities in Guangdong. We proposed that consumer behavior is one of the fundamental driving forces behind pangolin smuggling. Using the results of pangolin surveys, we explored—from the perspectives of enhancing public awareness of pangolins, changing public consumption concepts, consumption behavior, and improving legislation—approaches for guiding the public away from pangolin consumption. These findings are of important theoretical and practical value for the protection of pangolin species globally.

MATERIALS AND METHODS

Self-Administered Questionnaires

All respondents completed a self-administered questionnaire. The questionnaire was designed including 23 questions in four parts based on previous, unpublished research (see **Supplementary Material**): (1) basic information on the respondents (except their name and address), (2) their ability to identify pangolins and their derivatives, (3) consumption of pangolin meat and scales, (4) general awareness of pangolins. The purpose of this questionnaire was to grasp the consumption status of pangolins, the public's awareness of pangolin protection and relevant legislation, their purposes with regard to consumption and willingness to consume pangolin meat and scales, and the population characteristics related to pangolin consumption.

This survey was conducted in 21 prefecture-level cities in Guangdong Province, covering all regions of the province. Since the questionnaire involved some sensitive issues such as the consumption of pangolins, it was necessary for investigators to eliminate respondents' worries about potential punishment for answering questions about the consumption of pangolins and to gain the trust of the respondents during the survey. We recruited one middle school biology teachers as volunteers to help us with this survey in each city, because they had unique social relationships and had established good communication with students and their parents. Given there may be potential limitations regarding honest reporting of sensitive behaviors, using the special trust relationship between students, their parents and teachers, we ensured the smooth progress of the questionnaire survey and maximize the accuracy of the questionnaire's content, although we can't guarantee that all responders who have ever consumed pangolins or their derivatives were able to admit to illegal behaviors to teachers.

Before the survey, we had communicated with all volunteers face-to-face or via WeChat video. Volunteers were given careful training to ensure that they fully understood the survey, including the background, purpose, content of the questionnaire, and the difficulties of conducting the survey. All volunteers were required to master their communication skills with interviewees, and to recognize that they must explain the purpose of the survey to interviewees and assure them that the survey was anonymous, confidential and completely voluntary.

During the survey, our volunteers randomly selected students in their classes or their family members (e.g., parents, grandparents, uncles and aunts, cousins) as respondents, and had face-to-face communication with respondents. If the respondents were willing to fill in the questionnaire, our volunteers would give it to them to fill in; alternatively they were offered the option of completing the questionnaire by structured interview.

As students came from a variety of family backgrounds and were less influenced by their parents' education, occupation and income, selecting family members as respondents was a more comprehensive approach. Moreover, as consumption among members of the same family may be highly correlated, only one questionnaire was issued for each family, and was filled out by one person, so as to avoid deviations in the results.

Samples and Questionnaire Screening

The total population of Guangdong Province in 2017 was 111.69 million. According to the 2% allowable sampling error (Zhang, 2019), we had planned to collect 2,400 valid questionnaires in Guangdong Province; with an estimated recovery efficiency of 75%, we needed to issue 3,200 questionnaires. In total, 3,150 questionnaires were distributed in Guangdong, with 150 questionnaires distributed in each target city. Consider the social limitations of students (i.e., restrictions from parents), we controlled the proportion of students to no more than 20%.

Collected questionnaires were screened electronically. The attitude of respondents to the survey was judged by whether the information in the questionnaire was completely filled out, and whether the answers to the identification questions about pangolins and their derivatives were correct. We removed questionnaires that were missing key information, were from outside the survey area, or had obvious errors of logic in the content of the responses.

Data Analyses

We compiled the types of pangolin products consumed by pangolin consumers and the reported motivations for consumption. We used a chi-square test to check whether the gender ratio of valid questionnaire respondents conformed to the population sex ratio of Guangdong Province in 2017. To analyze the demographic profile of consumers, we conducted a binomial logistic regression, with the following explanatory variables: district, age, education, job, and income. We used these variables to determine which are the most important factors affecting the consumption of pangolins. Variables were selected using logistic stepwise regression ($\alpha = 0.05$). Among the variables included in the model, the variable with the largest change in log likelihood was taken as the most important factor.

Ethics Approval Statement

All questionnaires were in accordance with procedures approved by the Ethics Committee of South China Normal University. Informed consent was obtained from all subjects and the data from questionnaires were anonymized.

RESULTS

Pangolin Status and Consumption Survey Results

Across all 21 target cities in Guangdong, 1,957 valid questionnaires were collected, the rate of effective questionnaire response was 62.13% (the validity of the questionnaire was 97.8% and the confidence level was 95%). Among all respondents, Han Chinese individuals accounted for the vast majority; only 20 respondents were from other ethnic groups. The gender ratio in respondents was balanced relative to the estimated 2017 gender ratio in Guangdong (male:female = 110.48:100, Statistics Bureau of Guangdong Province, 2017), males and females accounted for 53.30% (n = 1,043) and 46.70% (n = 914) of the respondents, respectively ($\chi^2 = 0.48$, df = 1). Respondents were primarily people aged 36–56 years (**Figure 1**) who are more socially active and are the mainstays of consumption in society, whose consumption status often reflects trends in societal consumption. Income status among respondents was consistent with typical income distribution patterns in China, with the majority of the respondents having an annual income of <60,000 yuan (¥) (**Figure 2**). Few individuals were grouped in the high-income classes; only 3.83% of respondents had an annual income of >250,000 yuan (¥). Based on these measures, we consider the respondents to adequately represent the general population in Guangdong.

A total of 108 respondents had consumed or purchased pangolins or their derivatives in 21 prefecture-level cities (**Figure 3**), accounting for 5.52% of respondents (108/1,957, confidence interval 4.51–6.53%, confidence level 95%). All consumers were Han Chinese; 68 were male and 40 were female. Of the 21 prefecture-level cities, Dongguan, Shantou, Maoming, Heyuan, and Yunfu had higher proportions of consumers (**Figure 4**).

The models of the demographic differences among consumers showed that age, job and education were related to consumption

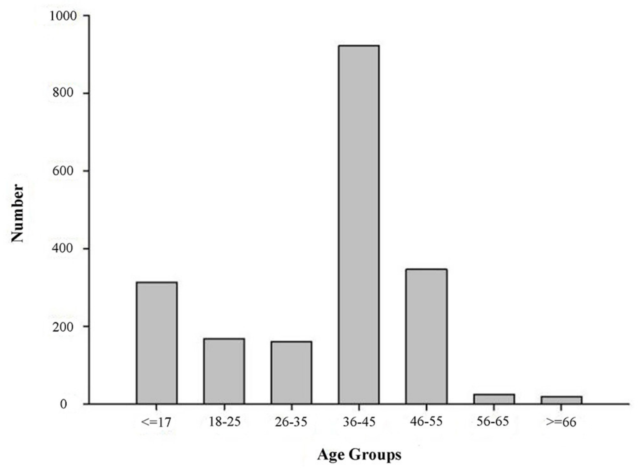

FIGURE 1 | Age-group distribution of 1,957 respondents.

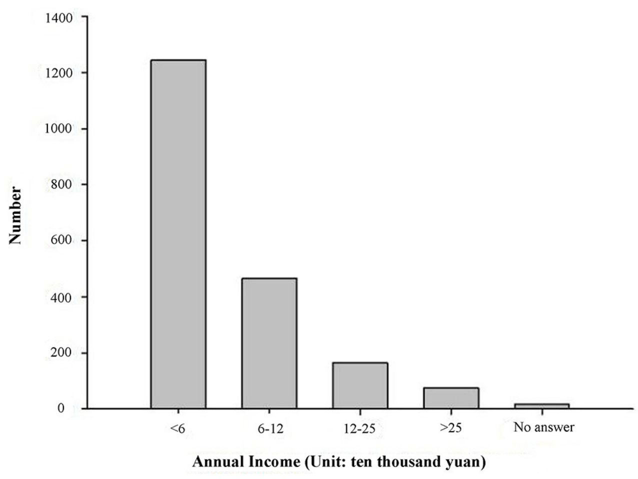

FIGURE 2 | Annual-income distribution of 1,957 respondents.

and job was the most important variable (**Table 1**). Civil servants were the most common consumers of pangolins, up to 17.19% (11/64), followed by enterprise executives and businessmen, at 11.48% (7/61) and 9.57% (9/94), respectively, while the consumption by students and unemployed was the lowest, accounting for 3.47% (14/403) and 2.08% (3/144), respectively (**Figure 5**).

Public Awareness of the Protection and Legal Status of Pangolin

The majority of the respondents were aware that pangolins are protected animals in China, but only 19.47% (381/1,957) could identify pangolins as Category II state-protected animals (**Figure 6A**). Only 0.20% (4/1,957) thought that pangolins were common, unprotected wild animals, and 4.80% (94/1,957) were not sure if the pangolin was a protected animal or not. Fourteen respondents declined to answer.

When asked if the term "threatened" implied pangolins are at risk of extinction, 48.24% (944/1,957) of the respondents believed that threatened does imply extinction risk (**Figure 6B**). Forty-two individuals declined to answer.

The most recent amendment to the "Law of the People's Republic of China on the Protection of Wild Animals" (hereinafter referred to as the "Protection Law") clearly states that the conscious consumption of protected animals is illegal. Upon evaluating public awareness of the Protection Law, an overwhelming majority of the respondents (87.89%) were aware that pangolin consumption was illegal (**Figure 7**). Among reported pangolin consumers, 75% (81/108) were aware of the Protection Law. According to our survey experience and volunteer feedback, we found that although the public understands the contents of the Protection Law, their legal awareness was weak overall or they were willing to flout the relevant law. For example, there are still quite a few people who believe that the consumption of pangolin scales for medicinal purposes is reasonable, and that there is nothing wrong in the consumption of pangolin meat; some people, when asked whether they would consume pangolins if given the chance, gave positive replies.

Types of Pangolin Products Consumed and Reasons for Consumption

The most widely consumed pangolin product was scales, followed by meat. Only a small proportion of individuals consumed pangolin wine and other derived products. Among 108 respondents who had consumed pangolin-related products, scales had been consumed by 61 respondents, 58 respondents had consumed meat, 4 individuals had consumed pangolin wine, and 18 indicated that they had bought or consumed other products, including scale ornaments (16 individuals) and other products (1 individual), or had experienced Guasha (scraping) therapy which is a popular treatment for neck and shoulder pain, gastritis and enteritis by scraping the patient's neck, back or chest (2 individuals). Note that among consumers, multiple pangolin products were consumed by the same individuals.

Regarding the consumption of scales, 80.43% (49/61) of the consumers identified curing diseases as their motivation (**Figure 8A**). General health care was also a common driver of consumption. In addition, in responses to the "other" category, we found that some respondents believed that the scales can ward off evil spirits or used them as decorative ornaments. However, most meat consumption was accidental; i.e., the individuals were invited by their relatives or friends. Among informed meat consumers, curiosity was the most common reason for consumption, followed by "showing-off," and as a nutritional supplement (**Figure 8B**). The treatment of disease and health care were uncommon motivations for meat consumption.

The Characteristics of Pangolin Consumption

Of all consumers (61 scale consumers and 58 meat consumers), nine respondents had consumed scales and 16 respondents had consumed pangolin meat in the past year. Considering that the

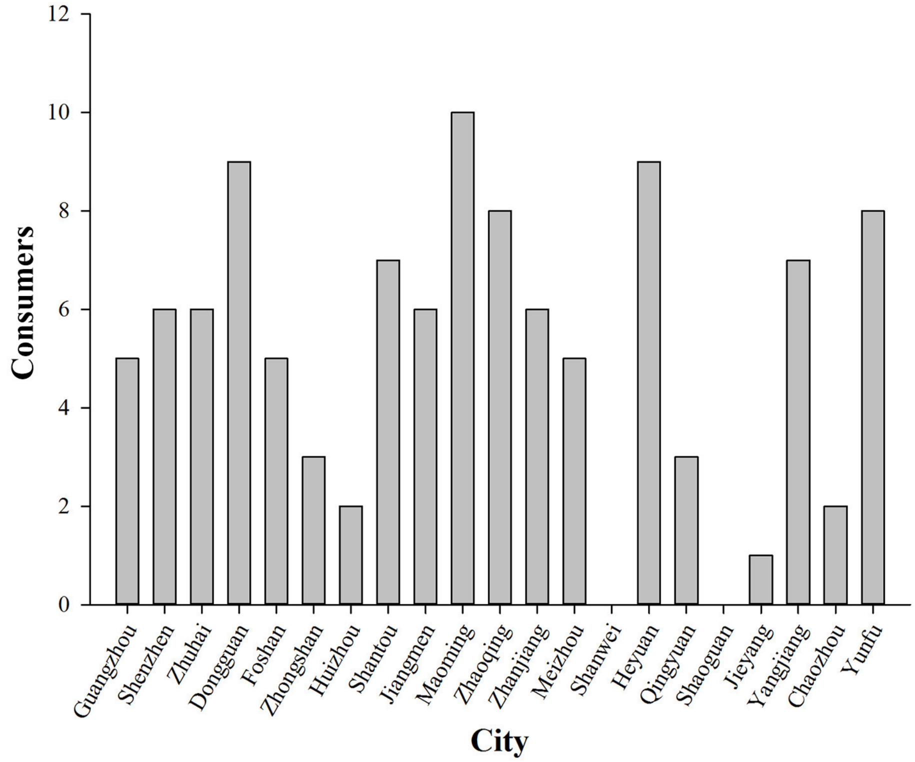

FIGURE 3 | The number of pangolin consumers across 21 prefecture-level cities in Guangdong province.

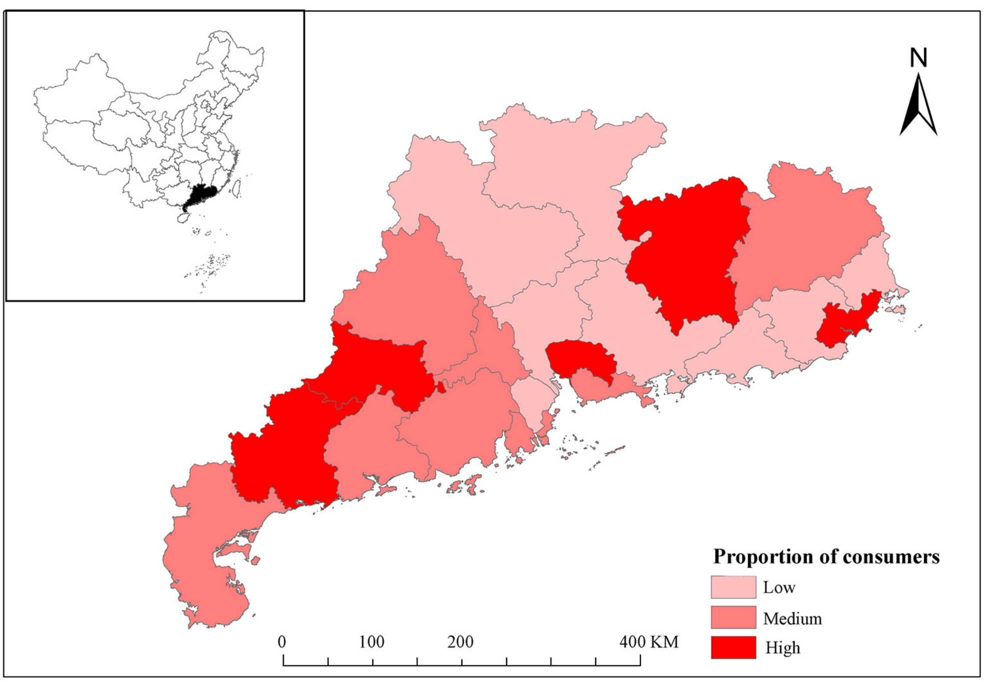

FIGURE 4 | The proportion of pangolin consumers across 21 prefectures in Guangdong province.

number of consumers was small, we did not estimate the amount of pangolin scale and meat consumption, we simply analyzed the consumption characteristics of all recorded consumers. Among meat consumers, nine consumed meat in groups of 4–6 people, four in groups of 7–10 people, and three in groups of >10 people. It can be seen that pangolin meat consumption generally occurred in groups. Additional questionnaire data indicated that 10 of the 16 consumers had consumed pangolin meat once in the past year, 1 had eaten it twice, 4 had eaten it 3–6 times, and 1 had consumed pangolin ≥7 times, resulting in an estimated average consumption rate of 2.31 events annually per consumer. This implied that although meat consumers were a minority among the populace, they were often not accidental, but habitual consumers.

We also attempted to provide statistics on the consumption of pangolin scales and meat, but the feedback on this aspect was insufficient. Among scale consumers, only five provided their consumption amount. Three people consumed ≤10 g of scales, one consumed 36.8 g, and one person consumed >100 g; the remaining four respondents did not provide an amount that they had consumed. Only two meat consumers estimated the amount of meat they ate in one sitting, as 2–3.5 and 5 kg were eaten by their groups, respectively. Therefore, we were unable to estimate pangolin consumption in Guangdong Province through this survey.

TABLE 1 | Models of the demographic differences among consumers*.

Variable	df	Log likelihood	Change in −2Log likelihood	Significance
Distribution	20	−417.844	41.769	0.277
Age	1	−319.973	13.443	0.000
Job	10	−400.732	30.962	0.001
Education	9	−396.940	23.377	0.005

*Based on conditional parameter estimates.

Respondents' Attitudes Toward the Future Consumption of Pangolin

To understand the potential future demand for pangolin more fully, we surveyed the willingness of respondents to consume pangolin in the future.

Regarding active consumption, a survey was conducted to examine whether the respondents would consume pangolin if they were sick or entertaining guests. For medicinal use, even if the efficacy of the scales is uncertain, 10.48% (205/1,957) of the respondents would still use the scales for treatment and the 23.86% (467/1,957) who were vacillating were also potential pangolin consumers (**Figure 9A**). Among banqueting guests, 94.58% (1,851/1,957) of the respondents would refuse to consume pangolin and thought that pangolin meat could be replaced by other high-end items; only 0.97% (19/1,957) were willing to consume pangolin for personal reasons (**Figure 9B**).

In terms of invited consumption, 1.38% (27/1,957) were willing to consume pangolin if they were invited to by relatives or friends, while 16.82% would decide whether to participate depending on the circumstances or who made the invitation. Of the respondents who refused to consume pangolin (80.46%), 19.98% (329/1,957) would also try their best to persuade the host not to consume it and another 43.79% (857/1,957) would choose to report restaurants anonymously to the relevant authorities (**Figure 10**).

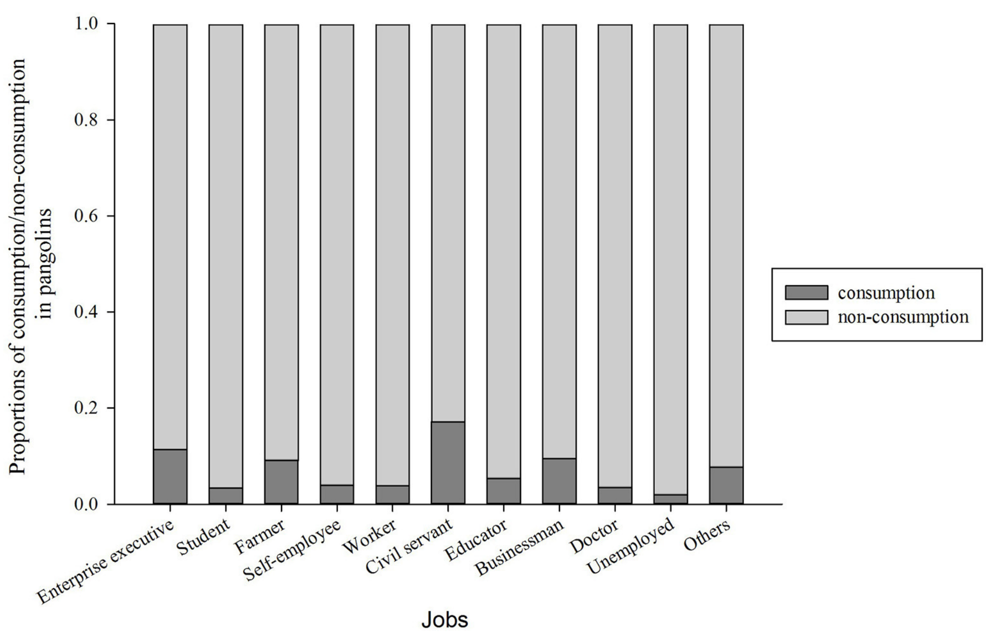

FIGURE 5 | Proportion of consumption/non-consumption by different occupations.

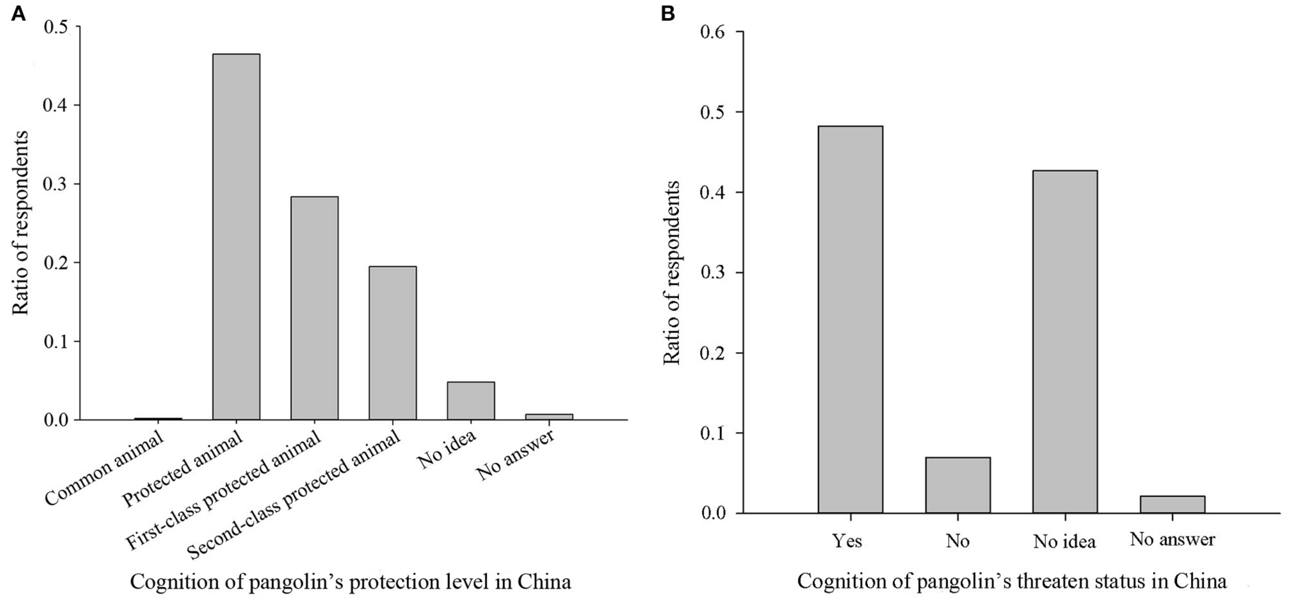

FIGURE 6 | Responses to a survey on pangolin status and consumption (1,957 respondents) asking if respondents were aware of the pangolin's protection level **(A)** and threatened status **(B)** in China.

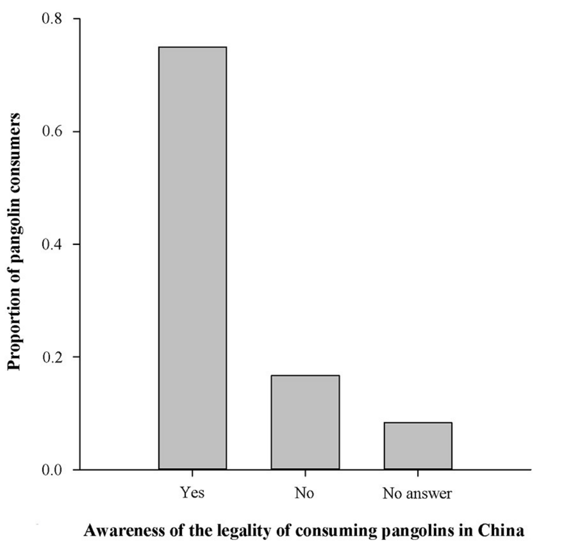

FIGURE 7 | Responses to a survey on pangolin status and consumption (1,957 respondents) asking if individuals were aware that the consumption of pangolin and pangolin products was illegal.

Examining the respondents' future willingness, we found that the public's consumption of pangolin for medicinal purposes was more difficult to change than its use for other purposes.

DISCUSSION

Our goal was to develop an in-depth understanding of the motivations behind wildlife consumption and targeted strategies to change public conceptions regarding pangolin consumption. In light of the present issue of pangolin consumption in Guangdong, we propose and discuss strategies to shift consumer behavior and thereby reduce or potentially eliminate the demand for the illegal pangolin trade.

Increase Public Understanding of Pangolin Status and Decline

The premise and basis for raising public awareness of the protection of threatened species is to first ensure that the public has a clear, comprehensive understanding of the species. Although pangolins receive widespread publicity in China as a species of public concern, only 19.47% of the respondents were aware that pangolins are Category II state-protected animals. Conservation education is critical to sensitize people to the threats facing a species, the need to protect it, and the action required to ensure its survival (Liu et al., 2017). We suggest that using additional local media types including local TV stations to create publicity will help to improve public understanding of pangolins, including their biodiversity value, role in the environment, protected status, population declines, major threats to their survival.

Human consumption psychology can change with improved science literacy and evolution in social culture (Liu et al., 2017). Surveys of wildlife consumption in Hunan Province administered before and after the SARS epidemic in 2003 showed that the consumption of frogs, snakes, pheasants, and hares decreased significantly when people became aware that wild animals are potential hosts for zoonotic diseases (Yang et al., 2007). Through captivity, it has been shown that pangolins can transmit a variety of parasites and multiple viruses (Zhang

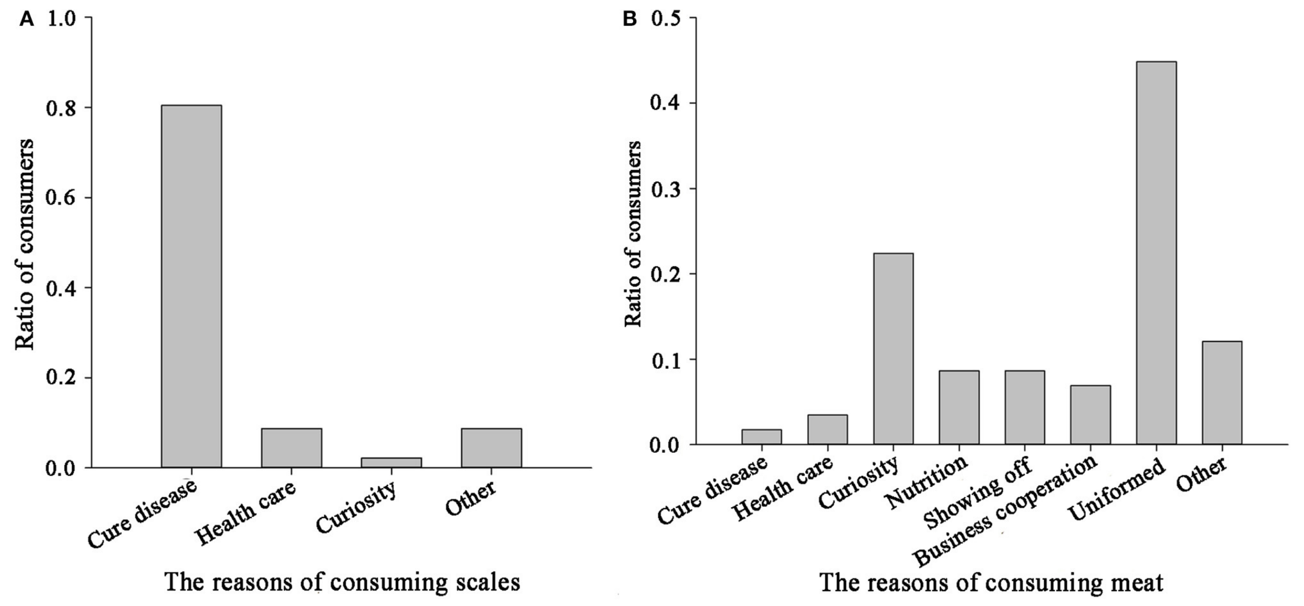

FIGURE 8 | Responses to a pangolin consumption status survey regarding individual reasons for consuming pangolin scales **(A)** and meat **(B)**.

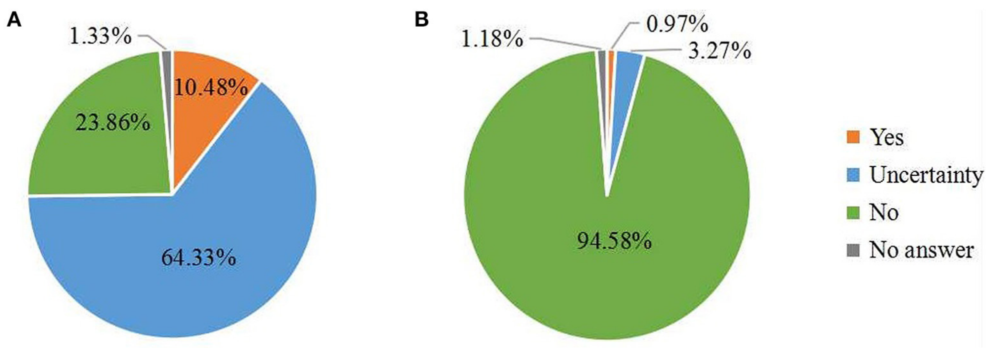

FIGURE 9 | Respondents' future willingness to consume pangolin scales **(A)** and meat **(B)**.

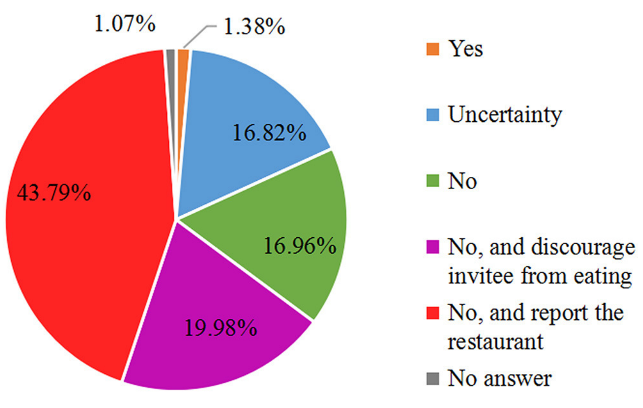

FIGURE 10 | Respondents' attitudes when invited to consume pangolin meat in the future.

et al., 2015, 2017b; Liu et al., 2019), and that there is a risk of human infection (Xiao et al., 2020). However, the vast majority of the public are unaware of this. We suggest that wildlife management institutions collaborate with more generalized science and technology workers to boost public knowledge of pangolin parasites and diseases. The relationship between avian influenza outbreaks and the consumption of birds and other wild animals in China was used as an example to warn the public about the potential risks and serious consequences of eating wild animals (Yang et al., 2007). Further, knowledge of the smuggling process could change public opinion on pangolin consumption. Tranquilizers and medications are administered to trafficked animals, which could have adverse effects for humans who consume them.

Building awareness around the legal implications of smuggling and consuming pangolins may also decrease demand. In our survey, it was found that some consumers knew only that consuming pangolins was illegal; they did not know the type or degree of punishment. For example, some offenders have even been given suspended death sentences (SINA.COM, 2007). From additional communication with the respondents, it was found that when consumers were told they could face several years in jail for consuming pangolins, they said they would refuse to consume them. Our results indicated that public awareness of the ramifications of the Protection Law was weak, as 75% of the respondents who consumed pangolin were aware that it was illegal. In addition, publicity materials tend to focus on protection knowledge and not related legal knowledge about pangolin consumption. We suggest including legal information in scientific publicity materials on pangolins. Online or televised videos of pangolin trafficking and seizure cases could enhance the understanding of relevant laws as well as the severity of the pangolin population decline due to overconsumption.

Promote Change in Product Choices Among Pangolin Consumers

We found three main motivations for pangolin meat consumption among respondents. The most prevalent was curiosity, with individuals pursuing a novelty food item. Another was "showing off," with individuals consuming pangolin, an expensive food, as a symbol of status and wealth. Finally, some individuals believe that the pangolin has significant nutritional value and their meat is a health supplement. In addition to using pangolin scales to treat diseases, many people believe that the scales also ward off evil spirits or use them as decorative ornaments. In other countries where pangolins are distributed, scales have a high importance value in certain communities' spiritual, cultural and medicinal beliefs (Adeola, 1992; Soewu and Adekanola, 2011; Boakye et al., 2014; Challender et al., 2019b).

We suggest that further public education efforts be made to advocate for a refusal to consume wild-caught wildlife. With the development of the social economy, organic food and food health preservation have gradually become the new fashions in Chinese public food consumption. Hence, people can be encouraged to choose organic foods or novel domesticated animals to achieve the goals of health care and luxury consumption.

Recommend and Develop Alternative Medicines to Cease the Use of Scales as Ingredients in Chinese Patent Medicines

The use of rare and endangered species as traditional medicine can have potentially significant impacts on populations of local species, which are already under pressure (Still, 2003; Williams et al., 2007). Pangolin scale is an effective ingredient in TCM (Xie et al., 2001; Wang et al., 2015; Zhou et al., 2019). The consumption motivation of scales as a drug was very high (80.43%, 37/46), due to doctor's advice. Based on previous, unpublished research, we found there is a lack of awareness among traditional medical practitioners and some old traditional medical practitioners don't even know what a pangolin is. Therefore, it's one of vital aspects to increase awareness among traditional medical practitioners and soliciting their support for pangolin conservation efforts, for instance, doctors should prioritize the use of preparations of Chinese medicine formulas or Chinese medicines that do not contain pangolin scales but are still effective. Boakye et al. (2014) also pointed it out.

In addition, although pangolins have been removed from the pharmacopeia in China, they are still in the lists of ingredients in patented medicines included in the pharmacopeia. Currently there are studies on the substitutes of scales, including cowherb seed (Hsieh, 2005; Wang, 2008), pig hooves (Hou et al., 2000), horns of Cervidae and Bovidae species (Luo et al., 2011), the thorns of Chinese honey locust and cockleshells (Bensky et al., 2004), the effectiveness of these substitutes has not been proven and traditional medical practitioners had reservations about the use of substitutes (Wang, 2008). To achieve the removal of scales from Chinese medicinal use, the pharmacological study of scales must be conducted to determine their efficacy in disease treatment and relevant active compounds, with the goal of creating alternative medicines to replace scales in treating diseases.

Regarding the respondents' attitudes to future consumption, some respondents would still use the scales to treat diseases at the risk of breaking the law, and the willingness to consume pangolin for medicinal purposes was significantly greater than it was to consume it as meat. As a result, it's very important to develop alternative medicines for pangolin protection.

Enhance the Protection Level of Pangolin in China and Strengthen Law Enforcement

Prior to 2020, the Chinese government's monitoring and investigation research was relatively weak and the illegal wildlife trade were relatively active. However, since the COVID-19 outbreak, China has strengthened the management of wildlife breeding, customs, market management, forest police law enforcement and other links. Given that China is a major region

TABLE 2 | The observations of Chinese pangolins in June 2020 in China.

Date	Location	Gender	Mass (kg)	References
2020.6.8	Huangshan district, Anhui	♂	–	Anhui Forestry, 2020a
2020.6.9	Suichang county, Zhejiang	–	–	Zhejiang Forestry, 2020
2020.6.14	Xiangqiao district, Guangdong	♂	1.9	Guangdong Forestry, 2020
2020.6.15	Ningguo county, Anhui	♂	6.6	Anhui Forestry, 2020b
2020.6.19	Ningguo county, Anhui	♂	3.5	CR Zheng pers. commu.
2020.6.23	Huidong county, Guangdong	–	–	C. Li Pers. Commu.
2020.6.25	Chun 'an county, Zhejiang	♂	2.45	Zhejiang Forest, 2020

of pangolin consumption, on the basic of upgrading its protection level and increasing penalties for trafficking, we suggest that the daily monitoring of wild animal and Chinese herbal medicine markets is necessary, wherein appropriate government departments fully investigate illegal trade dynamics and routes related to the pangolin (Yin et al., 2016). Associated businesses such as game restaurants should also be monitored. The illegal trade of pangolins is inseparable from human behavior. Social norms which include descriptive norms and injunctive norms, have important influence on people's consumption behavior (Cruwys et al., 2015). Descriptive norms which rely on situational factors through most of the other people's behavior influence consumer behavior (Kim et al., 2012), while injunctive norms by rules or sanctions placed on a person's behaviors by others (Kim and Seock, 2019), if their behavior violates injunctive norms, they will be punished (Jiang and Ma, 2014). Therefore, carrying out public education to guide the public to avoid consumption of pangolins, increased consumer penalties can reduce or eliminate the willingness of the public to flout the law and consume pangolins (Liu et al., 2017). Since the Chinese government has cracked down on the illegal trade and consumption of wildlife across the country, the consumption of wild animals has been significantly lower (Liu et al., 2017). In addition, with increasing public awareness of pangolin protection, some citizens have taken the initiative to report the behavior of those destroying pangolin resources to law enforcement authorities, and there is also a growing number of cases of the public reporting wild pangolin encounters to managers. For example, in June 2020, we recorded at least seven cases that were reported by the public in China, 5 cases were from news and another 2 cases were from personal communication (**Table 2**). Regarding the respondents' attitudes to the future consumption of pangolins, potential consumers still remain. Therefore, to protect pangolins more effectively, the penalties for pangolin consumption and media coverage of related cases should be increased to deter potential consumers. To increase public participation further in pangolin protection, we suggest the establishment of a standardized reporting reward system. Individuals would receive rewards for reporting cases of pangolin trafficking and consumption, once verified.

CONCLUSIONS

Although the public is generally aware that pangolins are protected animals, few are aware of their protection level in China or their critically endangered status. Only a small proportion of individuals in Guangdong have consumed pangolin, but among these, most knew that pangolin consumption was illegal, which indicates that they had a weak understanding of the Protection Law or were willing to flout the relevant law. Scales and meat were the primary items consumed, and scales were generally consumed for disease treatment and health care. Aside from accidental consumption, the primary motivation for eating pangolin meat was curiosity and "showing off." To reduce the consumption of pangolin, we suggest that it is necessary to simultaneously improve public knowledge of pangolin status, disease risks, and the Protection Law. Further necessary efforts include developing alternative drugs and ceasing the use of scales in Chinese patent medicine. We believe that these actions are fundamental to ensuring pangolin protection.

DATA AVAILABILITY STATEMENT

The data analyzed in this study is subject to the following licenses/restrictions: protect the personal privacy of interviewees. Requests to access these datasets should be directed to Fuhua Zhang, zhangfuhuahbu@163.com.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Ethics Committee at South China Normal University. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

FZ and SW: conceptualization, writing—review and editing, and funding acquisition. FZ, YY, and JY: methodology. FZ, YY, and YM: formal analysis and investigation. FZ, YY, and AM: writing—original draft preparation. FZ: resources. SW: supervision. All authors: contributed to the article and approved the submitted version.

FUNDING

This research was supported by the public program Conservation Action for Critically Endangered Pangolins funded by China Environmental Protection Foundation, the Wildlife Protection and Management Project of Forestry Administration of Guangdong Province, the National Natural Science Foundation of China (31572286, 31702029), and Science and Technology Program of Guangzhou, China (201804010475).

ACKNOWLEDGMENTS

We thank all volunteers in 21 prefecture-level cities for their help in data collection in Guangdong Province.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fevo.2020.574161/full#supplementary-material

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

frontiers in Ecology and Evolution

PERSPECTIVE
published: 02 February 2021
doi: 10.3389/fevo.2021.604929

Opportunities for Transdisciplinary Science to Mitigate Biosecurity Risks From the Intersectionality of Illegal Wildlife Trade With Emerging Zoonotic Pathogens

A. Alonso Aguirre[1], Meredith L. Gore[2], Matt Kammer-Kerwick[3], Kevin M. Curtin[4], Andries Heyns[5], Wolfgang Preiser[6] and Louise I. Shelley[7]*

[1] Department of Environmental Science and Policy, George Mason University, Fairfax, VA, United States, [2] Department of Geographical Sciences, University of Maryland, College Park, MD, United States, [3] Bureau of Business Research, IC[2] Institute, The University of Texas, Austin, TX, United States, [4] Laboratory for Location Science, Department of Geography, University of Alabama, Tuscaloosa, AL, United States, [5] Humanitarian Logistics and Supply Chain Research Institute, Hanken School of Economics, Helsinki, Finland, [6] Department of Pathology, Faculty of Medicine and Health Sciences, Stellenbosch University and NHLS Tygerberg, Cape Town, South Africa, [7] Terrorism, Transnational Crime and Corruption Center, SCHAR School of Policy and Government, George Mason University, Arlington, VA, United States

OPEN ACCESS

Edited by:
*Amy Hinsley,
University of Oxford, United Kingdom*

Reviewed by:
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University of Agricultural Sciences and Veterinary Medicine of Cluj-Napoca, Romania
Sarah-Anne Jeanetta Selier,
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***Correspondence:**
*A. Alonso Aguirre
aaguirr3@gmu.edu*

Specialty section:
*This article was submitted to Conservation and Restoration Ecology,
a section of the journal Frontiers in Ecology and Evolution*

Received: *10 September 2020*
Accepted: *07 January 2021*
Published: *02 February 2021*

Citation:
Aguirre AA, Gore ML, Kammer-Kerwick M, Curtin KM, Heyns A, Preiser W and Shelley LI (2021) Opportunities for Transdisciplinary Science to Mitigate Biosecurity Risks From the Intersectionality of Illegal Wildlife Trade With Emerging Zoonotic Pathogens. Front. Ecol. Evol. 9:604929. doi: 10.3389/fevo.2021.604929

Existing collaborations among public health practitioners, veterinarians, and ecologists do not sufficiently consider illegal wildlife trade in their surveillance, biosafety, and security (SB&S) efforts even though the risks to health and biodiversity from these threats are significant. We highlight multiple cases to illustrate the risks posed by existing gaps in understanding the intersectionality of the illegal wildlife trade and zoonotic disease transmission. We argue for more integrative science in support of decision-making using the One Health approach. Opportunities abound to apply transdisciplinary science to sustainable wildlife trade policy and programming, such as combining on-the-ground monitoring of health, environmental, and social conditions with an understanding of the operational and spatial dynamics of illicit wildlife trade. We advocate for (1) a surveillance sample management system for enhanced diagnostic efficiency in collaboration with diverse and local partners that can help establish new or link existing surveillance networks, outbreak analysis, and risk mitigation strategies; (2) novel analytical tools and decision support models that can enhance self-directed local livelihoods by addressing monitoring, detection, prevention, interdiction, and remediation; (3) enhanced capacity to promote joint SB&S efforts that can encourage improved human and animal health, timely reporting, emerging disease detection, and outbreak response; and, (4) enhanced monitoring of illicit wildlife trade and supply chains across the heterogeneous context within which they occur. By integrating more diverse scientific disciplines, and their respective scientists with indigenous people and local community insight and risk assessment data, we can help promote a more sustainable and equitable wildlife trade.

Keywords: biosecurity, COVID-19, emerging infectious diseases, illegal wildlife trade, One Health, operations research, spatial analytics, transdisciplinarity

INTRODUCTION

The contemporary scope and scale of the illegal wildlife trade (IWT) is unprecedented (Goldenberg et al., 2017; UNODC, 2020). This transnational environmental crime includes harms against tens of thousands of vertebrates (Scheffers et al., 2019) generating an estimated \$5–\$23 billion annually (May, 2017). IWT threatens species, ecosystems and societies both locally and globally (Hinsley et al., 2017; May, 2017). IWT is linked to the spread of zoonotic diseases (Gómez and Aguirre, 2008; Pavlin et al., 2009) and is associated with kleptocracy, corruption, money laundering, degradation of the rule of law, national insecurity, undercutting of sustainable development investments, erosion of cultural resources, and convergence with other serious crimes (Shelley, 2018). IWT-related risks are reinforced by the cross-border and transboundary nature of wildlife crime, diversity of wildlife populations, community-based management regimes, and rural-urban connectivity (Hübschle, 2017; Gore et al., 2019). Efforts to reduce risks associated with IWT may generate new risks. For example, indigenous peoples and local communities (IPLCs) have long been seen as either culprits of biodiversity decline or as "unseen sentinels" effectively managing and monitoring their territories. A binary approach to IWT solutions can exclude IPLC cultural and livelihood dimensions of risk management, provoke existing or new environmental injustices. It may also preclude informed consent of people who will be directly affected by decision making (Matias et al., 2020).

Transdisciplinary science can support efforts to promote sustainable and equitable trade of wildlife because IWT involves both overt and covert human behaviors. These behaviors create new biosecurity risks, including spaces, exposure pathways, and transmission routes for emerging and resurgent pathogens. Humans across all stages of the IWT supply chain—from IPLCs to law enforcement officials to conservation biologists—are at risk from exposure to trafficked wildlife and their pathogens, regardless of their intention in interacting with wildlife (Van Borm et al., 2005; Gómez and Aguirre, 2008). Despite the overall human health risks associated with exposure to pathogens with pandemic potential, the connections of IWT with zoonotic pathogens and vector spread, the intersectionality of the issue has not received sufficient attention from the scientific community (UNODC, 2020; WWF Global Science, 2020). Widespread infections and epidemics are potential outcomes of the trafficked wildlife and as seen most recently with COVID-19, a disproportionate risk from pandemics falls on already vulnerable human populations.

A serious problem confronts policy makers who seek to support evidenced based decisions because the intersectionality can create new, significant, or modified biosecurity and environmental risks that remain unquantified. Failing to understand the impact in unmodeled, unmanaged, and unmitigated human health risks can have serious impacts as illustrated by the following discussion of the biosecurity risks associated with pathogens of pandemic potential and IWT. Conversely, opportunities abound to leverage collaborative research and innovative analytic approaches to expand our understanding of IWT and manage future risks in an equitable and sustainable manner (Aguirre and Nichols, 2020). After our discussions of the risks, we consider the biosecurity risks associated with pathogens of pandemic potential and IWT by identifying four scientific opportunities for the use of transdisciplinary science to mitigate biosecurity risks associated with pathogens of pandemic potential and IWT.

PAST AS PROLOGUE AND THE REPEATING BIOSECURITY RISKS OF ZOONOTIC TRANSMISSION

Destruction of habitats in many parts of the world have promoted contact with new species and their pathogens. Furthermore, urban demand for wildlife in particular, illustrated by the size and number of wet markets and wildmeat consumption, often of endangered or threatened wildlife species, are not only hastening species extinction but are changing human-wildlife interactions in ways not previously seen.

Several "stuttering" events occurred over decades since the 1920s before HIV crossed over to humans and was first detected in the 1980s. Wildmeat hunting and subsequent consumption of these catches is thought to be the primary human-wildlife interaction that enabled the spillover of AIDS from chimpanzees to humans (Wolfe et al., 2007; Ordaz-Nemeth et al., 2017). Today, interactions across species are influenced by the rise of the internet and social media that facilitate illicit trade and poaching of endangered and other species across the globe.

In Africa this has been even visually documented. The open and dark web, social media, smart phones and mobile banking enable IWT as ever before (IFAW, 2012; Lavorgna, 2014). Virtual platforms for buying and selling products blur the lines between the legal and illegal wildlife trade, and the lack of monitoring and regulation of virtual "ecosystems" complicate efforts to reduce biosafety risks and promote sustainable trade. The ability to engage in IWT anonymously has increased access to wildlife for diverse stakeholders while at the same time obfuscating some options for pandemic-related contact tracing (Siriwat and Nijman, 2018; FATF, 2020).

Human-wildlife interactions enable zoonotic infections in at least two ways. First, infections can move from animals to humans. This infection pathway is most common in geographies where wet markets, wildmeat hunting, and trade of non-native species are common. This trade is driven by legitimate and illegitimate motivations. These interactions increase the spatial and temporal likelihood of transmission. Second, infections may transfer from humans to other animal species through a process known as zooanthroponosis (Messenger et al., 2014). This less common pathway of transmission can still generate substantial risks. For example, SARS-CoV-2 has been reported in domestic dogs, domestic cats, tigers, and lions (Gönültas et al., 2020; Wang et al., 2020). Spillover of SARS-CoV-2 from humans to mink was also reported in several countries confirmed through contact tracing. As a result, millions of minks have been culled globally (Kevany, 2020; Koopmans, 2020).

Several epidemics and pandemics devastating to humans were detected in recent times including H1N1 swine flu (1.4B infected;

151-575k dead), Ebola virus of 2014-16 in West Africa (28.6 k cases and 11.3 k deaths). Zika virus, SARS and MERS emerged in between these others. These emerging infectious diseases (EIDs) underscore the intersectionality of environmental and animal well-being with maintenance of human health. These outbreaks not only caused the death of hundreds to thousands of people, they increased risks from comorbidity factors such as diabetes, negatively impacted economies, and caused tensions among decision-makers (Madhav et al., 2017; Khubchandani et al., 2020).

The large number of initial patients of COVID-19 associated with a wet market in Wuhan, China originally suggested that the locale, where people closely interacted with legally (and potentially illegally) traded wildlife, was key in its transmission among humans. Some scientists have speculated that the market could, however, have been a focus of human-to-human rather than animal-to-human spread (Mackenzie and Smith, 2020). However, SARS-CoV-2 was not detected in Sunda pangolins (*Manis javanica*) confirming that this may have been an incidental host in the transmission (Lee et al., 2020). Zoonotic transmission of COVID-19 has not been determined, and ultimately, scientists may never be able to determine a specific animal host and whether it was linked to legally or illegally traded wildlife (Dhama et al., 2020).

A ONE HEALTH APPROACH TO SURVEILLANCE, BIOSAFETY, AND SECURITY

Existing collaborations among medical personnel and veterinarians seldom consider the role of IWT in zoonotic transmission of pathogens in surveillance, biosafety, and security (SB&S) efforts (Graham et al., 2013). This observation is striking within the context of One Health (OH), or "the collaborative effort of multiple disciplines—working locally, nationally, and globally—to attain optimal health for people, animals and our environment" (American Veterinary Medical Association, 2008). A OH approach is well-suited for globally distributed challenges such as IWT and pandemics. OH can accommodate dynamic changes in the relationship among humans, wildlife, and ecosystems.

Although academia has moved toward more transdisciplinary research, many challenges remain in governments where agencies tasked with different mandates discourage strong collaborations. A legislation framework will be required to deal with the restrictive nature and slow response to dynamic changes in the landscape (Hyatt et al., 2015). Despite these challenges, integrating theories, methods, and analytical techniques from diverse disciplines with different skill sets can serve as a force multiplier for the policy-relevance of science focused on the threats to human security and global health posed by pathogens of pandemic potential. Pandemic-related impacts such as those associated with COVD-19 (e.g., human death and illness, economic declines, politicization of science) and the increasing sophistication, impact, and economic value of IWT combine to demonstrate that future collaborations and more diverse partnerships are needed. Incorporating OH approaches may be most effective at advancing sustainable and equitable objectives if they engage diverse experts across domains such as conservation criminology, transnational crime, and corruption, supply chain analytics, operations research, and data science. Such transdisciplinary science can at least help clarify a common vision for sustainable use, establish shared values and goals, prioritize equitable allocation of limited resources, guide response protocols, support scalability of decision-making tools, and enhance communication.

We propose four collaborative initiatives to help extend and enhance SB&S efforts in support of more sustainable and equitable treatment of IWT. The OH framework accommodates the range of transdisciplinary perspectives involved in assessing existing SB&S efforts and detection networks for zoonotic pathogens that pose disease burdens for humans and animals. Beyond leveraging existing capacity, technology, and health systems identified through an OH assessment, bespoke, cutting-edge, and locally-sensitive decision and location science-based surveillance and response models can be incorporated to support more effective policy-making and sustainable use of wildlife (Hyatt et al., 2015; Aguirre et al., 2019; Wilcox et al., 2019).

OPPORTUNITIES TO MITIGATE BIOSECURITY RISKS USING TRANSDISCIPLINARY SCIENCE

One pathway for improving detection of pathogens in trafficked wildlife is through enhanced technical capacity for effective detection networks, outbreak analysis, and surveillance. Such capacity can generate inferences and inform efforts to decrease the risk of transmission of these pathogens to people and animals. Endemic and cross-boundary zoonotic pathogens (e.g., anthrax, bovine tuberculosis, brucellosis, echinococcosis, Lyme disease) are often underreported or are reported late, due to a lack of local diagnostic capacity and missing data on disease prevalence (Halliday et al., 2012; Tambo et al., 2014). A surveillance system focusing on specific pathogens by country or region along supply chain components of trafficked wildlife requires an understanding of the factors promoting emergence. Identifying approaches for prevention, rapid control, and mitigation is key (https://www.unodc.org/documents/Advocacy-Section/Wildlife_trafficking_COVID_19_GPWLFC_public.pdf). The health, societal, economic, and geopolitical impacts caused directly and indirectly by the COVID-19 pandemic, illustrate the range of risks associated with leaders or public officials who are unable (or unwilling) to identify and respond promptly and adequately to emerging zoonotic pathogens.

Populating a data landscape with analytically relevant variables will enable tracking of trends over time, facilitate aggregation, and disaggregation of data, support monitoring and evaluation efforts, enhance transparency in decision making, and promote accountability to donors. At present, the data landscape is devoid of many of these characteristics, to the detriment of sustainable wildlife use and human health and well-being. We propose actionable opportunities to address these shortcomings.

First, decision makers, civil society, and partner sectors may leverage enhanced SB&S to respond in an appropriate and timely manner to EIDs and strengthen national and local response capacities to prevent future outbreaks. A range of relevant activities includes:

- Comprehensive and co-created prevention education component for at-risk populations.
- A surveillance sample management system for enhanced diagnostic efficiency in collaboration with local partners to further establish or link existing surveillance networks (e.g., Rhinoceros DNA Index System in South Africa https://erhodis.org/).
- Integration of systems analysis and decision science methods within an economic, environmental, social ecosystem and IPLC perspective.
- Integrate transport industry such as aviation providers into enforcement efforts to prevent zoonotic transmission and wildlife trade (USAID, 2020).
- Consideration of the spatiality and intersectionality of wildlife trafficking and biosafety from cross-boundary zoonotic transmission.

Many stakeholders around the world already have the ability to create and manage highly efficient systems and networks across domain areas including logistics, commerce, and health care. SB&S can use those same tools to weaken illicit networks having negative outcomes including health risks, corruption, or abuse (Wood, 1993; Guo et al., 2016). That said, these methods require not only data regarding the nature of disease risk, but also need information on the behaviors of people who participate in those networks that lead to pathogen spillover (Alexander and McNutt, 2010). This requires multi-cultural perspectives and sensitivities.

Second, there exists an opportunity to leverage insights from IPLCs using community-based participatory methods and combining such knowledge with expert assessments, inducing the development of novel analytical tools and approaches that decision-makers can use to respectfully and equitably support local livelihoods by addressing the following enduring challenges: monitoring, detection, prevention, interdiction, and remediation. Improved decision-making for these challenges can be achieved with insights from IPLCs, through a clearer understanding about the operational environment and the economic and societal drivers that motivate local community members to participate in IWT.

Third, decision support models informing behavioral change policies can dramatically enhance local capacity to prevent, detect, and respond to pathogen risks. Supporting compliance with existing rules and enhancing crime analysis and prevention capacity of law enforcement authorities can help address the needs of community members who may otherwise resort to participation in IWT. Participatory methods can help ensure that local populations inform the development of solutions and these strategies are more likely to be consistent with cultural needs and priorities.

At the same time decision-support tools also need to be based on broad systematic evidence appropriate for long term sustainability—and it is imperative that these tools provide ease-of-use and interpretability for implementation by local stakeholders unfamiliar with sophisticated models and diagnostic tools; for example, the common use of Nobuto filter-paper blood samples collected during field surveys to detect exposure to an array of infectious diseases including avian influenza, canine distemper, malaria, and sylvatic plague (Advantec, 2009). Community outreach and engagement can produce accurate and reliable information about the prevalence of wildlife trafficking and EIDs that would otherwise not be known; community engagement will support the sustainability of detection and prevention strategies. We know that poverty, deforestation, urbanization, and human behavior are comorbidity factors underlying EID emergence that may progress into a pandemic (Patz et al., 2004; Aguirre and Tabor, 2009; Hassell et al., 2017). These variables influence epidemiology of pandemics in dynamic ways. Even without the benefit of hindsight on the pandemic, past responses to pandemics reveals that local capacity building, integrative research and transdisciplinary collaborations using the social ecological systems and resilience approach (Wilcox et al., 2019) will be prerequisites to untangle these complex issues that may result in severe harm across large populations. Broader efforts can and should be integrated with our understanding of the illicit wildlife trade. Best practices from efforts to combat other elements of the illicit economy such as study of supply chains, corruption, and illicit financial flows is crucial (Aguirre et al., 2020; FATF, 2020).

Finally, more can be done to harmonize a "network of networks"—including local communities—with enhanced capacity to promote joint SB&S efforts that encourage improved human and animal health, timely reporting, emerging disease detection, and outbreak response along with reporting on IWT. We already have global structures in place to support such a network of networks through science diplomacy, such as The One Health Tripartite Agreement between the Food and Agricultural Organization, World Health Organization and World Organization for Animal Health, supported by the World Bank Group (Vandersmissen and Welburn, 2014).

We can promote resilience in ecosystem function by enhancing education for justice, promoting legislative science advice, and funding interdisciplinary research teams. Science teams can help increase awareness and data integration capacity to facilitate new threat information that can be used strategically and tactically in both responsive and proactive ways. Such information could be particularly useful when it intentionally captures local community knowledge and integrates datasets to dramatically decrease the biosafety security gap between urban and rural areas (OECD, 2020).

PREVENTION OUTWEIGHS REACTIVE APPROACHES

Future efforts for containing zoonotic disease of pandemic potential may require a significant shift from scientific prediction to prevention, interdiction, and remediation strategies to deliver any practically beneficial outcomes (Dobson et al., 2020). It also requires efforts to reduce habitat destruction. The COVID-19 pandemic demonstrates that finding a virus, and managing the virus from a public health perspective, are two very different things. The world population and its many different cultures constitutes a complex system within which the virus circulates. Across the social, biological, and engineering sciences there is knowledge, and there are methods that can individually be brought to bear to more fully understand this complex system. More importantly, when diverse disciplines and their resources are brought together to address a complex challenge, they can answer questions and gain insights that no single discipline could generate in isolation.

CONCLUSIONS

Supporting SB&S efforts by government agencies and authorities [i.e., 1972 Biological Weapons Convention, 2004 UN Security Council Resolution 1540, 2005 World Health Organization International Health Regulations, Biosafety Level 4 containment laboratories (BSL-4)] from the local to the international levels, is critical for sustainable use of wildlife. These SB&S efforts can create new—and enhance existing—collaborations and capacity to address security issues at the intersection of human and animal health, wildlife trafficking, and infectious pathogens. This intersectionality is well-situated within the OH approach, particularly within the context of current consumption rates of animals for food, culture, traditional medicine, or the exotic pet trade. These activities have persisted for millennia and are highly likely to persist in a post-COVID-19 world. If there are wildlife consumption or trade bans instituted in countries where wildlife products are consumed, what will the impact of these be on curbing disease transmission? How successful would a ban of limited scope be in reducing the risks to human health and well-being from zoonotic transmission? In reality, banning wet markets is unlikely to wholly eliminate or even significantly reduce the disease transmission risks associated with IWT. It may, for example, help drive IWT underground, decrease nutritional options for vulnerable populations, degrade social and cultural identity or alter expressions of power and status. These are phenomena with policy implications that can be most accurately addressed by transdisciplinary scientific research with policy analysis (Alves and Rosa, 2007; Aguirre et al., 2019). Attention can be focused on the supply chains that allow zoonotic pathogens to be so rapidly distributed around the globe. Local capacity building is an essential element of global prevention, and such capacity can be combined with resourceful and well-trained networks at the global level to encourage diverse approaches to sustain biodiversity. This requires unprecedented cooperation by those in the OH world with the specialists in illicit trade in wildlife and illicit supply chains. This also requires transdisciplinary teams spanning science and engineering, environmental studies and social science as well as NGOs and corporations.

We need to ensure that businesses are not complicit in shipping animals with harmful diseases around the world. This requires closer cooperation with the business community such as occurred with the Routes partnership (USAID, 2020).We need interdisciplinary research to address illicit supply chains. More work is needed with the tech sector to ensure that online platforms and social media are not facilitators of illicit sales of endangered species of poached animals, and illicitly obtained flora and fauna. By involving participants at all levels and in all sectors of society we can encourage policies that improve environmental conditions in local communities and at the regional level. Habitat conservation, wildlife protection and a focus on the diverse skill sets of communities is key to accomplishing these objectives. By integrating more diverse scientific disciplines, and their respective scientists with indigenous people and local community insight and risk assessment data, we can promote a more sustainable and equitable wildlife trade.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding authors.

AUTHOR CONTRIBUTIONS

All the authors participated in the drafting the manuscript and discussion of all topics related to this perspective manuscript.

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

frontiers in Ecology and Evolution

ORIGINAL RESEARCH
published: 04 February 2021
doi: 10.3389/fevo.2021.612355

Trade in African Grey Parrots for Belief-Based Use: Insights From West Africa's Largest Traditional Medicine Market

Délagnon Assou[1,2], *Angie Elwin*[3], *John Norrey*[4], *Emma Coulthard*[4], *David Megson*[4], *Delphine Ronfot*[5], *Mark Auliya*[5,6], *Gabriel H. Segniagbeto*[1,2], *Rowan O. Martin*[7,8] and *Neil D'Cruze*[3,9*]

[1] Laboratory of Ecology and Ecotoxicology, Department of Zoology and Animal Biology, Faculty of Sciences, University of Lomé, Lomé, Togo, [2] Togolese Society for Nature Conservation (AGBO-ZEGUE NGO), Lomé, Togo, [3] World Animal Protection, London, United Kingdom, [4] Department of Natural Science, Ecology and Environment Research Centre, Manchester Metropolitan University, Manchester, United Kingdom, [5] Department Herpetology, Zoological Research Museum Alexander Koenig, Bonn, Germany, [6] Department of Conservation Biology, Helmholtz Centre for Environmental Research GmbH–UFZ, Leipzig, Germany, [7] World Parrot Trust, Hayle, United Kingdom, [8] FitzPatrick Institute of African Ornithology, DST/NRF Centre of Excellence, Department of Biological Sciences, University of Cape Town, Cape Town, South Africa, [9] Wildlife Conservation Research Unit, Department of Zoology, Recanati-Kaplan Centre, University of Oxford, Abingdon, United Kingdom

OPEN ACCESS

Edited by:
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Aarhus University, Denmark

***Correspondence:**
Neil D'Cruze
neildcruze@worldanimalprotection.org

Specialty section:
This article was submitted to Conservation and Restoration Ecology, a section of the journal Frontiers in Ecology and Evolution

Received: 30 September 2020
Accepted: 12 January 2021
Published: 04 February 2021

Citation:
Assou D, Elwin A, Norrey J, Coulthard E, Megson D, Ronfot D, Auliya M, Segniagbeto GH, Martin RO and D'Cruze N (2021) Trade in African Grey Parrots for Belief-Based Use: Insights From West Africa's Largest Traditional Medicine Market. Front. Ecol. Evol. 9:612355. doi: 10.3389/fevo.2021.612355

Over 1.2 million wild-sourced African Grey parrots (*Psittacus erithacus*) have reportedly been traded internationally since the 1970s, the majority of which were taken from the wild with serious implications for conservation, animal welfare, and biosecurity. While international trade has mostly been for the pet trade, in some West African countries, Grey parrots are also consumed for belief-based use. However, to date there has been little research into the scale and scope of this trade and its drivers. Here, we explore multiple facets of the trade in Grey parrots for belief-based use through interviews with five vendors at the largest "fetish" market of West Africa in Togo. We focus on understanding the purpose of medicinal and spiritual use of Grey parrots, and the socio-economic dimensions of this trade. Parrot heads were the most valuable and most frequently traded body part over the last year (2017), sold primarily for the medicinal purpose of helping to "improve memory." Feathers were the most common transaction for spiritual use, largely purchased for "attracting clients", "love", and to "help with divorce". Whole parrots and parrot heads had also been traded for spiritual use, mainly for "good luck" and "protection from witchcraft". Our findings suggest ∼900 Grey parrots were traded over the past 10 years in the market. Most vendors perceived an increase in the rarity of Grey parrot body parts over the past 5 years, which may reflect increased restrictions on international trade and/or the deteriorating state of wild populations. Although the sale of feathers collected from beneath roosting sites does not negatively impact wild populations, the relatively low value of these parts compared with other parrot derivatives and live parrots, suggests there may be minimal opportunity to leverage market mechanisms to protect wild populations through sustainable use. We identify a need for further investigations to examine the complex relationship between capture to supply the international pet market, a process in which many parrots die, and the local trade in belief-based use of derivatives.

Keywords: animal welfare, belief-based use, conservation, *Psittacus erithacus*, wildlife trade

INTRODUCTION

Parrots (order *Psittaciformes*) have long been hunted and captured in large numbers in the wild (Beissinger, 2001). Highly desired for their intelligence, beautiful appearance, and remarkable ability to mimic (Pepperberg, 2006; Pires, 2012), thousands of wild parrots are captured and traded around the world each year (UNODC, 2016), largely destined for the exotic pet trade where they can fetch US$100's—1000's (Bush et al., 2014; Yin et al., 2020). Since the 1980s, around 12 million live parrots have been legally traded globally, two thirds of which were either captured from the wild or were of unknown origin (UNODC, 2016). Along with the detrimental impact on wild parrot populations (Martin et al., 2014; Annorbah et al., 2016; Valle et al., 2018), trade in wild parrots also has human health and biosecurity implications, including the potential spread of infectious diseases (Fogell et al., 2018) and invasive species (Cassey et al., 2004). Trapping and trading of wild parrots is also a major animal welfare concern; the mortality rate from capture to market is estimated to be as high as 40–60% for some species, such as the Grey parrot (*Psittacus erithacus*) (Fotso, 1998; McGowan, 2001; Clemmons, 2003).

Grey parrots are native to the lowland moist forests of tropical West and Central Africa. The IUCN recognizes two distinct allopatric species belonging to the Psittacus genus; Grey parrots (*P. erithacus*) and Timneh parrots (*P. timneh*) and we follow this taxonomy here. However, other authors recognize a continental nominotypic species comprising *Psittacus e. erithacus* and *P. erithacus timneh* (e.g., Clements et al., 2019). Timneh parrots are native to Guinea-Bissau, Guinea, Sierra Leone, Liberia, and western parts of the Ivory Coast (BirdLife International, 2020), while Grey parrots are patchily distributed from eastern Ivory Coast eastwards through the forest of central Africa to Tanzania and Kenya, and south to northern Angola; the species is considered at very low numbers or extinct for Togo and Benin (Martin et al., 2014; BirdLife International, 2020). The recent assessment of the status of the species in Togo indicates that the presence of the species in the country is doubtful, with all breeding farms agreeing that specimens exported from Togo are of Nigerian or Cameroonian origin (Segniagbeto, 2016). Of the 3.3 million African parrots reported in international trade since 1975, Grey and Timneh parrots have been among the most exploited species (Martin, 2018a). Over this period, net exports of over 1.2 million wild-sourced Grey and Timneh parrots were reported to CITES (Martin, 2018b). Population declines have been reported in multiple areas driven largely by unsustainable harvesting and habitat loss (Martin et al., 2014; Annorbah et al., 2016; Hart et al., 2016; Lopes et al., 2019; Valle et al., 2020). In some countries (such as Ghana), population declines have been in excess of 90% over the past 25 years (Annorbah et al., 2016). Due to this ongoing and rapid decline, and the facilitating role of trade, Grey parrots were listed as Endangered on the IUCN Red List of Threatened Species in 2016 (BirdLife International, 2017) and were transferred to Appendix I of CITES in 2017 ending international trade in wild-sourced specimens for commercial purposes (CITES Notification No. 2016/063), although the Democratic Republic of Congo (DRC) were reserved from this change in CITES status of the species. However, despite the reservation, the DRC remained under an existing trade suspension and no permits for exports of wild Grey parrots for commercial purposes have been issued (CITES Notification 2018/01).

While international trade of Grey parrots has mostly been for the pet trade (Bush et al., 2014), in some West African countries they are also consumed for belief-based use (e.g., Fotso, 1998; Sodeinde and Soewu, 1999; McGowan, 2001; Clemmons, 2003; Williams et al., 2014; Ajagun et al., 2017). The use and trade of animal body parts (such as feathers, head, bones, feet, scales, etc.) for belief-based use has been of cultural importance for many people across the world for millennia (Alves and Rosa, 2013). Such practices remain widespread and varied, involving a wide range of species across all taxonomic groups (e.g., Soewu, 2008; Williams et al., 2014; Svensson et al., 2015). Compared to other continents, hunting pressure on wild animals for belief-base use is thought to be more intense in Africa, especially in central (Pauwels et al., 2003), southern (Simelane and Kerley, 1998; Whiting et al., 2013), and western (Atuo et al., 2015; Ezenwa et al., 2019) African countries where the domestic consumer demand for wild animals and their derivatives is particularly thriving (e.g., Williams et al., 2014; Djagoun et al., 2018). For instance, at least 350 bird species are targeted across the African continent for belief-based use (Williams et al., 2014). Birds are often sought to bring luck, fertility, intelligence, and money (among other things) (Nikolaus, 2011). It has been suggested that belief-based healers are widely consulted in many African countries because of the low ratio of university-trained medical doctors to patients (Williams, 2007), particularly in rural areas where belief-based healers are much more accessible (Williams, 2007; Williams and Whiting, 2016).

Although some aspects of this trade might be carried out sustainably, albeit in lieu of official management plans, and provide economic opportunities for rural and urban communities, the trade of wildlife for belief-based use can put pressure on wild populations presenting challenges for biodiversity conservation (Alves and Rosa, 2013; Williams et al., 2014; Buij et al., 2016; Moorhouse et al., 2020). From capture through to sale and slaughter, this trade can also be associated with negative animal welfare impacts (Baker et al., 2013). Predictions show that Africa will be responsible for more than half of human global population growth by 2050 (United Nations, 2018). Internationally, there are also concerns about the increasing sourcing of wildlife from Africa for use in belief-based medicine in other regions of the world [e.g., African pangolins (Manidae spp.) for use in China (Ingram et al., 2018) and rhino horn for use in Vietnam (Milliken et al., 2012)]. In the decades to come, it is clear that Africa will play an increasingly important global role in shaping the scope and scale of the use of wildlife in belief-based medicine (Williams et al., 2014).

In order to develop effective strategies to mitigate the threats posed to wildlife by trade for belief-based use, it is crucial to understand the patterns and drivers associated with the utilization of species of conservation concern, such as Endangered Grey parrots (Challender et al., 2015; Martin, 2018a). However, to date, there has been little research into the nature of this trade and its potential implications. For instance, while the trade in wildlife for belief-base use in Southern Africa is thought to be significant and widespread, the socio-economic context of this trade remains poorly understood (but see Simelane and Kerley, 1998; Whiting et al., 2013; Williams and Whiting, 2016; Djagoun et al., 2018; Dossou et al., 2018). In Togo and other West African countries, studies are particularly rare (but see Fretey et al., 2007; Segniagbeto et al., 2013; D'Cruze et al., 2020).

Here we explore multiple facets of the wildlife trade for belief-based uses through interviews with vendors in the "Marché des Fétiches" (French for fetish market), situated in Lomé (the largest fetish market in West Africa), Togo. We focus on understanding the purpose of belief-based use of Grey parrots, and the socio-economical context of this trade.

MATERIALS AND METHODS

Survey Area

The Marché des Fétiches is situated in Akodessewa in the eastern part of Lomé, the capital city of Togo (Segniagbeto et al., 2013). Since the late 1990s, the Marché des Fétiches has grown to be the biggest market for belief-based medicine in West Africa (Segniagbeto et al., 2013). As of 2018, there were 12 different stalls in operation at this location that were staffed by ~60 individuals. Eight of the stalls were involved directly in the sale of wildlife derivatives, and the others provided consultations for customers. Although wild meat is sold at other markets in Lomé, it has not been openly observed for sale at the Marché des Fétiches (D'Cruze et al., 2020). The market ultimately services the urban population from the city, as well as rural and urban healers and consumers from neighboring areas seeking to purchase products they are unable to source locally (Segniagbeto et al., 2013).

The market was moved from Bè market "Marché de Bè" to Akodessewa in 1998, and since 2013 has also operated as a tourist attraction. As such the throughput and turnover of some wildlife derivatives may be low in comparison to other markets elsewhere (with parts of some species remaining at stalls for years, serving as ornaments to draw tourist attention, with only small pieces being sold at irregular intervals). Wildlife trade is conducted openly at the market even though some species are protected under national legislation (Segniagbeto et al., 2013; D'Cruze et al., 2020).

Data Collection

Interviews were conducted by four local field staff asking a set of predetermined questions that included open-ended, closed and multiple-choice questions (see **Supplementary Material**). Interviews were conducted in Ewe, Fon, and French and later translated into English. Interviews were carried out with vendors at five of the eight stalls that were in operation selling wildlife derivatives at the time, all of which had been previously observed to have sold parrot derivatives. Vendors were interviewed in September (22nd—23rd) 2018. Vendors that were willing to participate in the study were identified through a process of chain referral (Newing, 2010), whereby participants recommended other potential participants or asked others to take part.

In accordance with the British Sociological Association Statement of Ethical Practice (BSA [British Sociological Association], 2017), informed consent was obtained verbally from every survey participant prior to the interview, participants were made aware of their rights to voluntarily participate or to decline, no identifying participant or household data were collected and the database collated was entirely anonymous. In addition, vendor stands were coded in the database and names are not reported to further protect study participants from harm or discrimination (John et al., 2016).

Interviews involved questions focused on Grey parrots based on vendor recollections of their own trade activity (see **Supplementary Material**). Questions focused on specific body parts sold, purpose and price per item, source country, estimated number of animals sold, customer type [tourists (one visit), causal customers (<five visits per year), and regular customers (>five visits per year)], and species availability (a mean "availability score" was calculated based on respondents answers to the question on how available Grey parrots were now compared to 5 years prior) (see **Supplementary Material**).

Data Analysis

All data analysis was performed in R statistical software (R Core Team, 2020). Descriptive statistics were used to examine patterns in parrot sales, including part of parrot sold, cost, source, sales availability, and type of customer. The number of parrots sold per year per vendor across three time periods [last year (2017), 2–5 years ago (2013–2016), and 6–10 years ago (2008–2012)] was compared using an ANOVA (data were normally distributed: Shapiro-Wilk test, $P = 0.05$, $W = 0.88$) to assess any pattern of change in sales in recent years (e.g., whether sales were increasing or decreasing).

RESULTS

Interviews were conducted with five vendors (three men and two women), ranging between 17 and 45 years in age. Vendors indicated that they were from the Fon ($n = 3$) and Watchi tribes ($n = 2$), living in households of between two and six individuals, with between zero and four children. Some vendors were married ($n = 2$), others were single ($n = 3$), and all five were educated

TABLE 1 | Summary of respondent responses to questions regarding trade in Grey parrot (*Psittacus erithacus*) body parts.

Body part	**Average cost (Medicinal)**	**Frequency**	**Average cost (Spiritual)**	**Frequency**
Head	10.4 (9.0–14.5)	4	3.6	1
Feather (single)		0	2.2 (1.8–2.7)	5
Whole animal		0	10.8	1
Source	**Where (Number of respondents)**		**Who (Number of respondents)**	
	Benin (4)		Hunter (2)	
	Togo (3)		Middlemen (5)	
	Ghana (1)			
	Nigeria (3)			
Sales period	**Mean (range) parrot sales per year**		**Most frequent part sold**	
Last year (2017)	64 (10–100)		Head	
2–5 years ago (2013–2016)	44 (16–90)		Feathers	
6–10 years ago (2008–2012)	31 (2.5–92.5)		Feathers	
Mean availability score	4.2			
Buyer (Number of respondents)	Regular Customer (5)			

Mean average cost (min–max) in USD and frequency reported by vendors is provided according to body part sold, type of use, source frequency (i.e., where and by who), along with estimated mean number of Grey parrots sold. The mean availability score (how available the species is compared to 5 years ago) could range from 1 ("a lot more") to 5 ("a lot less"). West African CFA was converted to USD at an exchange rate of 0.0018.

to primary school level only. All five vendors were from Lomé, Togo, but had moved from Benin, and self-described themselves as belonging to the traditional religious belief (Vodou). All vendors described belief-base medicine as their primary source of income, and stated that they had been trading between 2 and 30 years, with an estimated income of between $1,644 USD and $20,552 USD per annum [this is compared to the annual minimum wage in Togo in 2017 ($756 USD) and the average annual wage in 2018 ($1,848 USD) (International Labour Organization, 2020), which suggests that this can be a lucrative business for some traders].

Table 1 provides an overview of vendor responses to questions related to Grey parrot trade for medicinal and spiritual use in Togo. Four of the five vendors mentioned the use of the "parrot heads" for medicinal purposes. All five vendors mentioned "feathers" in relation to spiritual use with one vendor referring to "parrot heads" and "whole parrots". The red tail feathers (tail coverts) were the only feathers of the Grey parrot that the vendors referred to in terms of commercial value. Benin, followed by Togo, and then Nigeria were most cited as the main source country, with middlemen (cited by all five vendors) and hunters ($n = 2$) cited as the main individuals used to source these body parts.

Vendors reported that "parrot heads" were the most frequently sold body part during the last year (2017), with feathers reported as being the most frequently sold body part in both the last 5 and 10 years prior to this. The most frequently cited type of buyer was "regular customers" ($n = 5$), rather than "people buying out of curiosity" ($n = 0$), and "tourists" ($n = 0$). The majority of vendors referred to the reduced availability of Grey parrot body parts ["a lot less" ($n = 3$), and "quite a few less" ($n = 1$)]. Although one vendor stated that there was "quite a few more" ($n = 1$).

One-way ANOVA revealed no significant difference in the number of Grey parrots sold (per vendor, per year) across the three different time periods (2017; 2013–2016; 2008–2012) ($F = 1.165$, df = 2, 12, $p = 0.345$). Pairwise Tukey *post-hoc* testing also revealed no significant differences between the time periods ($P > 0.05$). However, the estimated number of Grey parrots sold by vendors during 2017 was higher than the average per year reported both for the period 2013–2016 and 2008–2012, respectively (**Figure 1**).

The most frequent type of use reported by vendors was "parrot heads" for medicinal purposes to help "improve memory" ($n = 4$) (**Figure 2**). With regards to spiritual use, vendors stated that "feathers" were used by customers to help them with "attracting clients" ($n = 2$), "love" ($n = 2$), and to "help with divorce" ($n = 1$) (**Figure 2**). Vendors also reported that "whole parrots" ($n = 1$) and "parrot heads" ($n = 1$) were used as "protection from witchcraft" and for "good luck", respectively.

DISCUSSION

Our study confirms that Grey parrots and their derivatives (heads and feathers) are being openly sold at the "Marché des Fétiches" in Togo for both medicinal and spiritual purposes (**Figure 3**). The vendors, all of which were from Benin, had in some cases relied on income from trade in wild animal derivatives for belief-based use for up to 30 years. According to the vendors, parrot heads were the most frequently traded Grey parrot body part over the last year (2017), the majority of which were sold for the medicinal purpose of helping to "improve memory". With regards to spiritual use, Grey parrot feathers were the most common transaction, largely purchased for "attracting clients", "love", and to "help with divorce". Parrot heads and whole parrots had also been traded for spiritual use over the past 10 years (2008–2018), the most cited purpose being for "protection from witchcraft" and for "good luck", respectively. All transactions over the past 10 years had involved regular customers, indicating local demand for this trade, rather than purchases by tourists, despite the market operating as a tourist attraction since 2013. Vendors stated that parrot heads were the most valuable body part sold, and they could fetch several times the value of parrot feathers. The higher value of the head of birds (compared to other body parts) in belief-based medicine in Africa has also been documented for other bird species, such as vultures, eagles and hawks (e.g., Atuo et al., 2015). Interestingly, no vendors

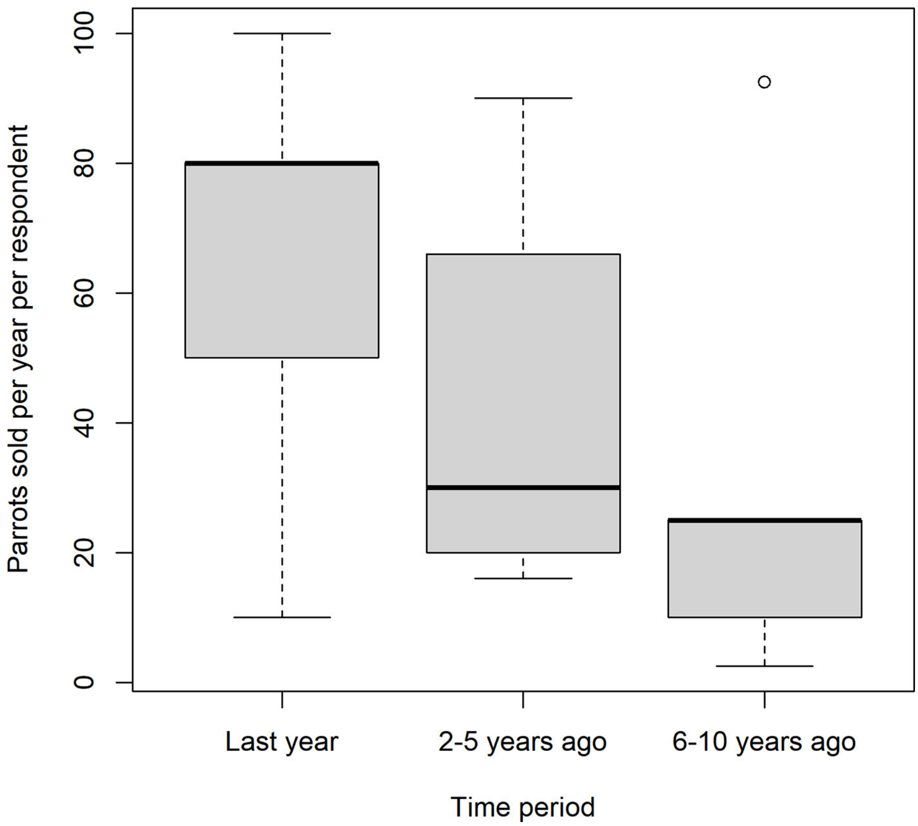

FIGURE 1 | Number of Grey parrots (*Psittacus erithacus*) sold per year per respondent across three periods [last year (2017), two to five years ago (2013–2016), and six to ten years ago (2008–2012)]. One-way ANOVA revealed no significant difference in the number of Grey parrots sold (per vendor, per year) across the three different time periods ($F = 0.98$, df = 2, 12, $p = 0.404$). Pairwise Tukey *post-hoc* testing also revealed no significant differences between time periods (2017: $P = 0.43$; 2013–2016: $P = 0.52$; 2008–2012: $P = 0.98$).

reported sales of parrot feathers for other cultural uses such as in traditional attire which is seen in other Grey parrot range states (Ezenwa et al., 2019).

Our findings highlight a number of conservation concerns associated with this type of trade in West Africa, given the Endangered status of Grey parrots (IUCN, 2020) due to rapid population declines, driven in part, by unsustainable capture and trade. Vendors stated that Benin and Togo were the main source countries for Grey parrot derivatives sold at the "Marché des Fétiches". However wild populations in these countries are already considered to be negligible or extinct (CITES, 2016; Segniagbeto, 2016; BirdLife International, 2020) and there is currently no specific national legislation protecting Grey parrots in Togo. Even low levels of exploitation could be catastrophic for any remaining populations. Unsustainable harvesting in regions where populations are already drastically reduced could set Grey parrots on course for further extinctions locally (Valle et al., 2018). For example, in neighboring Ghana, populations have been estimated to have declined between 90 and 99% since the early 1990s (Annorbah et al., 2016). Concerningly, the majority of vendors perceived an increase in the rarity of Grey parrot derivatives over the past 5 years. Although this decline might reflect collapsing populations, it might also reflect a reduced supply due to increased restrictions on international trade (Grey parrots were transferred to Appendix I of CITES in 2017, prohibiting cross border trade for commercial purposes). However, despite these increased restrictions, due to on-going consumer demand, it is possible that Grey parrot derivatives purchased by traders in the "Marché des Fétiches" may have been ultimately sourced from wild populations in Nigeria or central Africa, where Grey parrots are captured to supply the pet trade (Ezenwa et al., 2019).

There are also a number of animal welfare issues associated with the capturing and trade of wild parrots. Our results indicate that ~900 Grey parrots were sold at the "Marché des Fétiches" by the vendors in this study over the past 10 years. It is likely that many of the parrots whose derivatives were on sale at the market would have suffered to some degree, either during capture, transportation or slaughter (McGowan, 2001; Baker et al., 2013; Tamungang, 2016). While hunting and trapping methods may vary from country to country, inhumane capturing techniques have been reported in Cameroon, involving the use of glue to bind the feet and feathers of birds during capture (Tamungang, 2016). Furthermore, McGowan (2001) estimated that around 40% of Grey parrots trapped in Nigeria die before leaving their hunter. An additional 25% will die before reaching a market,

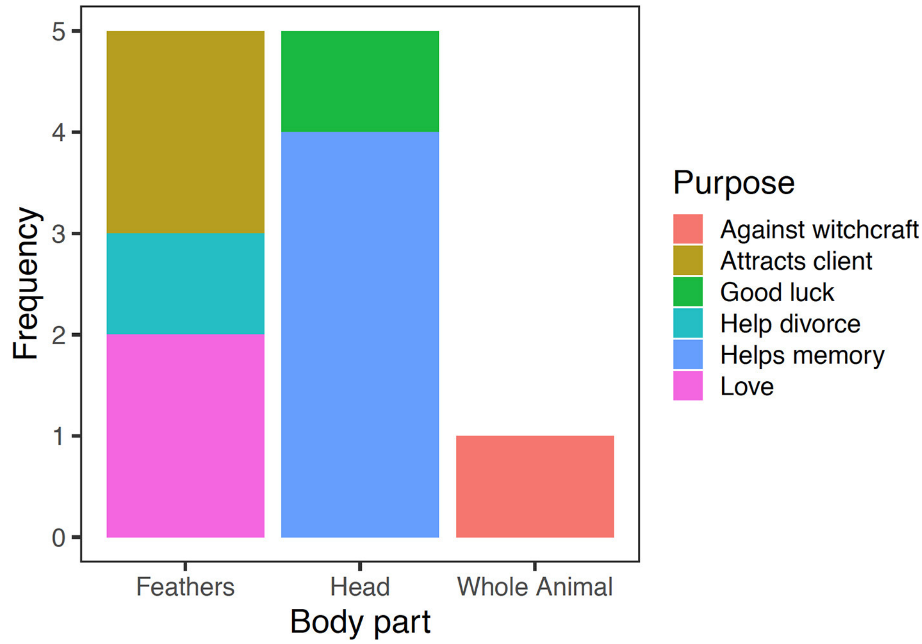

FIGURE 2 | Frequency of cited Grey parrot (*Psittacus erithacus*) purposes (both medicinal and spiritual) and body part used.

often because young birds are removed from their nest too early (McGowan, 2001). High mortality rates of captured Grey parrots are also reported during transportation in Cameroon, with parrots often dying in transit because of physiological stress, and lack of food and drinking water (Tamungang, 2016).

Although the majority of captured wild parrots are destined for the international pet trade (Bush et al., 2014), the high pre-export mortality rates of captured Grey parrots would indicate that this trade is likely integrated and interrelated with the trade for belief-based use, which is based on the sale of parrot derivatives (Williams et al., 2014). The extent to which parrots may be trapped specifically for belief-based use or are trapped for the exotic pet trade (with those that die being sold to belief-based medicine market vendors), is not yet fully clear. However, there is some evidence of a cross-over between these two trades. For example, seized Grey parrots in Cameroon have been found to have had their tail feathers removed (Martin, R.O. 2020, personal communication, 1 September). While this could be to make them harder to identify by enforcement agencies, it is possible that the tail feathers are removed from the parrots to sell separately, further adding to the suffering of the trapped parrots. Alternatively, there is evidence that some lethal techniques are used to hunt Grey parrots for belief-based use. In Cameroon, for example, the use of chemical substances and catapults to shoot Grey parrots have been documented, along with the use of handheld explosives to kill flocks of parrots at feeding sites (Tamungang, 2016). This suggests that some level of direct killing of parrots for the trade in parrot derivatives does occur. The extent to which these two trades are integrated is a significant knowledge gap that will need to be addressed to help determine the degree of threat it poses to wild populations. In particular, more research is needed to identify the extent to which the supply and demand for Grey parrot derivatives for belief-based use is driven by the number of parrots dying during the process of capture and trade for the pet market. In addition, in order to fully understand the animal welfare implications of this trade, more research is needed to identify how Grey parrots used in belief-based medicine are slaughtered and prepared.

Establishing the impact of belief-based medicine on wildlife is no easy task (Williams and Whiting, 2016). In particular, information provided by interviewees reporting on wildlife trade should be approached with caution, especially when illegal and or unsustainable aspects may be involved (Newton et al., 2008; D'Cruze et al., 2018). For example, we recognize it is possible that interviewees may have exaggerated or underestimated (either intentionally or unintentionally) the volume of trade or profits generated from their involvement in the trade of Grey parrots for belief-based use at the Marché des Fétiches in Togo. Similarly, it is important to note that, while the younger respondents stated that they had been involved in the trade for a number of years, they were also in part reporting on historical trade activity based on local knowledge passed to them by more experienced vendors (mostly their parents), rather than solely on their own direct experiences. However, the main aim of this study was not to establish the full impact of this particular trade activity on the conservation of wild populations or the welfare of individual parrots, rather it was to better understand what Grey parrots might be used for (by consumers) so as to better inform and direct future research and efforts to protect remaining wild parrot populations. Consequently, although our interview-based approach involved a relatively small number of vendors, we believe that our findings provide valuable insights that can be used to inform future efforts to protect Grey parrots.

FIGURE 3 | Top left–image of people searching for feathers under a parrot roost in Nigeria (Rowan Martin/World Parrot Trust); top right and bottom left–images of Grey parrot (*Psittacus erithacus*) intended for commercial sale, Togo, West Africa (Neil D'Cruze/World Animal Protection); bottom right Grey parrot tail feather in Nigeria (Rowan Martin/World Parrot Trust).

Some aspects of the trade in Grey parrot body parts might be entirely sustainable and potentially support conservation and be non-detrimental for animal welfare. For example, the scarlet red tail feathers of Grey parrots are gathered by local people from beneath roosts in Nigeria and it has been suggested that trade in tail feathers may provide important incentives for communities living near to roosts to protect parrots from trappers. However, recent surveys in Nigeria have found that roosts that were used in this way in the early 2000's are no longer present (Ezenwa et al., 2019) suggesting that current market structures do not lead to site protection as a result of sustainable use. As this study has illustrated, the value of tail feathers is often very small compared to the live bird or other body parts, and it is not clear whether there may be any models of sustainable harvest of feathers from beneath roosts that could yield conservation benefits. Furthermore, while gathering of feathers from beneath roosts provides a small income for communities living near to roost sites, this practice is only sustainable if there are healthy Grey parrot populations in the wild (Ezenwa et al., 2019).

The demand for Grey parrot derivatives for belief-based use could potentially be reduced through interventions which promote the use of herbal alternatives as has been proposed for trade in other wild animal species in West Africa (D'Cruze et al., 2020). This would require engaging with relevant stakeholders including representatives of traditional medicine associations to identify alternatives. The use of red tail feathers in traditional attire is likely to require a different approach. In Bolivia, where feathers of the Critically Endangered Blue throated Macaw are used for cultural activities, a community-based conservation initiative, aimed at increasing the use and production of alternative headdresses with artificial feathers, has been turned into an opportunity to enhance pride and engagement with parrot protection (Salvatierra da Silva et al., 2016). There may be opportunities to do something similar among some key consumer groups in West Africa. Studies have shown that communities living near to roost sites in West Africa are often unaware of the conservation status and plight of the Grey parrot (McGowan, 2001; Ezenwa et al., 2019). Working with local communities to raise awareness and to emphasize and promote the cultural and economic value of thriving wild populations of parrots in West Africa may help to reduce unsustainable hunting pressure, population declines (Ezenwa et al., 2019) and negative impacts on parrot welfare.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

Ethical approval was not provided for this study on human participants because the study was conducted in accordance with the British Sociological Association Statement of Ethical Practice (BSA [British Sociological Association], 2017). Informed consent was obtained verbally from every survey participant prior to the interview, participants were made aware of their rights to voluntarily participate or to decline, no identifying participant or household data were collected and the database collated was entirely anonymous. In addition, vendor stands were coded in the database and names not reported to further protect study participants from harm or discrimination. Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

AUTHOR CONTRIBUTIONS

ND'C, DA, MA, and GS: conceptualization. ND'C, DA, and DR: methodology. EC, DM, and JN: formal analysis and visualization. DA and DR: investigation and resources. ND'C and DA: data curation. AE: writing—original draft preparation. AE, ND'C, DA, and RM: writing—review and editing. ND'C and GS: supervision. All authors have read and agreed to the published version of the manuscript.

FUNDING

JN, DM, EC, DR, and MA received a grant from World Animal Protection to carry out this research.

ACKNOWLEDGMENTS

We wish to thank all of the vendors and Mark Dako (a local guide) at the Marché des Fétiches for their participation and patience during our study. We also thank all of the Masters students from the Ecology and Wildlife Management programme, from the Laboratory of Ecology and Ecotoxiology, Faculty of Sciences, University of Lomé (Kossivi Inès Akagankou, Afi Florence Konko and Ayaovi Doh Agomedje-Hounfodji) who helped us to conduct the survey. Finally, we sincerely thank Agbo-Zegue NGO for providing necessary logistics for the study.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fevo.2021.612355/full#supplementary-material

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

frontiers in Ecology and Evolution

BRIEF RESEARCH REPORT
published: 04 February 2021
doi: 10.3389/fevo.2021.609558

The Pandemic as a Conservation Marketing Intervention: Could COVID-19 Lower Global Demand for Wildlife Products?

Tom P. Moorhouse[1]*, *Neil C. D'Cruze*[1,2] *and David W. Macdonald*[1]

[1] *Wildlife Conservation Research Unit, Department of Zoology, Recanati-Kaplan Centre, University of Oxford, Tubney, United Kingdom,* [2] *World Animal Protection, London, United Kingdom*

We wished to assess whether the COVID-19 pandemic, thought to have a zoonotic origin, may lead to a reduction in consumer demand for wildlife products. In 2018, we surveyed the effect of demand reduction messaging on consumers' desire to own exotic pets with 1,000 respondents in each of Brazil, China, the USA, and Vietnam. In July 2020, during the pandemic, we repeated the survey with 100 new respondents in each country. Mean desire to own a given exotic pet was 40–60% lower in 2020 during the pandemic, but only for respondents from Brazil, China, and the USA, and only for the group of respondents who had high *a priori* purchase likelihoods: those who had already owned an exotic pet. The stated desire to own of non-owners was no different in 2020, but this group already had extremely low purchase likelihoods. Vietnamese pet owners, in contrast to those in other countries, exhibited higher purchase desire during the pandemic than previously. We speculate that this arose because Vietnam has a long history of dealing with epidemic disease, had no COVID-19 related deaths by the time of survey, and so population uncertainty about the consequences of exotic pet ownership may have decreased. While limited, our initial evidence indicates that the global pandemic is unlikely to permanently curb demand for wildlife products.

Keywords: COVID-19, coronavirus, demand reduction, conservation marketing, exotic pet

OPEN ACCESS

Edited by:
Tien Ming Lee,
Sun Yat-sen University, China

Reviewed by:
Elizabeth Davis,
San Diego Zoo Institute for Conservation Research, United States
Bilal Habib,
Wildlife Institute of India, India

***Correspondence:**
Tom P. Moorhouse
tom.moorhouse@zoo.ox.ac.uk

Specialty section:
This article was submitted to Conservation and Restoration Ecology, a section of the journal Frontiers in Ecology and Evolution

Received: *23 September 2020*
Accepted: *05 January 2021*
Published: *04 February 2021*

Citation:
Moorhouse TP, D'Cruze NC and Macdonald DW (2021) The Pandemic as a Conservation Marketing Intervention: Could COVID-19 Lower Global Demand for Wildlife Products? Front. Ecol. Evol. 9:609558. doi: 10.3389/fevo.2021.609558

INTRODUCTION

The COVID-19 pandemic has at the time of writing infected 30.6 million people globally, and caused 950,000 deaths (World Health Organisation, 2020a). The pandemic is considered to have a zoonotic origin, with initial studies suggesting it spilled-over from a wildlife reservoir among bat (Lu et al., 2020; Shereen et al., 2020) or pangolin populations (Zhang et al., 2020). Later work appears to have exonerated pangolins as a potential source (Frutos et al., 2020; Lee et al., 2020), but the most likely origin for COVID-19 remains zoonotic (Guo et al., 2020). With emphasis in the press and popular culture on the zoonotic origins of COVID-19 (e.g., CaptainJon720, 2020; McGorry, 2020), and given that considerations of zoonotic disease risk reduces purchase desire among consumers of exotic animals or wildlife products (e.g., Moorhouse et al., 2017, Moorhouse et al., 2020; Moorhouse et al., this volume), a key question is whether the public's response to this zoonotic pandemic led to a reduction in consumer demand for wildlife products.

METHODS

In a 2018 survey of respondents from Brazil, China, the USA, and Vietnam, we tested the effect of different conservation marketing messages on respondents' stated likelihood of buying exotic pets (Moorhouse et al., this volume). We addressed our above research question by repeating this survey in July 2020, 6 months after the emergence of COVID-19, with a reduced sample size of 411 respondents (102 from each of Brazil, China, and USA, and 105 from Vietnam).

We combined data from 2018 and 2020 into a single dataset and reanalyzed the results reported in Moorhouse et al. (this volume) to assess whether survey year (2018 vs. 2020) correlated with a change in respondents' desire to purchase a given exotic, or interacted with the effects of the experimental treatments.

All research was subject to ethical approval, references R57894/RE001 and R57894/RE004, Oxford University CUREC.

RESULTS

Our results showed an effect of year on stated desire to purchase exotic pets, mediated by two factors: whether a respondent had ever owned an exotic pet, and the respondent's nationality (**Figures 1A–C**). Among non-owners (who had never owned an exotic pet) of any nationality there was no evidence that desire to purchase differed between surveys. In 2018 mean stated desire to purchase mammals, birds, and reptiles (on a 1–10 scale) was 2.07, 3.28, and 1.70, respectively, among non-owners. In 2020, these figures were 2.85, 3.68, and 1.94 (LRT effect of year >1.2027, d.f. $= 1$, $p > 0.27$ across all analyses).

Among pet owners (respondents who currently, or had at some point previously, owned an exotic), the effect of year varied with respondents' nationality. Among respondents from Brazil, China, and the USA, desire to own any pet was significantly lower in 2020 than in 2018 (LRT effect of year $= 11.875$, 3.8631, 14.353, d.f. $= 1$, $p < 0.001$, $p = 0.049$, $p < 0.001$ for mammals, birds, and reptiles, respectively) in models that excluded respondents from Vietnam (see **Figures 1A–C**). Mean odds ratios for the effect of year were 0.40, 0.58, and 0.39 for mammals, birds, and reptiles, respectively, indicating that across these taxa the onset of COVID-19 was associated with a reduction of 40–60% in the likelihood of respondents selecting high desires to own. There was no evidence that responses varied between Brazil, China, and the USA (LRT effect of year*country on desire to own <1.778, d.f. $= 2$, $p > 0.4111$ in all analyses of mammals, birds, and reptiles), and also no evidence that the effect of experimental treatments varied with year (LRT effect of year*treatment <3.9274, d.f. $= 4$, $p > 0.416$ in all analyses) in models in which these interactions were fitted.

For pet-owners from Vietnam the above relationship was reversed: in 2020 Vietnamese pet-owners selected higher desires to own mammals and birds than they did in 2018, with the effect for reptiles less pronounced, but consistent with the direction of the effect (LRT effect of year $= 3.8813$, 12.471, 3.1876, d.f. $= 1$, $p = 0.0488$, $p < 0.001$, $p = 0.0742$ for mammals, birds, and reptiles, respectively; **Figures 1A–C**). Odds ratios for the effect of year were 2.24, 3.43, and 1.93 for mammals, birds, and reptiles, respectively, indicating that Vietnamese respondents were twice to three times more likely to select higher desires to own in 2020 than in 2018. There was no evidence that treatments interacted with year in a model in which this interaction was entered (LRT effect of year*treatment <6.7624, d.f. $= 4$, $p > 0.149$ in all analyses).

In both 2018 and 2020, respondents from Brazil and the USA were asked to rate their agreement with a number of attitudinal statements (see Moorhouse et al., this volume).

In an updated analysis incorporating the 2020 survey results there was no evidence that levels of agreement with any statement varied for either owners or non-owners between the 2018 survey and the 2020 resurvey (LRT effect of year <2.444, d.f. $= 1$, $p > 0.118$ for all analyses). The only exception was the statement "People have a duty to make sure they don't buy pets that come from the wild," with which non-owners (counter-intuitively) selected higher levels of agreement in 2018 than in 2020 (7.94 vs. 6.98, LRT effect of year $= 12.541$, d.f. $= 1$, $p < 0.001$).

DISCUSSION

Our results show that the pandemic decreased the stated likelihood of pet-owners from Brazil, China or the USA buying a given exotic pet. That there was no evidence for such a relationship among non-owners is explicable in that non-owners already exhibited very low likelihoods of purchasing an exotic: 54.1% of non-owners stated that they did not want to buy an exotic vs. 0% of owners; and 24.8% of non-owners stated they had a high likelihood of purchase vs. >77% of owners. That experimental treatment did not interact with year in our analyses suggests that COVID-19 had a blanket effect of lowering desire in pet owners from these countries. This latter finding may indicate that respondents did not necessarily recognize the zoonotic origin of the pandemic, given that the effect of disease statements in lowering desire to own was not more pronounced in 2020 than in 2018. We therefore speculate that the decreasing desire to own among these respondents in 2020 did not represent a recognition of the dangers of zoonotic disease arising from the consumption of wildlife products, but more likely arose as a response to some other facet of the social disruption resulting from the pandemic (e.g., abrupt financial shock or uncertainty about the future). This conclusion is supported by a finding from Morcatty et al.'s (2020) study of 20,000 Facebook posts from buyers and sellers of wildlife in Brazil and Indonesia between February and April 2020: online sellers and consumers did not discuss zoonotic disease risks, and viewed COVID-19 as a logistical (e.g., shipping) challenge, rather than a risk potentially arising from local wildlife trade.

By contrast to respondents from the other countries, Vietnamese pet-owners were between twice and three times more likely to select higher desires to own a given exotic in 2020 than 2018. A plausible explanation for this discrepancy is that by the end of July 2020 (the month during which we conducted our survey) Vietnam had recorded only 446 confirmed cases and zero deaths from coronavirus (World Health Organisation, 2020b), compared with 2,442,375 cases and 87,618 deaths in Brazil (World Health Organisation, 2020c), 87,457 cases/4,664 deaths in China (World Health Organisation, 2020d), and 4,263,531 cases/147,449 deaths in the USA (World Health Organisation, 2020e). Vietnam has also experienced multiple epidemics in the

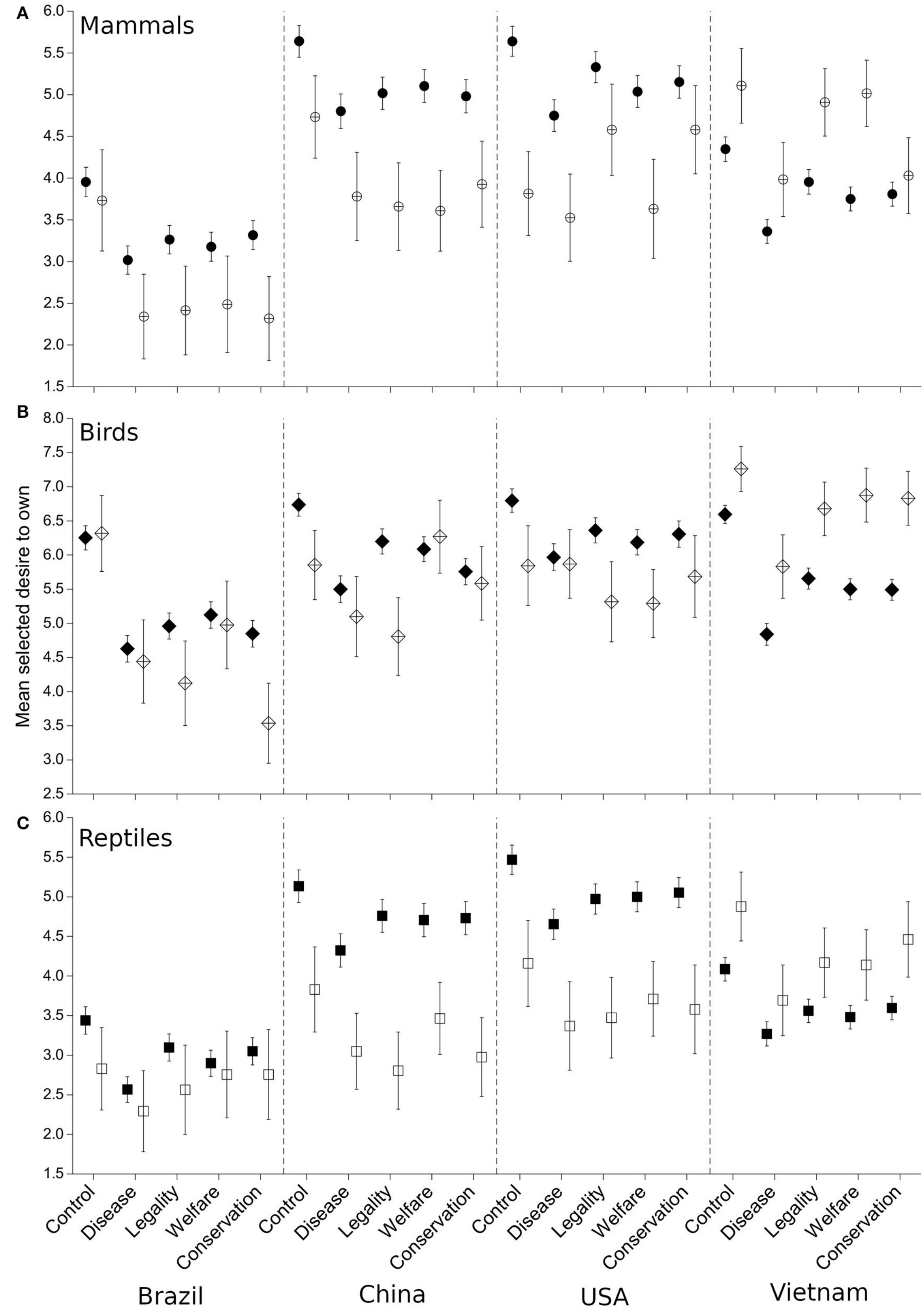

FIGURE 1 | The mean selected desire to own of pet-owning respondents in Brazil, China, the USA, and Vietnam, in 2018, prior to the inception of COVID-19 (black, filled symbols) and in July 2020 (open symbols) for **(A)** mammal species, **(B)** bird species, and **(C)** reptile species.

recent past, including Sars in 2003, avian influenza in 2010, as well as substantial outbreaks of measles and dengue fever, and their government moved swiftly to implement strict containment measures far before those of the majority of other countries acted (Jones, 2020).

Speculatively, the response of participants in Brazil, China, and the USA may reflect societal shock from the impacts of COVID-19, whereas Vietnamese respondents may have experienced little equivalent shock due to their prior experience with epidemics, familiarity with state measures to contain these, and having recorded no deaths from coronavirus. We have no data that could explain why Vietnamese respondents should choose *higher* desires to own exotics post-COVID-19, as opposed to their responses being unchanged, but speculatively if Vietnam was comparatively unaffected the population may perceive there to be few negative consequences to buying a pet: any arising could be expected to be successfully managed, and so individual uncertainties about the consequences of purchasing exotics may in fact have decreased in the wake of the pandemic.

Consumer demand for different wildlife products (e.g., meat or medicines) may respond to the COVID-19 pandemic in different and complex ways, but our results indicate that for exotic pets any resulting decrease in consumer demand may only be temporary. We found little evidence that fundamental attitudes shifted: levels of agreement with attitudinal statements concerning purchasing exotics were similar in both years. The difference in response in Vietnam, compared with Brazil, China, and the USA, suggests that increasing familiarity with epidemic disease, and with state measures to control its spread, has the potential to negate any initial decrease in desire to purchase these commodities. It remains to be seen whether the populations of other countries will in time react similarly to that of Vietnam. Whether they do may rely on how effectively their governments contain future epidemics. Our explanation does, however, make the counter-intuitive prediction that increasing instances of spill-over of zoonoses into human populations, if increasingly well-managed, could quickly result in a return to normal—or increased—levels of consumer demand for exotic pets in the future.

Our findings are preliminary results from a small survey and further work is clearly required to substantiate and develop them. On the face of our initial evidence, however, the sobering conclusion is that even a global pandemic of (most likely) zoonotic origin may not be sufficient on its own to permanently reduce consumer demand for exotic pets in particular, and perhaps wildlife products in general—although more evidence is needed as to what the impact of COVID-19 will be on medicinal and meat consumption of wildlife.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The survey involved human participants and was reviewed and approved by Oxford CUREC. The participants provided informed consent to their participation in this study.

AUTHOR CONTRIBUTIONS

TM: conceptualization, methodology, analysis, writing—original draft, writing—review and editing, and funding acquisition. ND'C: writing—review and editing and funding acquisition. DM: writing—review and editing and supervision. All authors contributed to the article and approved the submitted version.

FUNDING

TM received a grant from World Animal Protection to carry out this research. ND'C occupied a position held jointly held between Oxford University and World Animal Protection. The design, conduct, analysis, interpretation, and conclusion of the study were in no way influenced by the source of funding.

ACKNOWLEDGMENTS

The study was conducted in close collaboration with Tim Baker and Jon Darby or Touchstone Partners Ltd., for whose expertise and professionalism throughout we are extremely grateful.

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

frontiers in Ecology and Evolution

ORIGINAL RESEARCH
published: 17 February 2021
doi: 10.3389/fevo.2021.609547

Information About Zoonotic Disease Risks Reduces Desire to Own Exotic Pets Among Global Consumers

Tom P. Moorhouse[1]*, *Neil C. D'Cruze*[1,2] *and David W. Macdonald*[1]

[1] *Wildlife Conservation Research Unit, Department of Zoology, Recanati-Kaplan Centre, University of Oxford, Oxford, United Kingdom,* [2] *World Animal Protection, London, United Kingdom*

Demand for exotic pets is a substantial driver of the illegal wildlife trade. Previous work has suggested that this demand could be reduced by conservation marketing messaging highlighting the potential consequences to individual purchasers, in the form of zoonotic disease risks, or legal ramifications. Such work, however, has been limited only to respondents from culturally Western countries, and has not accounted for how underlying attitudes to the keeping of exotic pets may influence desire to own one, or affect the effectiveness of demand reduction messaging. We surveyed 1,000 respondents in each of Brazil, China, USA and Vietnam, showing each five mammal, bird, and reptile pets in random order. Each pet was accompanied with either a "control" statement, describing the species' diet, or one of four types of "treatment" statement describing zoonotic disease, animal welfare, legal or species conservation consequences. Respondents were asked to rate how much they would like to own the pet on a 1–10 scale. All respondents demonstrated decreased desire to own a given exotic when shown any of the types of treatment information, but disease information provoked the greatest decrease, relative to controls (a mean decrease of 26.9%, compared with 16.2, 17.9, and 18.9% for legality, welfare and conservation information, respectively). We also found that respondents with the highest stated likelihood of purchasing pets possessed a series of beliefs that could facilitate this purchase while maintaining an ethical self-image: in particular they believed that shops were well-regulated, and that they were able to distinguish captively-bred from wild caught animals. In summary all respondents of any nationality were motivated particularly to avoid the risk of zoonotic disease, and we recommend that demand reduction campaigns leverage this desire, particularly in the new context of COVID-19.

Keywords: zoonotic disease, experimental survey, social marketing, demand reduction, exotic pet

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Edited by:
Tien Ming Lee,
Sun Yat-sen University, China

Reviewed by:
Andres Garcia,
National Autonomous University of Mexico, Mexico
Jared D. Margulies,
University of Alabama, United States

****Correspondence:***
Tom P. Moorhouse
tom.moorhouse@zoo.ox.ac.uk

Specialty section:
This article was submitted to Conservation and Restoration Ecology,
a section of the journal Frontiers in Ecology and Evolution

Received: *23 September 2020*
Accepted: *15 January 2021*
Published: *17 February 2021*

Citation:
Moorhouse TP, D'Cruze NC and Macdonald DW (2021) Information About Zoonotic Disease Risks Reduces Desire to Own Exotic Pets Among Global Consumers. Front. Ecol. Evol. 9:609547. doi: 10.3389/fevo.2021.609547

INTRODUCTION

Recent decades have witnessed a substantial increase in the keeping of exotic (non-domesticated) companion animals (Grant et al., 2017; Ribeiro et al., 2019; Lenzi et al., 2020). Demand for exotic pets accounts for almost a fifth of global wildlife trade reports (Baker et al., 2013) making them a key driver of a global wildlife trade that is worth (excluding fisheries and timber) an estimated $30.6–42.8 billion annually, of which ∼$22.8 billion is legal (Engler and Parry-Jones, 2007), and $7.8–20 billion illegal (Haken, 2011; Pires and Moreto, 2011). Many of the exotic pets bought by consumers are sourced from wild populations (Bush et al., 2014; Harrington, 2015) after being poached from the wild (Pires and Moreto, 2011) and then distributed through criminal organizations to consumers (Engler and Parry-Jones, 2007; Dalberg, 2012; Ayling, 2013). While captive breeding facilities meet some of the global demand for pets, many launder wild-caught individuals into the captive-bred market (Nijman and Shepherd, 2009; TRAFFIC International, 2012). As a consequence, purchasers of exotic pets in consumer regions support, whether knowingly or not, the illegal trade in wildlife (TRAFFIC International, 2012)—and thereby a substantial, and growing, threat to global biodiversity, species conservation and animal welfare (Sodhi et al., 2004; Grieser-Johns and Thomson, 2005; Pires and Moreto, 2011; Fernandes-Ferreira et al., 2012; Baker et al., 2013; Dutton et al., 2013; Challender et al., 2015).

Efforts to stem illegal and/or unsustainable wildlife trade have traditionally focussed on tackling the supply of products, through enforcement and regulation (Veríssimo et al., 2012; Challender and MacMillan, 2014). There is, however, an increasing, additional, focus on measures to reduce consumer demand through educational and public awareness campaigns (Courchamp et al., 2006; Dalberg, 2012; Baker et al., 2013; Veríssimo and Wan, 2019). At present the relative effectiveness of demand reduction approaches often remains untested and under-reported (Olmedo et al., 2018; Veríssimo et al., 2018; Veríssimo and Wan, 2019). To be effective campaigns must understand the factors that influence customers' behavior, and deliver the correct message through the right communications medium (Dalberg, 2012; Challender et al., 2015). While a lack of information can be a barrier to changing behavior (Schultz, 2002), not all information will motivate individuals to alter their behavior (Stern, 2000). As an example, Moorhouse et al. (2017a) demonstrated that consumers' desire to purchase exotic pets was reduced by 39% by the provision of information concerning the negative legal and zoonotic disease consequences of purchasing exotic animals, but not by messages about the negative welfare or conservation consequences for the animals. Moorhouse et al. (2017a) concluded that information campaigns could be useful to reduce demand for exotic pets, or redirect demand onto non-exotic species, or those sourced from rescue centers or legitimate captive breeders, likely to be most successful through leveraging consumers' desire to avoid zoonotic disease and/or legal consequences.

A key limitation of the above study was that 90% of its respondents derived from only a relatively small number of principally English-speaking countries: the USA, UK, Australia and Canada, with 10% from eight other countries or of unknown origin. Attitudes toward wildlife (Tao et al., 2004; Cong et al., 2014) and responses to demand reduction messaging surrounding the ownership and use of that wildlife (Moorhouse et al., 2017b, 2019) can vary between nationalities and so it is unknown whether Moorhouse et al. (2017a) findings may be applicable outside of these countries. While there are no exact figures on patterns of global exotic pet ownership, the exotic pet market is known to be expanding rapidly as living standards improve in regions such as Asia and South America (Ding et al., 2008; McNeely et al., 2009; da Nóbrega Alves et al., 2010). For example the compound growth rate of China's pet industry was 49.1% from 2010 to 2016, the fastest among all industries, attributed to the population's increasing wealth (Yiwei, 2020). Principal consuming regions for the global wildlife trade are the United States, the Middle East, South East Asia, South America and the European Union (Haken, 2011; Bush et al., 2014) and insofar as exotic ownership is a driver of this trade, the attitudes—and their amenability to change—of a substantial proportion of consumers of exotic pets therefore remains untested.

In this study we employ an experimental survey to assess the potential for demand reduction messages to influence the desire of respondents to buy exotic pets of respondents in Brazil, China, and Vietnam, as representatives of key consuming regions. We also analyse the demographic factors that correlate with respondents' desire to own exotics, and examine whether this desire influences the effectiveness of treatment messaging or respondents' attitudes and beliefs regarding the impacts of exotic pet ownership.

METHODS

We surveyed 4,000 respondents, comprising 1,000 from each of Brazil, China, the USA and Vietnam. Respondents from the USA were included to permit comparison with results from Moorhouse et al. (2017a). Our sample size in each country was sufficient to meet the statistical power required for our experimental design. All questions were professionally translated from English into respondents' local language, and translations independently verified by native speakers. All questions were presented to all respondents: they answered six initial questions about their sex, age, educational level, income, occupation and household composition (whether respondents lived alone, with adults, or with children under 15 years of age). They were then asked "How do you feel about exotic pets?"—which we defined as "animals that are traditionally not domesticated for farming or in the house in close interaction with humans"—and asked to select one response from: "I have never owned an exotic pet and don't want to," "I have never owned an exotic pet but would like to," "I own at least one exotic pet" and "I have previously owned an exotic pet but don't at the moment." Respondents who stated either that they had previously or currently, or would like to, own a pet, were then asked "How likely are you to buy an exotic pet in the next 2 years?" with options "Very likely," "Quite likely," "Neither likely nor unlikely," "Quite unlikely" and "Very unlikely."

Following these questions all respondents were shown the statement: "We're going to show you a series of exotic pets, with some information about each one. Some of the information may not be true about the pet, but for this exercise please assume that it is, and based on the information you are given, say how interested you would be in owning this" and sequentially shown 15 different pets, each accompanied by information about it. The identity of each pet was randomly selected from eight mammals, eight birds and eight reptiles, with five of each shown to any given respondent. Information for any pet was randomly selected from five possible types, of which one was control information and four types were treatment information. Control information comprised information about

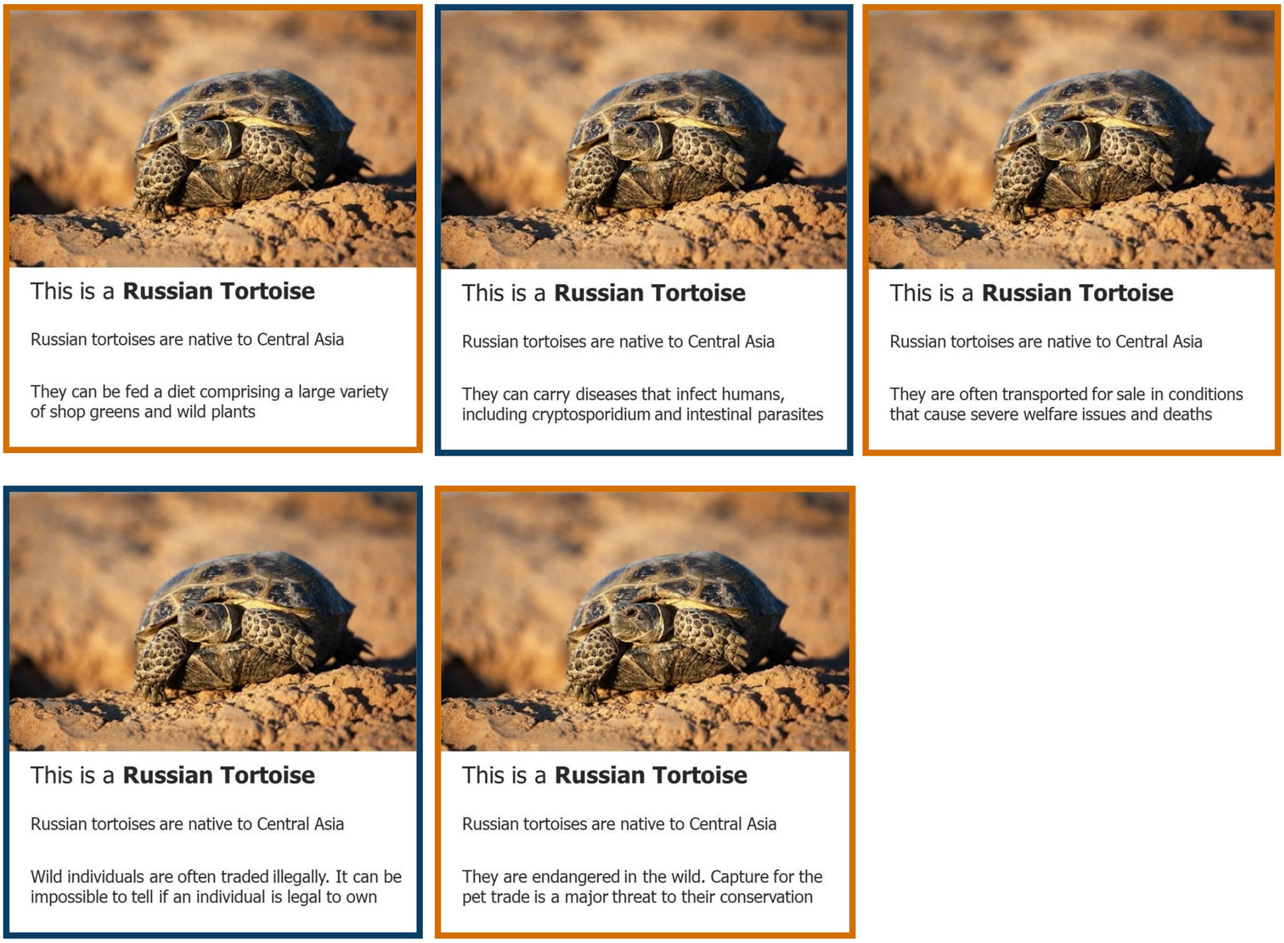

FIGURE 1 | An example set of control and treatment statements for one species, the Russian tortoise, *Testudo horsfieldii*. From left to right, top to bottom are control, disease, welfare, legality, and conservation information statements.

the pet's diet in captivity (**Supplementary Table 1**; **Figure 1**). Treatment information comprised text outlining the potential negative impacts of owning the pet for human disease/human harm, animal welfare, and the conservation status of the pet's wild populations, as well as the negative legal consequences of owning the pet (**Supplementary Table 1**; **Figure 1**). For any given pet all information presented was accurate [see Moorhouse et al., 2017a], with a small number of exceptions: of 120 statements (five statements for each of 24 different pets), 102 were accurate, and 18 were fabricated. Fabricated statements may or may not have been true (we found no evidence to support them, but they were nonetheless likely to be true—for example individuals from the majority of pet reptile species are likely to act as reservoirs for cryptosporidium; **Supplementary Table 1**), but were designed to sound plausible. These instances are highlighted in **Supplementary Table 1**. A further four statements were augmented with an additional word (again highlighted). This limited use of non-verified statements was required to permit full availability of control and treatment information across all experimental treatments—this in turn allowed for a balanced experimental design, minimizing the number of species required to deliver complete tests of each experimental treatment. For each pet/information combination respondents were asked to select a response from an eleven-point Likert-type scale (from 1—"I would never want to own this"—to 10—"I would definitely want to own this") before being shown the next pet.

Once all pets were rated, we asked respondents—from the USA and Brazil only, because respondents from China and Vietnam were required to participate in a further survey, the results from which are published elsewhere [see Moorhouse et al. (2020)]—to rate their level of agreement with eleven attitudinal statements divided across five broad, non-exclusive subject areas: (1) the likely source of exotic pets (wild caught or captively bred); (2) the degree of regulation of the market for exotic pets (3) consumer responsibilities (4) conservation impacts and; (5) welfare impacts (**Table 1**).

Statements within these subject areas were presented in random order. Ratings were made on a ten-point Likert-type scale, ranging from 1 = Disagree strongly to 10 = Agree strongly. Respondents from China and Vietnam were not asked to rate

TABLE 1 | Attitudinal statements, and the effect of respondents' stated likelihood of future purchase on their level of agreement with these figures.

Category	Statement	Estimate	Wald Z	*P*-value	Odds-ratio
Source of pet	I'm not worried about buying a pet that was caught from the wild	0.292	11.3	<0.001	4.30
Source of pet	I can tell if an animal for sale was bred in captivity	0.344	14.1	<0.001	5.58
Market regulation	If buying exotic pets was bad for conservation shops wouldn't be allowed to sell them	0.226	9.67	<0.001	3.10
Market regulation	If buying exotic pets was bad for animal welfare shops wouldn't be allowed to sell them	0.246	10.5	<0.001	3.42
Market regulation	I can trust traders not to sell animals from illegal sources	0.357	13.9	<0.001	5.97
Consumer responsibility	It is not my responsibility to make sure exotic pets come from a sustainable source	0.127	5.27	<0.001	1.88
Consumer responsibility	People have a duty to make sure they don't buy pets that come from the wild	0.161	−6.67	<0.001	0.447
Conservation impacts	Buying exotic pets could be bad for conservation	0.149	−6.10	<0.001	0.474
Conservation impacts	I'm not worried if buying exotic pets decreases wild populations	0.228	8.47	<0.001	3.13
Welfare impacts	I can give an exotic pet a better life than it would have in the wild	0.406	15.6	<0.001	7.61
Welfare impacts	Buying exotic pets could be bad for their welfare	0.166	−6.52	<0.001	0.444

Statistics given to 3 significant. Wald Z-test statistics are reported from models that also included the effect of respondents' age, sex, and nationality.

these statements, but were instead presented with another series of questions on a different topic [of traditional medicinal usage; see Moorhouse et al. (2020)], their answers to which would have been influenced by these attitudinal questions.

The survey was conducted in September 2018 and designed in collaboration with, and conducted by, a professional market-research company (Touchstone Partners Limited, http://www.touchstonepartners.co.uk) who coordinated respondent recruitment online through proprietary market research panels. Our sample size of 4,000 respondents was achieved after removing those who took less than one third of the median response time (a market research industry standard action to exclude disengaged respondents), and replacing these with additional respondents until the desired sample size was reached. Panelists were familiar with online surveys but not contacted so frequently as to have become unrepresentative of the wider population. All research was subject to ethical approval, references R57894/RE001, Oxford University CUREC.

Statistical Analysis

Initially we wished to understand what demographic factors might be associated with respondents' stated likelihood of purchasing an exotic pet in the future. We conducted an ordinal logistic regression analysis (implemented in Program R; Christensen, 2015; Christensen and Christensen, 2015) with a response variable derived from respondents' answers to the questions of "How do you feel about exotic pets" and the follow-up "How likely are you to buy an exotic pet in the next 2 years?" to create a six-point Likert-type scale. The lowest score (1) was awarded to the response "I have never owned an exotic pet but would like to" to the initial question, and then responses to the follow-up question were rated from 2 (="Very unlikely") to 6 (="Very likely") to construct a single metric ranging from 1 (=non-purchase) to 6 (="very likely" to purchase). Available explanatory variables were respondents' age, sex, country or origin, level of education (six point scale from "high school certificate" to "PhD"), their relative income (a seven point scale in local currency), whether they had previously owned an exotic pet, and whether they had children under the age of 15 living in their house (included to discern the extent to which the presence of children was a motivation for adults to buy exotics).

We assessed the effect of the experimental treatment on desire to own each pet using repeated measures ordinal logistic regression (Christensen, 2015; Christensen and Christensen, 2015). We analyzed each taxon (mammals, birds, reptiles) separately, because, *a priori*, different taxa may have different levels of attractiveness for respondents from different countries, arising from cultural norms (e.g., Herzog, 2014; Statista, 2016), which could potentially affect responses to treatment messaging. For each analysis, therefore, the response variable was respondents' selected desire to own (a 1–10 Likert-type scale) each of five pets from a given taxon. Available explanatory variables were respondents' age (entered as a covariate), sex, country, education, treatment (a factor with five levels encoding the type of information accompanying each pet for a given respondent: control, conservation, disease, legality, welfare), education-level and the identity of each animal. We also included respondents' previously stated likelihood of purchasing an exotic (on a 1–6 scale) as a covariate, because this was likely to correlate both with their desire to possess a given animal, but also their response to treatment information. We included, *a priori*, an interaction between purchase likelihood and treatment to test for this effect. We also included a variable encoding the order in which each animal, with its accompanying information, was shown to the respondent in question (a covariate with a value of 1–15 where 1 was the first animal shown, 15 the

TABLE 2 | Factors affecting respondents' stated likelihood of purchasing an exotic pet in the new 2 years.

Source	d.f.	LR statistic	*P*
Age	1	350	<0.001
Sex	1	2.66	0.103
Country	3	90.96	<0.001
Education	1	3.57	0.0590
Relative income	1	26.2	<0.001
Prior ownership	1	1143	<0.001
Children under 15	1	25.2	<0.001

Statistics given to 3 significant figures.

last). This was included to account for the possibility that the repetition of treatment messages for each respondent may alter the effectiveness of different types of treatment information. We included the interaction of treatment*order to test whether the size and direction of the effect of treatment information might vary with repetition of treatment information. See **Table 2** for a full list of explanatory variables.

We analyzed factors affecting the responses of participants from the USA and Brazil to the follow-up attitudinal questions using separate single measure ordinal logistic regression analysis for each statement ($n = 11$). Available explanatory variables were respondents' age, sex, country, education and income, and their previously stated likelihood of purchasing exotic pets (entered as a covariate, see **Table 1**).

RESULTS

Overview

We received full responses from 4,000 respondents, with 1,000 respondents from each of Brazil, China, the USA, and Vietnam for the 2018 survey. Exceptions to this were to the attitudinal questions, for which we elicited and received responses only from 2,000 respondents from the USA and Brazil.

Likelihood of Future Purchase

Likelihoods of purchasing exotic pets in the future varied between respondents' country of origin (**Table 2**), such that overall Chinese respondents were approximately half as likely to select higher purchase likelihoods than were respondents from Brazil, the reference level (*post-hoc* Wald test, $z = -6.494$, $P < 0.01$; odds ratio = 0.55). Respondents from the USA had equal likelihoods of future purchase to Brazilian respondents (*post-hoc* Wald test, $z = -0.835$, $P = 0.404$) while respondents from Vietnam were marginally more likely to select higher purchase likelihoods than those from the USA or Brazil (Wald test, $Z = 2.003$, $P = 0.045$; odds ratio = 1.19).

Respondents who had already owned an exotic were over nine times more likely to select a higher likelihood of purchasing one in the future than were respondents who had not (**Table 2**; odds ratio for the effect of prior ownership = 9.34). Of prior owners 77.3% stated that they were "quite likely" or "very likely" to buy an exotic, vs. 24.8% of those who had never owned an exotic. Conversely, 54.1% of non-owners stated they did not want to buy an exotic, vs. 0% of prior owners. Respondents' country and prior ownership were, however, partially conflated, such that 44.7% of Brazilian and 48.4% of Vietnamese respondents stated they had owned an exotic at some point, whereas in the USA and China these figures were 35.7 and 30.3%, respectively.

Older respondents selected lower future purchase likelihoods than did younger respondents. Of respondents under 34 ($n =$ 1,994), 56.8% stated they were "quite likely" or "very likely" to purchase an exotic in the future, and 21.1% stated they did not want to buy one. For respondents over 55 ($n = 424$) these figures were 15.8% (likely) and 64.4% (did not want), respectively. Respondents with children in the home were 1.39 times more likely to select higher purchase likelihoods.

Effect of Experimental Treatment on Desire to Own

Respondents shown images of exotic pets accompanied by any type of treatment information selected a lower desire to own them than respondents shown the same images and control information (**Figure 2**). With control information, respondents' mean selected desire to own any animal (on a 1–10 scale) was 3.50 (s.d. 3.50) for mammals, 5.09 (s.d. 3.71) for birds and 3.05 (s.d. 3.47) for reptiles (**Figure 2**). When presented with treatment information these figures were 2.79 (3.33) for mammals, 4.04 (3.76) for birds and 2.49 (3.25) for reptiles, such that desire to own was 17.8, 16.1, and 18.3% lower, respectively (**Tables 3A–C**) in separate analysis of each taxon (**Figure 2**).

Wald tests for the effect of levels of treatment (disease, legality, welfare, conservation) revealed that disease information provoked a greater decrease, relative to controls, than did legality, welfare or conservation information (**Figure 2**): respondents' mean selected desire to own was lower by 27.2% (mammals), 25.5% (birds), and 28.1% (reptiles) when shown disease statements, but decreases relative to controls were smaller when respondents were shown legality (16.3, 15.2, 16.7% lower for mammals, birds, reptiles, respectively), welfare (18.1, 17.2, 18.5%) or conservation (20.0, 15.9, 19.8%) statements (Wald tests for relative effect of disease, compared with legality, welfare and conservation $Z > 5.92$, $P < 0.01$ for all taxa and treatment levels; **Figure 2**). There was no consistent evidence across different taxa of any substantial difference in the size of the effect of the remaining treatment levels (legality, welfare, conservation): across all taxa and statements the maximum difference in desire to own was 3.2% (**Figure 2**).

Respondents' selected desire to own a given pet was strongly correlated with their previously stated likelihood of future purchase (**Figure 3**). For mammals, mean desire to own increased from 1.08 (s.d. 2.17) to 5.07 (3.61); for birds these figures were 1.94 (2.90) to 6.57 (3.44), and reptiles 0.870 (2.00) to 4.69 (3.72). The relative effectiveness of treatment statements, however, did not vary with likelihood of future purchase in models in which this interaction term was entered (LRT effect of treatment*likelihood of purchase < 4.5026, $p > 0.3422$ in all analyses).

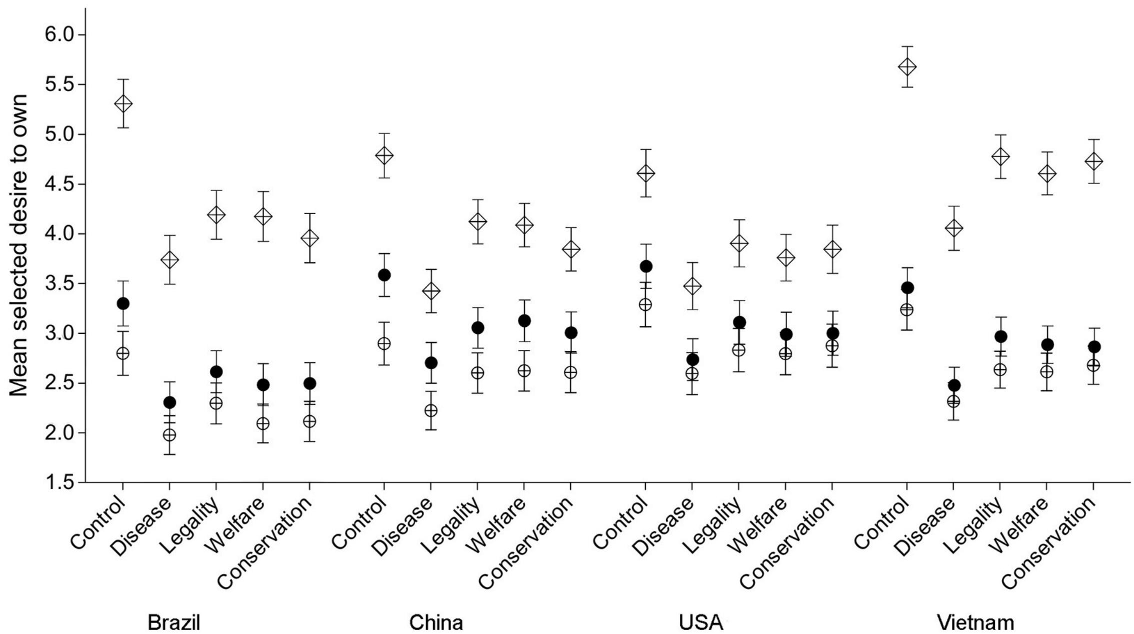

FIGURE 2 | The mean desire to own a given pet, on a 1–10 scale, of respondents from each country, given each type of experimental treatment, for birds (open rhomboid symbols), mammals (closed circle symbols), and reptiles (open circle symbols). Error bars represent standard error.

Each analysis revealed a main effect of the order in which treatment messages were shown (**Tables 3A–C**), but repetition of treatment messages reduced selected desire to own by a mean of $\leq$ 7% across all analyses of bird, mammal and reptile pets, suggesting that the effect size was small.

Respondents' Agreement With Attitude Statements

Attitude statements were shown only to respondents from Brazil and the USA. Across all attitude/belief statements in the 2018 survey respondents' level of agreement with a given statement correlated strongly with their stated likelihood of future purchase (**Figures 4A,B**; **Table 1**).

For statements concerning the source of exotic pets, mean level of agreement with the statements "I can tell if an animal for sale was bred in captivity" and "I'm not worried about buying a pet that was caught from the wild" was low (respectively, 3.39 and 4.21 out of 10; **Figure 4A**). Odds rations reveal that respondents who had earlier selected the highest purchase likelihoods were, respectively, 5.58 and 4.30 times more likely to agree with these propositions than were non-buyers (**Figure 4A**; **Table 1**).

With respect to beliefs about market regulation, respondents disagreed overall with the propositions that "If buying exotic pets was bad for [conservation or animal welfare] shops wouldn't be allowed to sell them" (mean agreement 4.86 and 4.93 for conservation and animal welfare, respectively; **Figure 4A**) but high likelihood purchasers were 3.10 and 4.12 times more likely to agree (**Table 1**), such that their mean response was to express agreement with these propositions (**Figure 4A**). All respondents disagreed with the statement "I can trust traders not to sell animals from illegal sources" (mean agreement 3.33) but high likelihood purchasers were 5.97 times more likely than non-purchasers to select higher levels of agreement (**Figure 4A**; **Table 1**).

Regarding consumer responsibilities, all respondents disagreed with the proposition "It is not my responsibility to make sure exotic pets come from a sustainable source" (mean 3.70/10), but high-likelihood purchasers were twice as likely (odds ratio 1.88) to agree than were non-purchasers (**Figure 4B**; **Table 1**). They were also half as likely to agree that "People have a duty to make sure they don't buy pets that come from the wild," although still agreeing with the proposition (odds ratio 0.45; mean agreement 7.72/10; **Figure 4B**; **Table 1**).

All respondents selected high agreement with the proposition that buying exotic pets could be bad for species conservation and animal welfare (means of 7.86 and 8.02, respectively) but high-likelihood purchasers were approximately half as likely to select higher levels of agreement than were non-purchasers (**Figure 4B**; **Table 1**). Similarly, respondents selected low agreement with "I'm not worried if buying exotic pets decreases wild populations" (conservation) and "I can give an exotic pet a better life than it would have in the wild" (welfare), but high-likelihood purchasers were, respectively, 3.13 and 7.61 times more likely to selected higher agreement with these than were non-purchasers (**Figure 4B**; **Table 1**), such that they overall agreed with the latter proposition (**Figure 4B**).

DISCUSSION

Respondents from all countries, and across all taxa, demonstrated a reduced desire to own a given exotic pet when shown any of the types of negative treatment statement in this study—but

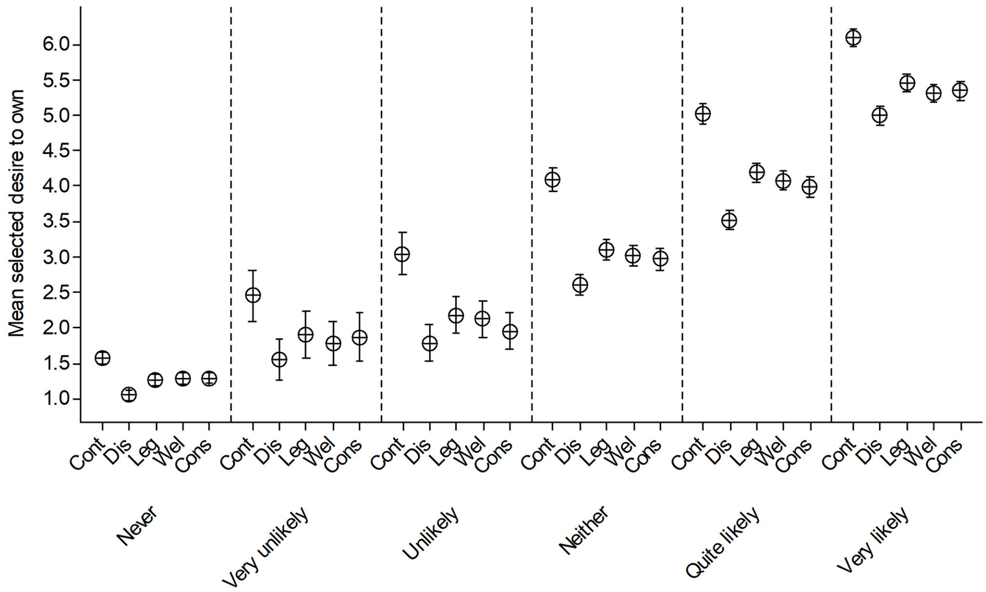

FIGURE 3 | Mean desire to own (on a 1–10 scale) across all taxa and respondents, showing how this, and responses to experimental treatments, varies with respondents' previously stated likelihood of purchasing an exotic in the next 2 years.

effect sizes of treatments were not equal. Statements describing the potential for transmission of zoonotic disease reduced stated desire to own by a mean of 26.9% relative to controls, compared with 16.1, 17.9, and 18.2% lower, for legality, welfare or conservation statements, respectively (**Figure 2**). These findings accord with the principal conclusion of Moorhouse et al. (2017a), that information campaigns focusing on the zoonotic disease consequences of exotic pet ownership were likely to have the greatest effect in lowering purchase desire. Our results confirm that the same conclusion applies to respondents across a range of nationalities and cultural backgrounds, not just to those from culturally Western countries. There was no evidence that respondents from Brazil, China or Vietnam responded to the treatment statements differently either to each other or to respondents from the USA (**Figure 2**).

A key correlate of respondents' desire to own a given exotic pet was their prior stated likelihood of purchasing an exotic in the next 2 years: the highest likelihoods correlated with desires to own that were ∼3–5 times higher than those who selected the lowest likelihoods of future purchase (**Figure 3**). The relative effect of treatment statements remained the same across all likelihoods of future purchase: treatment respondents consistently gave stated desires to own that were lower than those of control respondents, albeit that for those with higher prior likelihoods of future purchase the relative stated desires of both control and treatment groups were comparatively higher than for those with lower future purchase likelihoods (**Figure 3**).

Respondents' stated likelihood of future purchase of exotics was most strongly influenced by a combination of their prior ownership of pets, their nationality and age. Respondents' age had a substantial effect on likelihood of future purchase, which declined across the range of ages in the survey (18–92) by 95%. Similar findings have been shown among purchasers of traditional medicines, with younger respondents expressing a greater desire to buy than older respondents (Coals et al., 2020; Moorhouse et al., 2020). The inverse correlation between age and desire to buy both medicines and pets suggests that older consumers do have different attitudes to the consumption of wildlife products to younger consumers, but we possess no data which would allow us to attribute a cause to the difference. Further work focussing on this topic is required. We have two speculative, and competing, explanations for our finding that prior ownership correlated with a 9-fold increase in respondents' wish to buy further exotics. This association could arise if a set proportion of any population possessed a high desire to own an exotic pet, with these people likely both to have already possessed exotics and to wish to do so in the future. More plausibly, familiarity with exotic pets (e.g., through prior ownership or contact with other pet owners) may increase people's desire to own one. This latter scenario would imply that if exotic pet ownership becomes increasingly common in a society, then increasingly more people would wish to own one. Our data tentatively support this latter interpretation, given that nationality (which, however, only partially acts as a proxy for various cultural and social norms; (Taras et al., 2016) was a primary correlate of desire to own an exotic, with Chinese respondents, for example, being substantially less likely to wish to buy an exotic in the future, compared with respondents from Brazil or the USA, who in turn expressed lower likelihoods than Vietnamese respondents. Taken together the above findings accord with the arguments of Herzog (2014) in suggesting that desire to own certain types of exotic pet is to some extent culturally embedded. As such these desires are likely to be highly

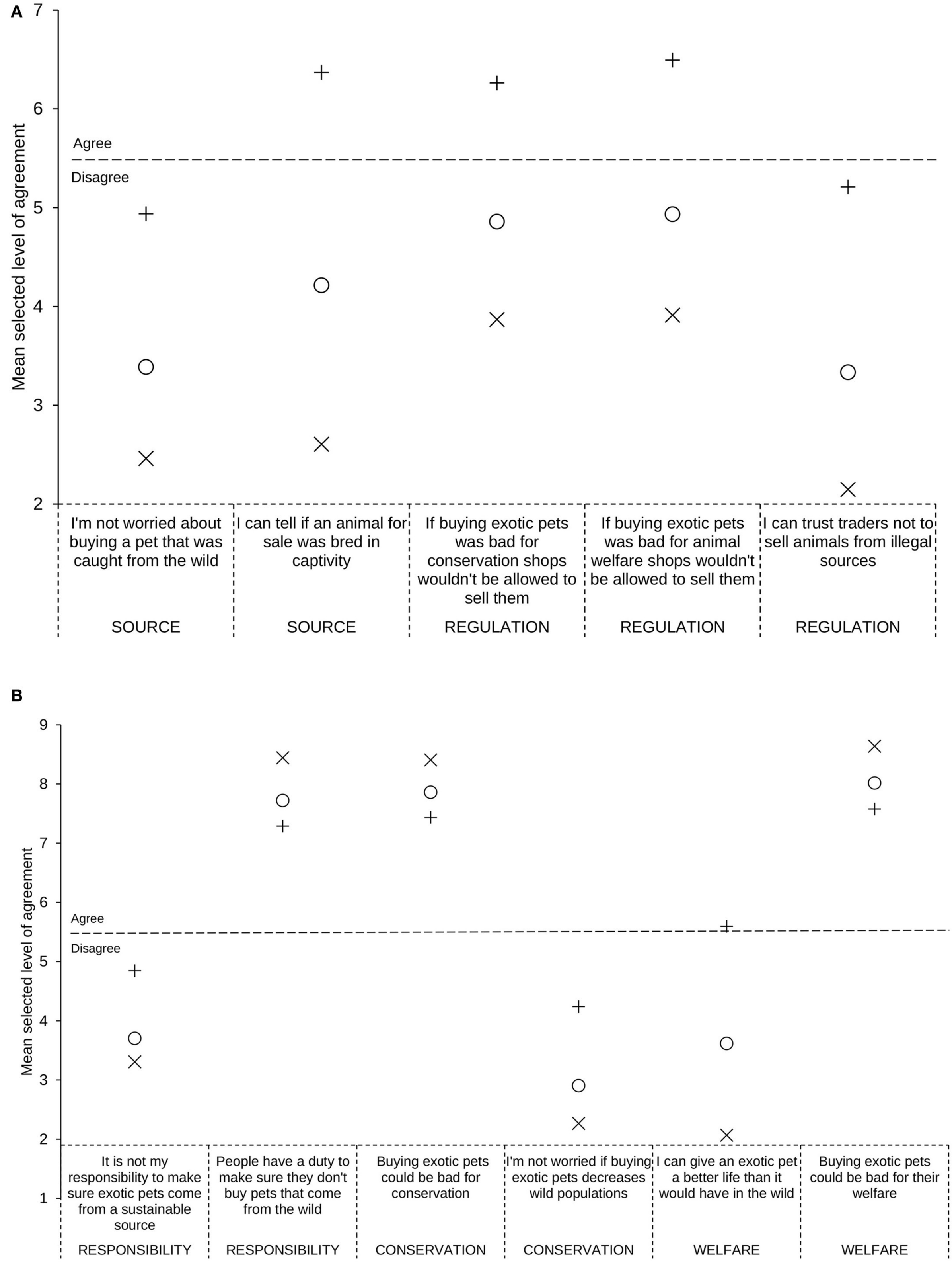

FIGURE 4 | Mean level of agreement (or disagreement) of high likelihood purchasers of exotic pets ("+" symbols), medium likelihood purchasers (open circles) and low likelihood purchasers ("×" symbols) with attitudinal statements describing **(A)** the source of exotic pets, and the regulation of impacts of the purchase and **(B)** Consumers' responsibilities, and the conservation and welfare impacts of purchasing exotics.

TABLE 3 | Factors affecting respondents' selected desire to purchase a given pet, for (A) mammals (B) birds (C) reptile.

Source	d.f.	LR statistic	*P*
(A)			
Age	1	140.1	<0.001
Sex	1	6.23	0.0125
Country	3	147.1	<0.001
Education	1	1.69	0.194
Purchase likelihood	1	1199	<0.001
Treatment	4	465	<0.001
Animal	7	605	<0.001
Order	1	223	<0.001
Income	1	-9.47	>0.99
Treatment*Order	4	3.53	0.473
Country*Treatment	12	13.0	0.366
Purchase Likelihood*Treatment	4	4.50	0.342
(B)			
Age	1	52.9	<0.001
Sex	1	10.5	0.00119
Country	3	15.7	0.00128
Education	1	-0.764	>0.99
Purchase likelihood	1	1188	<0.001
Treatment	4	821	<0.001
Animal	7	1015	<0.001
Order	1	101	<0.001
Income	1	2.28	0.131
Treatment*Order	4	2.41	0.661
Country*Treatment	12	57.8	<0.001
Purchase Likelihood*Treatment	4	1.76	0.780
(C)			
Age	1	131	<0.001
Sex	1	8.64	0.00329
Country	3	123	<0.001
Education	1	24.4	<0.001
Likely_purchase2	1	1276	<0.001
Treatment	4	308	<0.001
Animal	7	2367	<0.001
Order	1	361.12	<0.001
Income	1	-34.9	>0.99
Treatment*Order	4	-2.05	>0.99
Country*Treatment	12	25.4	0.0128
Likely_purchase2*Treatment	4	2.14	0.709

Statistics given to 3 significant figures.

amenable to change (Herzog, 2014), but this would require sufficient people's behavior to be influenced.

Repetition of different treatment types increased their overall effect in lowering respondents' desire to own pets. This effect was, however, minor: respondents rated 15 different animals, but mean desire to own was <7% lower for the last animal shown compared with the first. These findings permit the conclusion that having seen one message did not predispose respondents either to disregard the next, or conversely to treat the next message as substantially more serious than would otherwise have been the case. There was also no evidence that this repetition interacted with the type of message: repetition of statements did not have differential effects on different message types. Overall, therefore, we have a high degree of confidence that our experimental design, in testing multiple different animals and messages for each respondent, did not prejudice our results in favor of any given treatment.

Attitudinal questions were asked only of participants from the USA and Brazil, due to the Vietnamese and Chinese respondents being required for a separate, follow-on survey [see Moorhouse et al. (2020)]. Responses to these questions correlated strongly with respondents' stated likelihood of future purchase (**Table 1**; **Figures 4A,B**). In particular the mean response of high-likelihood buyers (those who stated they were "quite" or "very" likely to purchase an exotic pet in the future) appear to believe that buying exotic pets from shops would not give rise to negative welfare or conservation outcomes: their mean response to the proposition "If buying exotic pets was bad for [conservation or animal welfare] shops wouldn't be allowed to sell them" was to agree, whereas respondents with low likelihoods (non-buyers and those who chose "quite" or "very" unlikely) and moderate likelihoods ("Neither likely nor unlikely") disagreed (**Figures 4A,B**). Similarly, high likelihood buyers also agreed with the proposition that they could identify wild animals that had been bred in captivity and that they could provide a better quality of life for an exotic pet than it could have in the wild, while other respondents disagreed. These findings in particular, and responses shown in **Figures 4A,B** in general, indicate that high-likelihood purchasers possess a set of beliefs that enable them to justify buying exotic pets on the grounds that their purchases would not give rise to negative outcomes for those animals—and indeed may improve those animals' lives.

The trade in wildlife for pets, medicines and luxury items is now the joint largest driver of the global decline in biodiversity (along with agriculture): of the species listed as threatened or near-threatened by the IUCN, 72% are being exploited at unsustainable rates (i.e., at rates that cannot be compensated for by reproduction or regrowth) for commerce, recreation or subsistence (Maxwell et al., 2016). The conditions in which species are transported and the purposes for which they are used also create substantial animal welfare concerns globally (Baker et al., 2013). As a tool for combating the demand underpinning this trade, social marketing campaigns arguably are not achieving their potential—at least partially due to a lack of reporting of the effectiveness of approaches and correlates of success (Olmedo et al., 2018; Veríssimo et al., 2018; Veríssimo and Wan, 2019). A recent study concluded that of 236 such campaigns, only a quarter reported on outcomes (e.g., changes in the target audience regarding, for example, knowledge, attitudes, or behavior) and < 9% reported on conservation impacts (Veríssimo and Wan, 2019). Our approach in this study has been to experimentally test which messages are likely to be successful as a step toward improving impacts, by providing data to underpin the initial selection of messaging, so campaigns can focus on those messages most likely to influence consumers' behavior.

In conclusion, informing potential pet owners of the negative impacts of the purchase, in particular of the potential zoonotic disease impacts, was shown to lower demand for exotic pets. We also speculate that societal norms are likely to influence individuals' desires to own exotic pets. Respondents' nationality, age, and previous ownership of exotic pets all predispose them to be more likely to wish to buy a given exotic, notwithstanding that all of our respondents, regardless of background and prior disposition, reacted similarly to similar information. Taken together our evidence argues that demand reduction approaches on this topic are suitable for application to diverse audiences, but that the reduction in purchase desire of audiences that have a higher underlying disposition toward pet purchase is likely to still result in substantial numbers desiring to buy an exotic (**Figure 3**). Finally, our study reveals that the respondents most likely to buy pets in the future possess a series of beliefs that could facilitate this purchase while maintaining a self-image of being ethical (e.g., Bazerman et al., 1998; Tenbrunsel and Messick, 2004; Sezer et al., 2015). In particular they believed that shops were well-regulated, and that they were able to distinguish captively-bred from wild caught animals. Future research might investigate whether messaging designed to combat these beliefs may be effective at further lowering purchase desire among high-likelihood purchasers.

On the basis of these results, and those of Moorhouse et al. (2017a), we strongly recommend leveraging consumers' desire to avoid zoonotic disease consequences—especially in the light of the COVID-19 pandemic, which this study preceded (see submitted short communication)- by highlighting the zoonoses each species is known to harbor (see **Supplementary Table 1**). Our suggestion is not that demand reduction campaigns should indiscriminately invoke fear of disease to achieve their goals but that when consumers are made aware of the existence of genuine, potential disease risks, this awareness negatively influences their desire to acquire particular species. This approach could be used to encourage the substitute purchase of non-exotic species, or to advise that exotics are sourced either from rescue centers or from legitimate captive-breeders in the consuming country, thereby reducing the global demand for wild-caught individuals.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by CUREC, Oxford University. Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

AUTHOR CONTRIBUTIONS

TM: conceptualization, methodology, analysis, writing—original draft, review and editing, and funding acquisition. ND'C: writing—review and editing and funding acquisition. DM: writing—review and editing and supervision. All authors contributed to the article and approved the submitted version.

FUNDING

TM received a grant from World Animal Protection to carry out this research. ND'C occupied a position held jointly held between Oxford University and World Animal Protection. The design, conduct, analysis, interpretation, and conclusion of the study were in no way influenced by the source of funding.

ACKNOWLEDGMENTS

The study was conducted in close collaboration with Tim Baker and Jon Darby or Touchstone Partners Ltd., for whose expertise and professionalism throughout we are extremely grateful.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fevo.2021.609547/full#supplementary-material

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

frontiers in Ecology and Evolution

POLICY AND PRACTICE REVIEWS
published: 25 February 2021
doi: 10.3389/fevo.2021.639216

"Saving Lives, Protecting Livelihoods, and Safeguarding Nature": Risk-Based Wildlife Trade Policy for Sustainable Development Outcomes Post-COVID-19

Hollie Booth[1]*, Melissa Arias[1], Stephanie Brittain[1], Daniel W. S. Challender[1], Munib Khanyari[1,2,3], Timothy Kuiper[1], Yuhan Li[1,4], Alegria Olmedo[1], Rodrigo Oyanedel[1], Thomas Pienkowski[1] and E. J. Milner-Gulland[1]

[1] Interdisciplinary Centre for Conservation Science, Department of Zoology, University of Oxford, Oxford, United Kingdom, [2] Nature Conservation Foundation, Mysore, India, [3] School of Biological Sciences, University of Bristol, Bristol, United Kingdom, [4] School of Geography and the Environment, University of Oxford, Oxford, United Kingdom

The COVID-19 pandemic has caused huge loss of life, and immense social and economic harm. Wildlife trade has become central to discourse on COVID-19, zoonotic pandemics, and related policy responses, which must focus on "saving lives, protecting livelihoods, and safeguarding nature." Proposed policy responses have included extreme measures such as banning all use and trade of wildlife, or blanket measures for entire Classes. However, different trades pose varying degrees of risk for zoonotic pandemics, while some trades also play critical roles in delivering other key aspects of sustainable development, particularly related to poverty and hunger alleviation, decent work, responsible consumption and production, and life on land and below water. Here we describe how wildlife trade contributes to the UN Sustainable Development Goals (SDGs) in diverse ways, with synergies and trade-offs within and between the SDGs. In doing so, we show that prohibitions could result in severe trade-offs against some SDGs, with limited benefits for public health via pandemic prevention. This complexity necessitates context-specific policies, with multi-sector decision-making that goes beyond simple top-down solutions. We encourage decision-makers to adopt a risk-based approach to wildlife trade policy post-COVID-19, with policies formulated via participatory, evidence-based approaches, which explicitly acknowledge uncertainty, complexity, and conflicting values across different components of the SDGs. This should help to ensure that future use and trade of wildlife is safe, environmentally sustainable and socially just.

Keywords: COVID-19, public health, sustainable development goals, sdgs, multi-sector, livelihoods, wildlife trade, conservation

Edited by:
Divya Karnad,
Ashoka University, India

Reviewed by:
Pratheesh C. Mammen,
Kerala State Disaster Management Authority (KSDMA), India
Sahila Kudalkar,
Wildlife Conservation Society, India

****Correspondence:***
Hollie Booth
hollie.booth@zoo.ox.ac.uk

Specialty section:
This article was submitted to Conservation and Restoration Ecology, a section of the journal Frontiers in Ecology and Evolution

Received: *08 December 2020*
Accepted: *08 February 2021*
Published: *25 February 2021*

Citation:
Booth H, Arias M, Brittain S, Challender DWS, Khanyari M, Kuiper T, Li Y, Olmedo A, Oyanedel R, Pienkowski T and Milner-Gulland EJ (2021) "Saving Lives, Protecting Livelihoods, and Safeguarding Nature": Risk-Based Wildlife Trade Policy for Sustainable Development Outcomes Post-COVID-19. Front. Ecol. Evol. 9:639216. doi: 10.3389/fevo.2021.639216

INTRODUCTION

Background

The COVID-19 pandemic has caused a worldwide state of emergency, with immense human suffering, loss of life, and socio-economic instability. Several early cases of COVID-19 were traced to a wet market in Wuhan, China, which traded domestic and wild animals (Wu et al., 2020).

These early cases raised concerns about the role of wildlife trade in the emergence of COVID-19 and zoonotic diseases more broadly. A wide range of policy responses have been suggested. Extreme ones include calls to ban use and trade of wildlife entirely (Singh Khadka, 2020), or blanket global measures for entire Classes of wildlife, in the belief that this will protect public health, while also improving animal welfare and delivering conservation goals (The Lion Coalition, 2020; Walzer, 2020). Others have called for more balanced or targeted approaches, directed toward critical control points in the supply chain, or specific species which are more likely to harbor zoonotic viruses (Petrovan et al., 2020; Roe and Lee, 2021).

Some governments have acted decisively to implement new policy measures. For example, China's top legislature adopted a decision to "thoroughly ban the illegal trading of wildlife and eliminate the consumption of wild animals to safeguard people's lives and health." This decision covers all terrestrial wild animals; fish, wild plants, amphibians and reptiles, while animal products for non-edible use remain exempt from this measure, with use regulated under other instruments (Li, 2020; Koh et al., 2021). Vietnam temporarily banned imports of wildlife and wildlife products (with some exemptions for various non-edible products), and called for enforcement of existing laws to eliminate advertising, buying, selling and consumption of illegal wildlife products (Prime Minister of Vietnam, 2020). Similarly, a resolution was passed in Bolivia re-stating bans on wildlife trade and consumption as a matter of public health (Ministerio de Medio Ambiente y Agua, 2020). In Gabon, a more targeted approach has been adopted, via a ban on consumption of bats and pangolins (Afp, 2020).

However, while bats have been identified as a likely primary reservoir of COVID-19, evidence that the pandemic emerged due to wildlife trade remains inconclusive (Andersen et al., 2020; Huang et al., 2020; Shereen et al., 2020). Moreover, wildlife trade can both help and hinder the delivery of a broad range of health, livelihood and nature conservation outcomes, underpinning multiple UN Sustainable Development Goals (SDGs). While saving lives through pandemic prevention is undoubtedly a top policy priority, silver-bullet approaches such as blanket bans fail to acknowledge the heterogeneous public health risks present across species and contexts, and the diverse roles of wildlife trade in delivering sustainable development outcomes (Challender et al., 2015; UNEP and ILRI, 2020; Wang et al., 2020). These top-down approaches also fail to account for the complexity, uncertainty and plurality of values associated with wildlife trade, with non-compliance and the emergence of illicit markets potentially undermining such approaches (Fournie et al., 2013; Bonwitt et al., 2018; Zhu and Zhu, 2020).

Instead, policy responses to the pandemic should focus holistically on "saving lives, protecting livelihoods, and safeguarding nature" (IPBES, 2020), all of which are fundamental to delivering the SDGs. To broaden the discourse, we describe how wildlife trade affects sustainable development in diverse, complex and dynamic ways, with synergies, trade-offs and feedbacks within and between the SDGs. Based on this, we argue that a risk-based multi-sector approach to wildlife trade policy post-COVID-19 can support health, livelihoods, and the conservation of nature. We suggest how decision-makers might evaluate these trade-offs and synergies for different species and contexts in order to formulate risk-based policies through six illustrative case studies. Finally, we offer some general principles and processes for using such evaluations in decision-making in the face of uncertainty, complexity and plurality of values. Overall, we encourage decision-makers to think more holistically and participatorily about wildlife trade, and to adopt risk-based policies which minimize public health risks, while enhancing benefits across other dimensions of wildlife trade for sustainable development.

The Diverse Roles of Wildlife Trade in Meeting the Sustainable Development Goals

Wildlife trade is the sale or exchange of wild animals, fungi and plants, and their derivatives (Broad et al., 2002). It is extremely diverse and dynamic, encompassing a wide range of species, actors and supply chains at various scopes and scales, with different markets varying in their legality, sustainability and social legitimacy ('t Sas-Rolfes et al., 2019). For example, local trade of wild fungi in Ozumba, Mexico, is safe, sustainable, contributes to local livelihoods, and maintains traditional ethnobiological knowledge (Pérez-Moreno et al., 2008) and game ranching makes a significant contribution to South Africa's GDP, and can incentivize land and wildlife stewardship (Pienaar et al., 2017). In contrast, international trade in sea cucumbers is driving stock collapses, which is undermining coastal livelihoods and associated with illegal fishing activities (Purcell et al., 2013; González-Wangüemert et al., 2018). Similarly, high-value trade in pangolin parts has depleted some populations in Asia, with much trafficking attention now focused on Africa (Challender et al., 2020). With this diversity, wildlife trade has direct positive and negative contributions to the '5Ps' of the SDGs (People, Prosperity, Peace, Partnerships and Planet), and indirect contributions via SDG interactions, feedbacks and policy interventions (**Figure 1**).

"Saving Lives, Protecting Livelihoods": Direct Contributions Toward SDGs for People and Prosperity

The hunting, transportation and consumption of some wild animals can increase the risk of zoonosis emergence, and thus hinder progress toward good health and well-being (SDG 3) (Swift et al., 2007; UNEP and ILRI, 2020). Zoonotic pandemics can cost billions or even trillions of dollars in economic and social burden, also hindering progress toward no poverty and decent work (SDGs 1 and 8). For example, in the 2014 Ebola outbreak in West Africa, over 11,000 people lost their lives with a total economic burden estimated at US$ 53 billion (Huber et al., 2018), while the economic opportunity costs of the COVID-19 pandemic could amount to $10trn in forgone Gross Domestic Product (GDP) over 2020–21 (The Economist, 2021). Overexploitation also undermines progress toward responsible consumption and production (SDG 12) and can create poverty traps, thus weakening the capacity of ecosystems to support

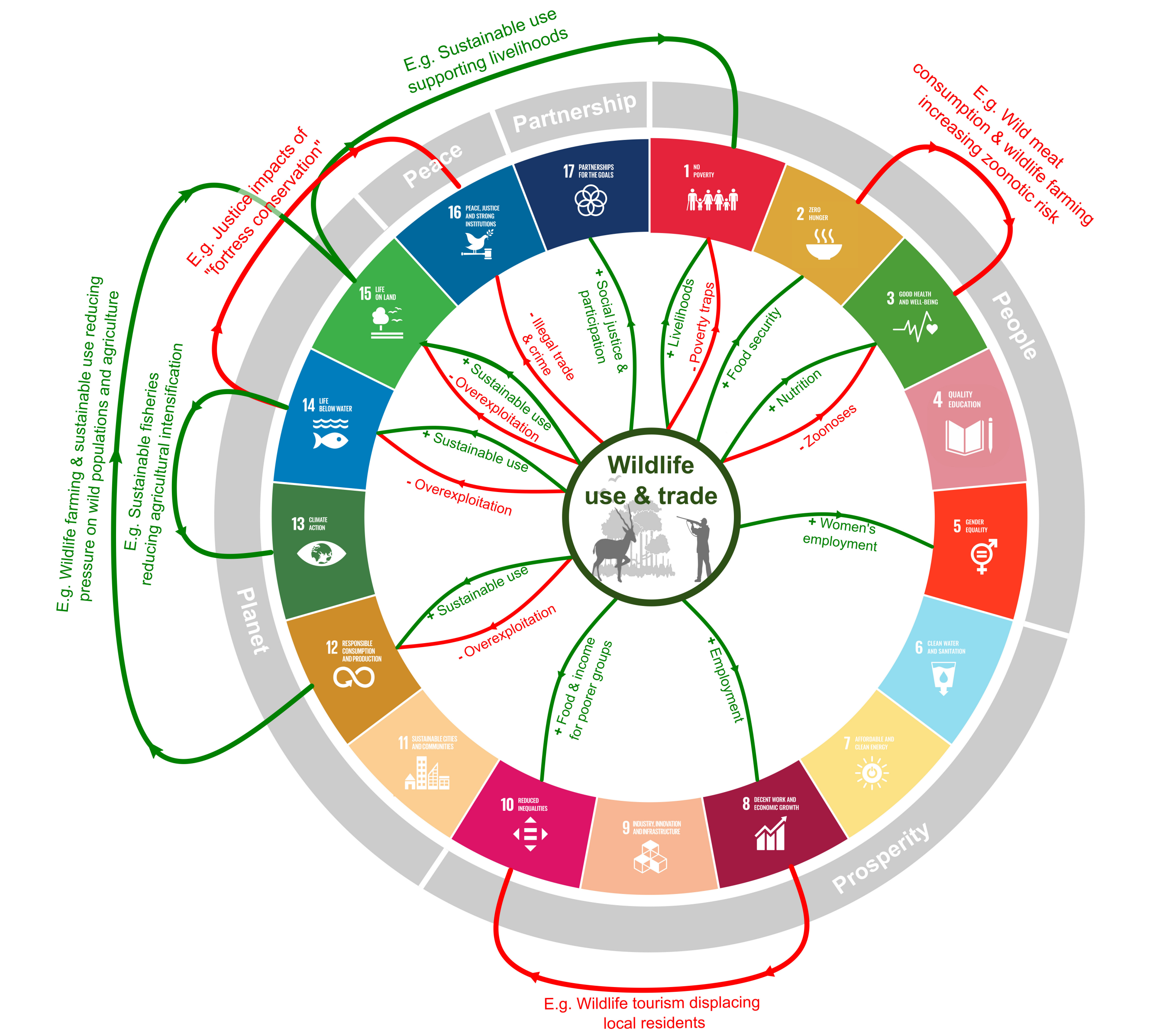

FIGURE 1 | Illustrative examples of some general positive (green) and negative (red) contributions of wildlife trade to the Sustainable Development Goals (SDGs). Direct contributions are denoted by arrows in the center of the diagram, while interactions between the SDGs are denoted by arrows around the outside (with trade-offs in red and synergies in green). This diagram is illustrative only; it is not intended to provide a complete review of all types of wildlife uses and trades, and their contributions and interactions.

good health, well-being and poverty alleviation (SDGs 1 and 3) (Pienkowski et al., 2017).

Conversely, wildlife trade also supports the diets and livelihoods of hundreds of millions of people, helping to deliver no poverty, zero hunger and decent work and economic growth (SDGs 1, 3 and 8, respectively) (Roe et al., 2020; Wang et al., 2020). For example, American bullfrog (*Lithobates catesbeianus*) is a common delicacy in China, with a farming industry valued at around US$ 120 million per year, which employed 24,000 people in 2016 (Chinese Academy of Engineering, 2017). In some cases, wildlife trade chains primarily involve female traders – for example, in Ghana, bushmeat wholesalers and market traders in urban areas are all women (Mendelson et al., 2003) - and these livelihood opportunities create important contributions to gender equality (SDG 5). Wildlife trade also has socio-cultural significance in rural and urban contexts worldwide (Alves and Rosa, 2013), such that restricting access to wildlife can harm social justice, particularly amongst indigenous and marginalized communities, thus hindering progress toward reduced inequalities (SDG 10), peace, justice and strong institutions (SDG 16) and partnerships for the goals (SDG 17) (Antunes et al., 2019). Alternatively, sustainable wildlife management, which is developed and implemented under good governance conditions and through fair participatory processes, can have positive impacts on security and support SDGs 16 and 17 (Cooney et al., 2018; Roe and Booker, 2019; **Figure 1**).

"Safeguarding Nature": Direct Contributions Toward SDGs for Planet

Wildlife trade can both help and hinder the protection of life below water (SDG 14) and on land (SDG 15). For example, nearly three-quarters of threatened or near-threatened species are being over-exploited for trade and/or subsistence purposes (Maxwell et al., 2016), representing a leading global threat to biodiversity (Tilman et al., 2017). For several Critically Endangered taxa, such as rhinos, pangolins and wedgefish, trade-driven overexploitation represents the greatest threat to their survival (Maxwell et al., 2016; Kyne et al., 2019; Challender et al., 2020). Capture and trade can also harm the welfare of individual wild animals, particularly the live animal trade, which can cause high stress and mortality (Baker et al., 2013).

Conversely, well-managed, sustainable trade can have benefits for biodiversity (Heid and Márquez-Ramos, 2020; McRae et al., 2020). For example, regulated trade in vicuña wool fiber in Bolivia allowed the recovery of the species from near-extinction, with direct benefits from harvesting for local communities and an estimated contribution of US$ 3.2 million to the national economy per annum (Cooney, 2019). Similarly, carefully managed trade of saltwater crocodiles has aided population recovery in Australia, with population density at least doubling since the introduction of an egg harvesting initiative [which also provides US$ 515,000 per year in income to Aboriginal communities (Fukuda et al., 2011; CITES and Livelihoods, 2019b)]; regulated hunting of bighorn sheep in the USA and Mexico has helped once-dwindling populations to recover at least three-fold, whilst funding conservation of associated ecosystems (Hurley et al., 2015); and game ranching in South Africa incentivizes private land stewardship (Pienaar et al., 2017; **Figure 1**), all of which pose little-to-no public health risk. In general, wildlife trade policies that incentivize sustainable use typically have more immediate positive effects on wildlife populations than outright trade bans (Heid and Márquez-Ramos, 2020).

Indirect Impacts on the SDGs Through Interactions, Policy Interventions and Feedbacks

The above examples also indicate interactions between the SDGs, such as trade-offs and feedbacks, which arise from wildlife trade. SDGs can interact in many ways, with potential cascading effects (Nilsson et al., 2016, 2018), and those which are most pertinent to COVID-19 and wildlife trade relate to counteracting interactions between food security, public health and life on land. For example, while trade and consumption of horseshoe bats may provide nutritional benefits for some people, they can also pose wide-spread public health risks (Mickleburgh et al., 2009; Wong et al., 2019), creating a trade-off between SDGs 2 and 3, and within SDG 3. In other cases, the substitution of wildlife with domestic livestock could drive agricultural expansion, and exacerbate anthropogenic drivers of zoonosis emergence (Allen et al., 2017; Booth et al., 2021), thus hindering progress toward improved health, responsible consumption, and life on land (SDGs 3, 12 and 15). Conversely, these interactions can also be reinforcing. For example, sustainable use of wild-sourced natural resources may contribute to food security (SDG 2), and reduce land use change and carbon emissions from commercial agriculture, thus contributing to life on land (SDG 15) with potential synergies for climate action (SDG 13) (**Figure 1**).

Wildlife trade policy interventions can also create feedbacks and unintended consequences for the SDGs. For instance, restricting wildlife trade can have conservation benefits (SDGs 14 and 15), but may harm food security, health and well-being (SDGs 2 and 3) (Larrosa et al., 2016; Bonwitt et al., 2018; Short et al., 2019). Overly stringent or socially illegitimate regulation can also lead to non-compliance and black markets, which can erode security and institutions (SDG 16) (Bonwitt et al., 2018; Oyanedel et al., 2020), and can backfire leading to further declines in populations of threatened species (Leader-Williams, 2003).

Overall, wildlife trade and its contributions to society are complex, uncertain and divergent. Designing policy interventions in response to COVID-19 therefore requires a holistic multi-sector approach, which explicitly acknowledges trade-offs, feedbacks and pluralistic values, and seeks to minimize direct public health risks from zoonoses, whilst optimizing benefits across other SDGs.

A WAY FORWARD: DATA AND PROCESS FOR HOLISTIC POLICY RESPONSES

Minimizing disease risk whilst delivering other SDGs requires that policy responses explicitly acknowledge the broader socio-ecological context of wildlife trade (Bonwitt et al., 2018; Eskew and Carlson, 2020; Zhu and Zhu, 2020). The nature and magnitude of the costs and benefits of wildlife trade will depend on the species and context. As such, considering the range of costs, benefits and associated risks in an integrated way could help to formulate robust policy responses that minimize the risk of future pandemics, contribute positively to SDG outcomes, and identify pinch points for targeting management interventions. We illustrate this through six case studies, and then offer some general suggestions regarding data, principles and process.

Case Study Examples

We first explore how direct and indirect contributions to relevant SDGs might be explicitly considered in decision-making for different species and contexts, based on qualitative assessments for six case study examples (**Table 1** and **Figure 2**). We selected these case studies to represent a range of geographic and taxonomic diversity, and a plurality of costs and benefits across the 5Ps of the SDGs; and because published data is available on implications of trade for at least three of the 5 Ps of the SDGs.

For each case study, we provide a qualitative judgment of the positive contributions (benefits) and negative contributions (costs) of each type of wildlife trade to the SDGs. These are categorized as high, moderate or low, according to available data on: the extent of the contribution, the intensity of the

TABLE 1 | Evaluating the diverse costs and benefits of wildlife trade across the SDGs: six case study examples.

Species and context	**People (SDGs 1,2,3,5)**		**Prosperity (SDGs 8 and 10)**		**Planet (SDGs 12,13,14,15)**		**Peace and Partnerships (SDGs 16,17)**		**Feasibility of regulation and implemen-tation issues**	**Policy options***	**Key refs**
	Negative contributions	**Positive contributions**	**Negative contributions**	**Positive contributions**	**Negative contributions**	**Positive contributions**	**Negative contributions**	**Positive contributions**			
Great Apes (*Gorilla* sp., *Pan* sp) **wild-caught** and locally consumed or traded in **DR Congo**	**High cost (?)** Reservoir and source of Ebola, SIVs and Hep B, with pandemic risk. Although rare, A-to-H and H-to-H transmission of pathogens can cost billions of dollars in economic and social burden.	**Low benefit (??)** Although illegal, great ape meat is consumed in DRC. However, consumption is mostly opportunistic and not a frequent or significant component of people's diets.	**Moderate cost (?)** Over-exploitation of great ape populations can undermine economic prospects of high-value ape-watching tourism.	**No benefit (?)** Trade of great apes provides benefits to small groups of hunters and traffickers, though it has no scalable or sustainable economic prospects.	**High cost (?)** Eastern gorillas are CR and declining, chimpanzees are EN and declining. Both threatened by hunting and trapping, primarily by armed groups, and zoonoses from humans.	**No benefit (??)** No evidence that consumptive use of great apes is linked to conservation benefits.	**High cost (?)** Hunting and trapping of gorillas is linked to armed groups and exacerbated by conflict.	**No benefit (??)** No evidence that consumptive use of great apes is linked to benefits for peace and partnerships. Tackling illegal hunting by armed groups may promote peace and security.	It is already illegal to hunt and trade Great Apes in DR Congo, but it continues in some areas. Political instability and limited capacity hamper enforcement.	**Strengthen implementation of existing conservation regulations, with additional focus on public health.**	Blomley et al., 2010; Keita et al., 2014; Plumptre et al., 2019
Horseshoe bats (*Rhinolophidae* sp.) **wild-caught** and sold in **South China Wet Markets**	**High cost (?)** Host coronaviruses, links to SARS in humans. Wet markets can lead to concentrated interactions between bats, other live animals and humans.	**Moderate benefit (???)** Consumption may supplement some rural diets, but horseshoe bats are usually only one of many species traded and consumed.	**No cost (??)** No evidence that bat trade has direct negative impacts on prosperity.	**Low benefit (???)** Harvesting and trade of bats may provide employment opportunities in some rural communities.	**Moderate cost (???)** Harvesting for consumption and trade may contribute to population declines, though rates of decline are uncertain and other threats likely more severe.	**No benefit (??)** No evidence that consumptive use of bats is linked to conservation benefits.	**No cost (??)** No evidence that bat trade plays a role in peace and partnerships.	**No benefit (??)** No evidence that bat trade plays a role in peace and partnerships, though important to include rural communities in management decisions.	Enforcement and awareness challenges, especially in remote rural areas where subsistence consumption may occur. Difficulties in bat identification.	**Ban trade and consumption of horseshoe bats. Provide training and guides on visual horseshoe bat identification, and/or handheld DNA barcoding technology for government officials and traders.**	Zhang et al., 2009; Han et al., 2016; Wong et al., 2019

(Continued)

TABLE 1 | Continued

Species and context	People (SDGs 1,2,3,5)		Prosperity (SDGs 8 and 10)		Planet (SDGs 12,13,14,15)		Peace and Partnerships (SDGs 16,17)		Feasibility of regulation and implemen-tation issues	Policy options*	Key refs
	Negative contributions	**Positive contributions**	**Negative contributions**	**Positive contributions**	**Negative contributions**	**Positive contributions**	**Negative contributions**	**Positive contributions**			
Waterfowl (Anseri-formes) **wild-caught, peri-domestic and farmed**, and sold in **live bird markets** (LBMs) in **Egypt**	**Moderate cost (?)** Reservoirs of H5N1, and traded in LBMs. H5N1 is pathogenic and LBMs create risk of A-to-A and A-to-H, though H-to-H transmission is rare.	**Moderate benefit (?)** Poultry meat trade in Egypt depends mainly on LMBs. Industry provides a source of employment, and an important protein source. Cultural preferences.	**No cost (??)** No evidence that waterfowl trade has direct negative impacts on prosperity.	**Moderate benefit (?)** Many people employed in LBM industry.	**Low cost (??)** Anseriform species in Egypt's live bird trade are not threatened with extinction, however there may be welfare issues for traded individuals.	**Low benefit (???)** Evidence from other places/species (e.g., wild turkeys) that well-managed wild bird harvesting can be sustainable and could reduce pressure to expand poultry farms.	**No cost (??)** No evidence that waterfowl trade disrupts peace and partnerships.	**Moderate benefit (?)** Important to include affected people in management decisions, given socio-cultural preferences.	Insufficient slaughter-houses and infra-structure. Many traditional LBMs with minimal standards create monitoring and enforcement challenge.	**Regulate markets with strict hygiene standards, routine surveillance, and no flock mixing between species and wild and farmed. Invest in improving slaughterhouses and infrastructure.**	Kayed et al., 2019
American bullfrog (*Lithobates catesbe-ianus*) **farmed** and sold in **China**	**Low cost (?)** Known diseases are bacterial and treatable, with non-severe symptoms. Risks of antibiotic overuse in farms, and bacterial contamination in processing.	**High benefit (?)** Frogs are commonly farmed and traded for food and medicinal uses. Breeding industry employs ~1 million people and is an important livelihood source.	**No cost (??)** No evidence that frog trade has direct negative impacts on prosperity.	**High benefit (?)** Bullfrog breeding alone employs ~24,000 people, while the whole frog breeding industry employs ~1 million people in a ~US$7.15 billion business.	**Low cost (???)** Farming may enable laundering of threatened, wild-sourced species. Trade may increase spread of amphibian diseases (e.g., *Batrachochy-trium dendrobatidis)*.	**Low benefit (??)** American bullfrogs can be sustainably farmed, and farming could reduce pressure on wild-sourced species	**No cost (??)** No evidence that frog trade disrupts peace and partnerships.	**No cost (??)** No evidence that frog trade benefits peace and partnerships, though important to include rural communities in management decisions.	Many farms, challenges identifying species and farmed vs. wild-caught frogs.	**Species-specific trade regulations with strict farming, processing and biosecurity standards. Certification for farmed frogs; quotas for wild-sourced frogs, with separate transport and sale routes.**	Feng et al., 2007; Kolby et al., 2014; Liu et al., 2015; Chinese Academy of Engineering, 2017

(Continued)

TABLE 1 | Continued

Species and context	**People (SDGs 1,2,3,5)**		**Prosperity (SDGs 8 and 10)**		**Planet (SDGs 12,13,14,15)**		**Peace and Partnerships (SDGs 16,17)**		**Feasibility of regulation and implemen-tation issues**	**Policy options***	**Key refs**
	Negative contributions	**Positive contributions**	**Negative contributions**	**Positive contributions**	**Negative contributions**	**Positive contributions**	**Negative contributions**	**Positive contributions**			
Bighorn Sheep (*Ovis canadensis*) **wild-caught** and consumed in **North/ Central America** (US, Canada, Mexico)	**Low cost (?)** Associated diseases are bacterial and treatable, with limited A-to-H and H-to-H transmission.	**High benefit (?)** Profits from hunting permits and sale of young are retained by local and indigenous communities, and re-invested in community development projects.	**No cost(?)** No evidence that big horn hunting and trade has direct negative impacts on prosperity.	**Moderate benefit (?)** Hunting and range management creates employment for people and park staff, including rural and indigenous communities, in key bighorn habitats.	**Low cost (?)** Small risk of overexploitation if poorly managed, however populations are stable due to strong socio-economic benefits for sustainable use.	**High benefit (?)** LC species, stable populations. Income from hunting supports range mgmt., with population increases and wider ecosystem benefits.	**No cost (??)** No evidence that bighorn trade disrupts peace and partnerships.	**Moderate benefit (?)** Hunting and range management has fostered participation and partnerships for rural and indigenous groups, and equitable management of land tenure.	Setting, managing and enforcing permit systems can be challenging, with overharvesting in some areas. Managing interactions with livestock in areas of potential overlap.	**Sustainability and welfare standards, with hygiene protocols for handling and transport of trophies and meat.**	Callan et al., 1991; CITES and Livelihoods, 2019a; Hurley et al., 2015
Rays (Batoidea) **wild-caught** and locally consumed/ traded in The Gambia	**Low cost (?)** Few zoonotic diseases in fish, bacterial with no H-to-H transmission.	**High benefit (?)** Elasmobranch use important for food security in coastal communities.	**Moderate cost (?)** Overexploitation undermines long-term prospects of fishing industry.	**High benefit (?)** Fisheries and processing contribute to employment in coastal areas.	**Moderate cost (?)** Rhinobatidae and Glaucostegidae are CR and overexploited.	**Low benefit (???)** Well-managed fisheries could theoretically create incentives for sustainable use.	**No cost (??)** No evidence that batoidea trade disrupts peace and partnerships.	**No cost (??)** No evidence that batoidea trade benefits peace and partnerships, though important to include coastal communities in management.	Limited monitoring and enforcement capacity, can be challenging to identify species in derivative products such as meat.	**Fisheries and trade management, such as quotas, needed for sustainability. Can be supported by visual and/or genetic identification techniques.**	Boylan, 2011; Moore et al., 2019

*Costs highlighted in shades of orange, benefits highlighted in shades of green [darker colour = higher cost (orange) or benefit (green)]. Uncertainty represented by question marks [? = low uncertainty, ?? = moderate uncertainty, ??? = high uncertainty], based on a review of key literature and available data. CR = Critically Endangered, EN = Endangered, LC = Least Concern, based on the IUCN Red List of Threatened Species. A-to-H = Animal to human, H-to-H = human to human. *Policy options are greatly simplified for this exercise.*

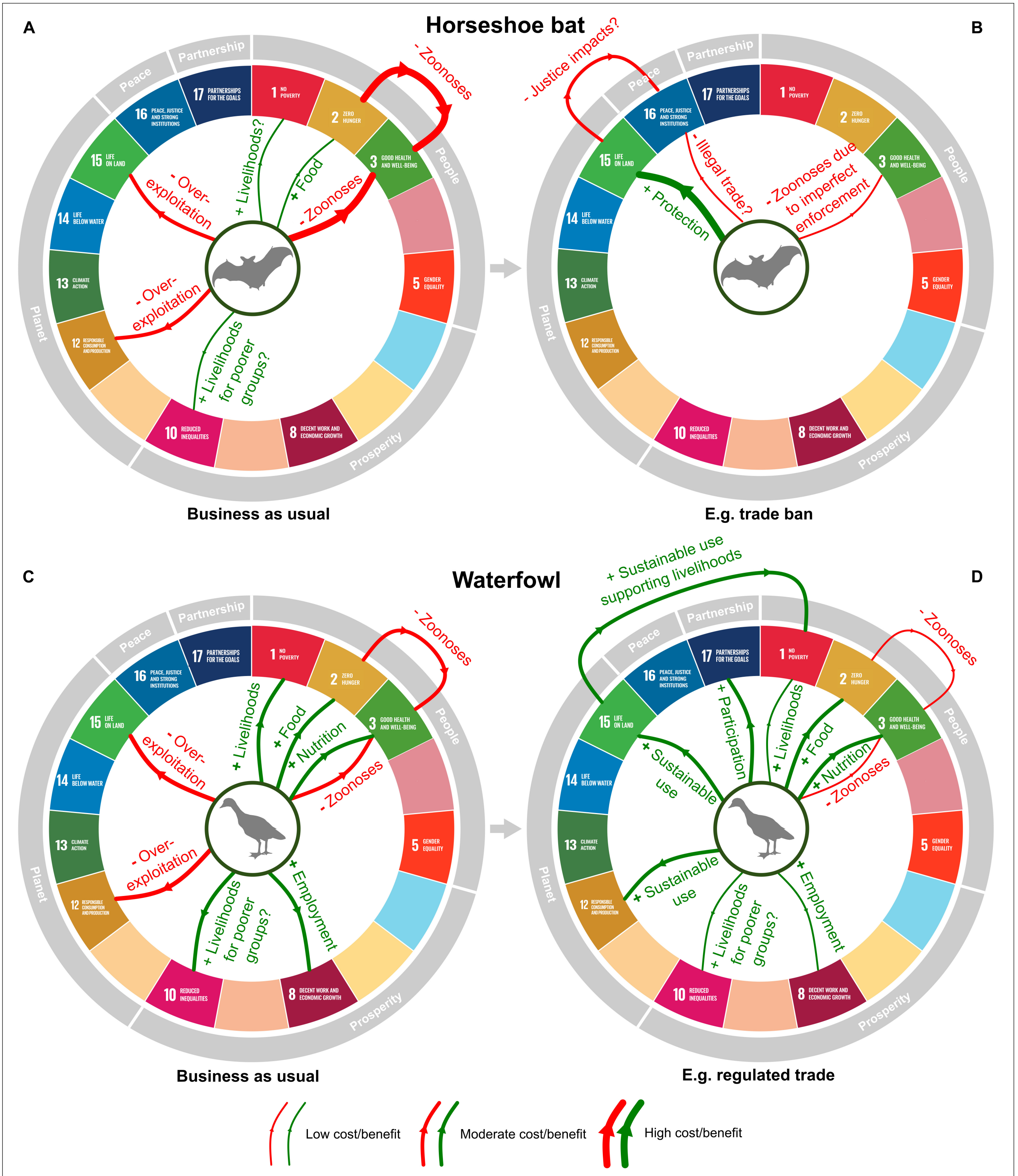

FIGURE 2 | Examples of current positive (green) and negative (red) contributions of horseshoe bat **(A)** and waterfowl **(C)** trade to the SDGs, and how context and species-specific policy responses could improve delivery of SDG outcomes **(B,D)**. Thickness of lines represents the relative size of the costs/benefits, based on the qualitative assessment conducted by the authors in **Table 1**.

contribution, and its perceived likelihood of occurrence, as per common risk assessment processes used in animal and human health (Narrod et al., 2012; Beauvais et al., 2018). To acknowledge uncertainty, we also offer a qualitative judgment, where: low uncertainty corresponds to robust and complete data available, with strong consistent evidence provided in multiple references; moderate uncertainty corresponds to some data available, but with few references and/or some inconsistencies; high uncertainty corresponds to scarce or no data available, with anecdotal evidence and/or highly inconsistent conclusions (Beauvais et al., 2018; Booth et al., 2020). We emphasize that these case studies are not based on exhaustive literature reviews, expert and stakeholder consultation, or comprehensive quantitative data, nor are the case studies fully representative of the wide range of species, geographies and contexts in which wildlife trade takes place. Rather they are illustrative examples of the types of issues and data that should be considered within real-world decision contexts. We encourage researchers and decision-makers to use all available data, values and expertise to consider the range of costs and benefits within their own decision-making contexts, and to transparently define and disclose their own evaluation criteria and associated thresholds when conducting context-specific risk assessments for policy formulation.

Trade in horseshoe bats (Rhinolophidae) in South China currently poses a high public health risk in terms of extent, severity and likelihood (Han et al., 2016; Wong et al., 2019) and creates potential negative impacts for bat populations and habitats (SDG 15, Zhang et al., 2009). These high potential downside costs may outweigh socio-economic benefits: while bats are consumed as supplements in some rural diets (SDG 2), often consumption is not targeted (Mickleburgh et al., 2009), making this benefit limited in terms of extent and intensity (**Figure 2A**). Thus, a ban on all trade and consumption of bats in South China may be appropriate, though enforcement challenges and the input and values of rural communities would need to be carefully and explicitly considered (**Table 1** and **Figure 2B**). Similarly, the high public health risks and limited benefits of great ape trade indicate that bans may be an appropriate pathway to simultaneously protect health (SDG 3) and life on land (SDG 15), (Keita et al., 2014; Plumptre et al., 2019). However, it is already illegal to hunt and trade great apes in most of their range states, so interventions may need to focus on implementation of existing regulations, or additional regulation with a public health lens, considering the concerns of affected residents and lessons from previous interventions (e.g., Bonwitt et al., 2018).

In contrast, trade in Bighorn sheep (*Ovis canadensis*) in North America and rays (Batoidea) in The Gambia do not pose immediate public health concerns in terms of extent and severity of disease outbreak. However, these trades provide significant benefits in terms of food security (SDG 2) and livelihoods (SDGs 1 and 8), though careful management is needed to ensure utilization is compatible with responsible consumption and production (SDG 12), and life below water (SDG 14) and on land (SDG 15), (Hurley et al., 2015; Moore et al., 2019). Trade in other species, such as live waterfowl (Anseriformes) traded in live bird markets in Egypt, represents a moderate public health risk (SDG 3). Influenza A (H5N1) is pathogenic with a high likelihood of transmission from animal-to-animal and animal-to-human, however human-to-human transmission is limited, such that the pandemic potential and thus extent of the cost is likely to be limited. However, this trade also provides myriad benefits for people, as a source of protein, income and cultural value (SDGs 1 and 2) (Kayed et al., 2019; **Figure 2C**). In this context, a regulated trade may be most appropriate, with strict hygiene standards, routine surveillance, and no flock mixing (Fournie et al., 2013). Evidence from live bird markets in Vietnam suggests that regulated trade may be more effective at minimizing public health risks and preventing illegal or illicit trade than poorly enforced bans (Fournie et al., 2013), thus creating a better delivery mechanism for protecting health (SDG 3) and peace, justice, and strong institutions (SDG 16) (**Table 1** and **Figure 2D**).

More detailed background information for each of these case studies is available in the SI. We emphasize that these worked examples are qualitative assessments to illustrate the plurality of values, context and uncertainties, and do not serve as formal policy recommendations.

Process Considerations

Given the plurality of values associated with different types of wildlife trade, iterative and participatory approaches will be needed to identify the most suitable and effective policy options. We offer a general process, which could be applied in the planning stages of a Plan-Do-Check-Act or adaptive management approach. Steps in this process include: defining the problem, gathering data, assessing synergies and trade-offs, acknowledging uncertainty and incorporating feasibility; all of which would inform a decision, followed by implementation, monitoring and adaption (**Figure 3**). This entire process can be strengthened by participation of policy-affected people, with expert elicitation methods, and application of integrated frameworks to draw together disparate data, and transparently communicate value judgments, risk and uncertainty (Milner-Gulland and Shea, 2017; Shea et al., 2020; **Figure 3**).

Defining the Problem

As per the 'species and context' column in **Table 1**, any decision-making process should first clarify the taxa in question, the scope of the policy decision and the socio-economic context. This will aid with identifying policy-affected people and stakeholders to include in the process, and the plurality of values that should be considered. The taxa in question could be considered as a broad taxonomic group, where biological characteristics, trade dynamics and public health risks are relatively homogenous (e.g., Batoidea, **Table 1**), or as a single species (e.g., *Ovis canadensis*, **Table 1**), where necessary due to exceptional characteristics and context. The scope should also consider the market dynamics and governance context.

This may need to be informed by a prioritization exercise, to create a shortlist of which taxa, geographic regions and/or markets warrant policy reform, which can be informed by available literature on hotspots, anthropogenic drivers and animal hosts of zoonotic diseases [e.g., see Allen et al. (2017) and Han et al. (2016)].

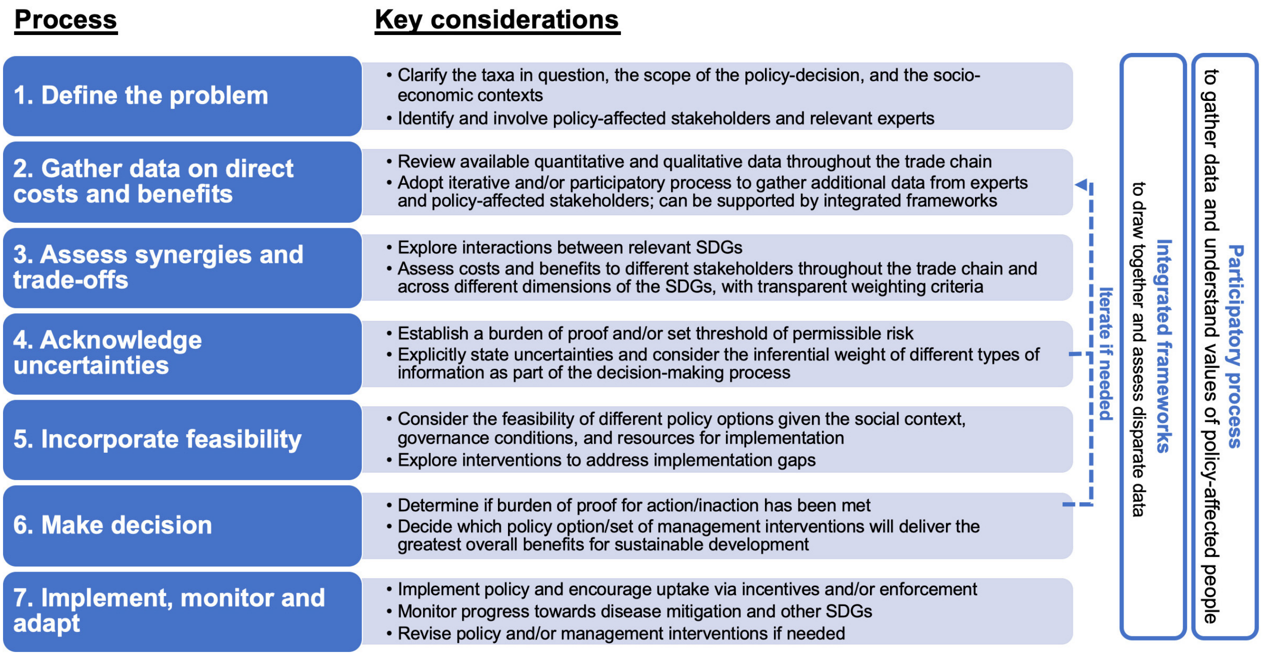

FIGURE 3 | A general process and key considerations for developing risk-based wildlife trade policy for sustainable development outcomes.

Gathering Data

As per **Table 1** (and the SI), a range of different datasets can be used to evaluate the costs and benefits of wildlife trade for the SDGs.

Where available, quantitative data can be used. For example, risks for health and well-being (SDG 3) could be measured through estimated disability-adjusted life years (DALY) lost as a result of a pandemic (Narrod et al., 2012), or the total estimated economic and social burden attributed to a zoonotic outbreak. For example, in the case of great apes, Huber et al. (2018) estimated that the total mortality and economic burden attributed to the 2014 Ebola outbreak in West Africa at 11,000 lost lives and US$ 53 billion (**Table 1**, SI). Similarly, in the case of coronaviruses in horseshoe bats, the current COVID-19 pandemic has led to an estimated 2 million lives lost worldwide (at the time of writing), and an estimated US$ 10 trillion in foregone GDP (The Economist, 2021). Likewise, other costs and benefits for people, such as poverty, hunger and inequality (SDGs 1, 2, 5 and 10) can be measured through both subjective and objective measures of well-being attributed to wildlife use (Milner-Gulland et al., 2014). Again, this can be measured in dollar values, such as the total income derived from the trade and total number of people employed (e.g., the American bullfrog case study, **Table 1**, SI), or in terms of contributions to DALY, such as via benefit of wildlife consumption to childhood nutrition (Golden et al., 2011).

The costs and benefits for life on earth and life below water (SDGs 14 and 15) can be measured in terms of extinction risk or rate of population change at the species level, as attributed to wildlife trade and associated policy responses (e.g., see the Bighorn sheep case study, **Table 1**, SI), or in terms of welfare-adjusted life years (WALY) for individual animals (Ripple et al., 2016; Teng et al., 2018).

In other cases, it may be more appropriate to use semi-quantitative or qualitative data, such as expert and stakeholder judgments. Such approaches are particularly useful in data-limited risk assessments (Beauvais et al., 2018; Booth et al., 2020), for consensus-building when integrating perspectives and evidence from diverse sources and stakeholders (Booy et al., 2017), and for accounting for risk and uncertainty (Shea et al., 2020). Importantly, consultative processes not only help to obtain data, but also weigh priorities, explore the feasibility of management options, set societal thresholds and the burden of proof needed for policy (in)action, engage diverse stakeholders and address inequalities (Booy et al., 2017; Defries and Nagendra, 2017); all of which will be needed to turn evidence in to action.

As well as indicating the direction and magnitude of costs and benefits, uncertainty and data gaps should be explicitly acknowledged. When using qualitative data, this could include qualitative judgments of uncertainty (as in **Table 1**). In quantitative assessments, uncertainty can be communicated using iterative or statistical methods, such as Value of Information Analysis, which is used to value the contributions of different types of research exercises in terms of expected reduced uncertainties (Runge et al., 2011).

Data gathering may be an iterative process, wherein available data is collated, data gaps are identified, and further research and/or expert and stakeholder consultation is conducted to fill data gaps. This can also be supported by a participatory process, and adoption of an integrated framework to collate and assess data (Booy et al., 2017; Booth et al., 2020; Li et al., 2020).

Assessing Synergies and Trade-Offs

As we have highlighted, it is not only important to consider the direct impacts of wildlife trade on public health and the SDGs, but also interactions and feedbacks. For example, bat trade may provide nutritional benefits for some people, but pose risks of zoonotic disease outbreaks for others (Mickleburgh et al., 2009; Wong et al., 2019); while a ban on wild-sourced wildfowl, to protect wild populations from overexploitation, could drive expansion of higher-risk illicit markets (Fournie et al., 2013), or agricultural expansion of poultry farms, which exacerbate other anthropogenic drivers of biodiversity loss and zoonosis emergence (Allen et al., 2017; Tilman et al., 2017; **Figure 2**). Frameworks and methods are available for exploring interactions between the SDGs, which have already been applied to other complex socio-ecological systems (e.g., Nilsson et al., 2016; Nash et al., 2020), and could easily be applied to wildlife trade decision-making. A highly quantitative approach to assessing synergies and trade-offs could involve assessing all positive and negative contributions of wildlife trade to the SDGs in terms of expected DALYs, and conducting a cost-benefit analysis (Narrod et al., 2012). However, this may be unfeasible in many cases, due to data limitations; and risks being and overly reductive, where certain values cannot be accounted for within this metric. Instead, a more realistic and inclusive approach could be an integrated framework with a simple high-to-low or traffic light categorization system, with qualitative or semi-quantitative assessments of the magnitudes of different costs and benefits (as outlined in **Table 1**), and various weightings applied to each category of cost/benefit based on uncertainties, risks and value judgments. Combining these different assessments and their weightings can then help to build consensus and make an informed judgment, even where the metrics for different costs and benefits are diverse and difficult to compare (Beauvais et al., 2018; Booth et al., 2020; Li et al., 2020).

Acknowledging Uncertainty and Setting Thresholds

Rigorously evaluating all costs and benefits may be challenging, particularly in data-limited contexts. Pre-defining the burden of proof, and acceptable levels of uncertainty for action or inaction, can help with iterative and adaptive decision-making. When establishing the burden of proof, a "do no harm" precautionary approach should be adopted as best practice (Cooney and Dickson, 2012). However, in many cases it will not be possible to identify optimal solutions which do no harm across all SDGs. Rather, it may be necessary to identify step-by-step solutions which are most acceptable to stakeholders in a given time or context (Head, 2008). Decisions may also entail moral dilemmas, such as weighing-up human disease risk against animal extinction risk, or human disease risk now against human disease risk in the future. This is particularly difficult in the face of uncertainty, such as cases where the likelihood of a pandemic is deemed very low, but its scope and severity are hypothetically large. In these situations, harm minimization may be more pragmatic. Decision-makers may wish to set thresholds of 'permissible harm' in each SDG, based on priorities and societal perspectives. If certain thresholds are reached – such as an unacceptable risk to human health, or an unacceptable cost to the economy – then that issue takes precedent above others. Thresholds of permissibility will be shaped by culture and social norms, and should therefore be adapted to each decision context, and transparently communicated. Methods from multi-criteria decision analysis, which help to explicitly evaluate multiple conflicting criteria in decision-making (e.g., Huang et al., 2011; Runge et al., 2011), could help to evaluate multiple conflicting values and objectives regarding wildlife trade policy, and identify thresholds for permissible costs under different SDGs.

In many cases, there may also be a pressing need for management action, yet insufficient time or resources to collect detailed information, creating trade-offs between knowing and doing (Knight and Cowling, 2010). Decision-makers must strike a balance between reactionary crisis-driven interventions, which may be suitable in the short-term, though can lead to perverse outcomes in the medium-term (Bonwitt et al., 2018), and evidence-based preventative measures, which lead to better outcomes in the long-term. The adage 'hard cases make bad law' should be considered here; i.e., the extreme case of COVID-19 may be a poor basis for a general law covering a wider-range of less extreme wildlife trade scenarios. 'Wicked problems' such as this call for adaptive management rather than definitive top-down technical solutions, so that policy interventions can be updated as feedbacks play out and knowledge of the system expands (Head, 2008; Defries and Nagendra, 2017).

Incorporating Feasibility

Policy formulation should also consider costs and feasibility of implementation, based on resources for monitoring and enforcement, and legitimacy of new measures as felt by the stakeholders most likely to be affected (Challender et al., 2015; Bonwitt et al., 2018; Oyanedel et al., 2020) (e.g. see 'implementation issues' outlined in **Table 1**). Lack of capacity and political will within government agencies can undermine laws, and is a commonly cited reason for the failure of many existing wildlife trade regulations (Dellas and Pattberg, 2013). As such, new policies may require investment in implementing agencies, to support monitoring and enforcement. Limited resources for implementation further emphasizes the need for risk-based problem-oriented approaches, with enforcement resources directed toward critical control points (Krumkamp et al., 2009). Interventions must consider the needs and preferences of affected people, the underlying drivers of wildlife use and trade, and the legitimacy of any new regulations. Failure to do so is not only unethical but may result in misguided policy responses that do not address the root causes of unsustainable wildlife trade and zoonoses emergence, resulting in non-compliance, with even greater risks to wildlife and public health (e.g., Fournie et al., 2013, Bonwitt et al., 2018; Oyanedel et al., 2020). Social research may help to identify and reduce drivers of non-compliance with wildlife laws or key barriers to behavior change (Travers et al., 2019).

Making Decisions; Implement, Monitor, Adapt

Finally, all information and options need to be drawn together to make a policy decision, which is likely to deliver the greatest overall benefits to the SDGs. If a participatory process and an integrated decision framework have been applied throughout, these tools can facilitate consensus and/or informed judgment on which to base a final decision (see below). If the burden of proof has not been met, it may be necessary to iterate the process, with further research and deliberation.

Once a policy decision has been made, a range of instruments and interventions will be required for implementation, such as investments in monitoring and enforcement, infrastructure and technology, or training and incentives. Monitoring of SDG outcomes after the policy intervention will help to determine its impact, and inform adaptive management.

Participatory Processes

Past experiences with previous complex, uncertain and divergent public policy problems suggest that the process is equally if not more important than the evidence-base (Head, 2008; Booy et al., 2017; Defries and Nagendra, 2017). Participatory processes can help to collate and evaluate data on the range of costs and benefits of wildlife trade across multiple SDGs and for multiple sectors of society. Group-based deliberation can also support valuation of costs and benefits, and co-learning amongst different groups (Kenter et al., 2011; Shea et al., 2020), thus facilitating multi-sector decision-making amongst local and national governments, inter-governmental platforms and policy-affected-people. Participatory processes for designing wildlife trade interventions can also build legitimacy and foster support for policy decisions, thus improving implementation, uptake and compliance (Weber et al., 2015; Roe and Booker, 2019).

Integrated Frameworks

All of the above could be supported by integrated frameworks, which can help to draw together and evaluate disparate data; facilitate multi-sector engagement; highlight information gaps, uncertainties and value judgments; and thus, guide transparent evidence-based decisions and collective action. For example, integrated frameworks have previously been used for risk management in human and animal health (Narrod et al., 2012; Beauvais et al., 2018), wildlife policy and management (Booy et al., 2017; Booth et al., 2020) and interfaces between the two (Coker et al., 2011). Existing frameworks are also available for mapping interactions between SDGs, which are intuitive, broadly replicable and could be easily adapted to a wildlife trade context (Nilsson et al., 2018, 2016; Nash et al., 2020). For example, Nilsson et al. (2016) offer a simple semi-quantitative scale for exploring the influence of one SDG on another, while Nash et al. (2020) suggest extensions to the current SDG assessment framework to better acknowledge interactions between SDGs for planet, prosperity and people. Importantly, integrated frameworks are flexible and can be used iteratively as part of participatory and adaptive processes, allowing incorporation of diverse values and uncertainty. For example, decision-makers can develop primary indicators for costs and benefits alongside secondary indicators on value judgments and uncertainty, and further indicators to evaluate feasibility, such as practicalities, costs and likely impacts of different policy responses (Booy et al., 2017; Booth et al., 2020). This could help to manage conflicting values and data, by explicitly assessing the relative weight or importance of different priorities, and thus improve the transparency of decision-making processes.

DISCUSSION

In the wake of COVID-19, there are calls for policy interventions to minimize public health risks related to zoonotic diseases through measures including banning wildlife trade. However, uncertainty remains regarding the role of wildlife trade in the emergence of COVID-19 (Cohen, 2020; Huang et al., 2020). Moreover, wildlife trade does not represent a homogeneous risk to public health, and can be beneficial to both biodiversity and people (Hurley et al., 2015; Cooney, 2019; McRae et al., 2020). As such, wildlife trade policies in responses to COVID-19 must consider the trade-offs within and between public health and other dimensions of the SDGs. We have presented how decision-makers might evaluate these trade-offs and synergies for different species and contexts, in order to formulate risk-based policies. Explicitly considering the diversity of costs and benefits of wildlife trade along supply chains could guide decision-makers toward more appropriate policy interventions for heterogenous species, contexts and scales, to maximize different sustainable development outcomes without compromising others.

Implementing a Risk-Based Approach to Wildlife Trade Policy: Practical Challenges and Potential Solutions

Despite the benefits of adopting a risk-based approach for formulating wildlife trade policy, challenges remain for practice and implementation. These include data needs and gaps, and effective and equitable compliance management.

For instance, the process we have outlined (**Figure 3**) will be more data intensive and time consuming than taking rapid, reactive (and potentially ill-informed) decisions, which may be necessary in times of crisis such as a global pandemic. A middle ground may be to adopt crisis measures in the short-term, with a shift toward more nuanced measures in the medium-term, once a range of potential policy options have been identified and evaluated. Data gaps may also hinder this process. For example, a lack of data on species' population statuses or the benefits from informal trade could create information asymmetries in cost-benefit analyses. Similarly, there are unknown unknowns, for example from new or undescribed zoonotic pathogens, which are difficult to predict or account for. Such data gaps underline the importance of adaptive management (step 7, **Figure 3**), so that policies can be adapted as situations change or new information comes to light.

A further challenge relates to how people and institutions respond to new policies, particularly if they are negatively affected, and therefore how to design effective and equitable compliance management systems. For example, if trade in a species is restricted, and existing traders face large barriers to adaptation, they could face large absolute costs in terms of income forgone. Though these costs should be minimized via a risk-based approach, they cannot always be completely avoided, and could create strong incentives for non-compliance or negative impacts on the well-being of certain groups. In such cases, a 'no net loss to human well-being' approach could be adopted (Griffiths et al., 2019), whereby opportunity costs are evaluated and compensation is provided to ensure vulnerable people are no worse off. Taxa- and location- specific policies can also create additional challenges for monitoring and enforcement, such as identifying prohibited species or monitoring diffuse and complex markets. These issues can be addressed via more significant investments in infrastructure, technology and human capacity for wildlife trade monitoring and bio-security, which are likely to become more serious political priorities following the COVID-19 pandemic. In most cases, 'smart regulation' will be needed, whereby a combination of instruments are used to create an appropriate policy mix, which can flexibly, efficiently and equitably incentivize multiple stakeholders and institutions (Young and Gunningham, 1997; Gunningham and Sinclair, 2017). Wildlife trade is also a highly emotive topic, and policy decisions can be influenced by strong public opinions, which aren't necessarily rational or data-driven (Hart et al., 2020). More transparent approaches to decision-making are needed to address wildlife trade in the face of public health crises and beyond, wherein decision criteria and costs and benefits are clearly outlined and publicly available.

Global Problems Require Global Solutions: The Role of Multilateral Agreements

Moving forwards, new or revised multi-lateral agreements may be needed to strengthen cross-sectoral coordination and political commitment at the intersection of wildlife use and sustainable development, with key stakeholders currently in the process of deciding what is needed and how it might be delivered. For example, discussions have begun on the role of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) in protecting human health, by regulating animal health in international trade (Ashe and Scanlon, 2020; CITES, 2021). However, relying on CITES would likely result in an overly narrow focus on CITES-listed species, whilst missing heavily traded taxa not under the purview of the Convention (e.g., farmed mink) and critically, other key drivers of zoonotic disease emergence, such as intensive animal agriculture and land-use change. In contrast, the Convention on Biology Diversity (CBD) has a broader remit, and is soon to establish the post-2020 agenda (CBD, 2020). However, the CBD arguably lacks compliance mechanisms and political commitment for instituting and incentivizing the necessary transformational policies, to unite multiple sectors and cut across multiple aspects of sustainable development (Leach et al., 2018; Díaz et al., 2019). Rather, a new and more integrated agreement, which perhaps builds on the Agreement on Climate Change, Trade and Sustainability (ACCTS) and the World Organisation for Animal Health, may be necessary to foster serious political will toward the cross-sectoral challenge of "saving lives, protecting livelihoods, and safeguarding nature," as a matter of global urgency.

Next Steps for Wildlife Trade and Beyond

In the medium-term, we must better understand the transmission pathways of zoonotic diseases in traded wild species, and the extrinsic and intrinsic drivers of zoonosis emergence across species and supply chains. Interactions and trade-offs between wild-sourced and domesticated food systems, and the substitution relationships between different protein sources, should also be better understood. This will help to predict potential displacement effects of policy interventions, and overcome some of the challenges highlighted above. More broadly, there is a need to expand the scope of policy responses to zoonotic disease risk, beyond the current narrow focus on wildlife trade. Evidence indicates that land-use change and agricultural expansion are major drivers of the emergence of zoonotic diseases (Han et al., 2016; Allen et al., 2017). Rather than a narrow focus on wildlife trade, the COVID-19 crisis should serve as a wake-up call to re-think many aspects of humanity's relationship with nature. A paradigm shift toward holistic risk-based management of wildlife trade, embedded within a broader socio-ecological systems perspective, could ensure that future use and trade of wildlife is safe, environmentally sustainable and socially just.

AUTHOR CONTRIBUTIONS

HB was responsible for conceptualization. HB, MA, SB, MK, TK, YL, AO, RO, and TP were responsible for analysis and writing the original draft. DC and EM-G were responsible for validation and review, editing, and supervision. HB and TP were responsible for designing graphics. All authors contributed to the article and approved the submitted version.

ACKNOWLEDGMENTS

All authors are grateful to the Oxford Martin Programme on the Illegal Wildlife Trade (OMP-IWT), support from which made this research possible. The authors also thank the following funding sources, respectively: HB the Oxford-NaturalMotion Graduate Scholarship in Zoology, University of Oxford; MA the Wildlife Conservation Society (WCS), the Wildlife Conservation Network, and the Secretaría de Educación Superior, Ciencia, Tecnología e Innovación of Ecuador (SENESCYT); SB the DEFRA Darwin Initiative; DWSC and AO the National Geographic Society; MK the Zutshi-Smith foundation; TK - the Commonwealth Scholarship Commission; YL the Rhodes Trust; RO the Agencia Nacional de Investigación y Desarrollo, Becas Chile Program; TP the Natural Environment Research Council Environmental Research Doctoral Training Partnership (NE/L002612/1), Oxford; DWSC and EJMG acknowledge funding from the UK Research and Innovation's Global Challenges Research Fund (UKRI GCRF) through the Trade, Development and the Environment Hub project (project number ES/S008160/1).

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fevo.2021.639216/full#supplementary-material

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

frontiers in Ecology and Evolution

POLICY AND PRACTICE REVIEWS
published: 02 March 2021
doi: 10.3389/fevo.2021.645427

Strengthening International Legal Cooperation to Combat the Illegal Wildlife Trade Between Southeast Asia and China

Yunbo Jiao[1]*, Pichamon Yeophantong[2]* and Tien Ming Lee[3,4]*

[1] School of Law, Sun Yat-sen University, Guangzhou, China, [2] School of Humanities and Social Sciences, University of New South Wales (Canberra), Canberra, ACT, Australia, [3] State Key Laboratory of Biological Control, Schools of Life Sciences and Ecology, Sun Yat-sen University, Guangzhou, China, [4] Oxford Martin School, University of Oxford, Oxford, United Kingdom

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Edited by:
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United Kingdom

***Correspondence:**
Yunbo Jiao
jiaoyunbo@mail.sysu.edu.cn;
yunbo.jiao@hotmail.com
orcid.org/0000-0001-6473-6357
Pichamon Yeophantong
p.yeophantong@unsw.edu.au
orcid.org/0000-0002-4685-5421
Tien Ming Lee
leetm@mail.sysu.edu.cn
orcid.org/0000-0003-2698-9358

Specialty section:
This article was submitted to
Conservation and Restoration
Ecology,
a section of the journal
Frontiers in Ecology and Evolution

Received: 23 December 2020
Accepted: 08 February 2021
Published: 02 March 2021

Citation:
Jiao Y, Yeophantong P and
Lee TM (2021) Strengthening
International Legal Cooperation
to Combat the Illegal Wildlife Trade
Between Southeast Asia and China.
Front. Ecol. Evol. 9:645427.
doi: 10.3389/fevo.2021.645427

China is among the world's leading consumer markets for wildlife extracted both legally and illegally from across the globe. Due to its mega-richness in biodiversity and strong economic ties with China, Southeast Asia (SEA) has long been implicated as a source and transit hub in the transnational legal and illegal wildlife trade with China. Although several cross-border and domestic wildlife enforcement mechanisms have been established to tackle this illegal trade in the region, international legal cooperation and policy coordination between China and its SEA neighbors remain limited in both scope and effectiveness. Difficulties in investigating and prosecuting offenders in overseas jurisdictions, as well as organized criminal groups that sustain the illicit supply chain, continue to undermine efforts by the region's governments to combat wildlife trafficking. In addition to reviewing the key trends in both the legal and illegal wildlife trade between SEA and China, this paper examines existing legal and policy frameworks in SEA countries and China, and provides a synthesis of evidence on the latest developments in regional efforts to curtail this multibillion-dollar trade. In particular, it discusses how proactive and effective China has been in cooperating with its SEA neighbors on this issue. The paper also draws on the United Nations Convention against Transnational Organized Crime (UNTOC) framework to suggest pathways to deepen legal cooperation between China and SEA countries in order to disrupt and dismantle transnational wildlife trafficking in the region.

Keywords: UNTOC, species conservation, wildlife trafficking, international cooperation, policy coordination, legal frameworks

INTRODUCTION

As one of the world's leading consumer markets, China's role in shaping the international trade in legal and illegal wildlife (specifically fauna species) cannot be understated (e.g., Nijman, 2010; UNODC, 2016). Over the past two decades, China's market for wildlife products has continually and markedly expanded (Jiao and Lee, in press)—a trend triggered largely by the country's economic boom, increased consumer affluence (CSRI, 2020) and traditional utilitarian culture that treats wildlife as an exploitable resource (Zhang et al., 2008; Zhang and Yin, 2014). This expansion in China's appetite for wildlife products (e.g., medicines, meat, skins) has further contributed to the growth in the scale and scope of the global wildlife trade. Partly owing to a reduction in the country's biodiversity (NFGA, 2008; MEE and CAS, 2015), much of the wildlife found in the Chinese market has overseas origins and will have entered through both legal and illegal channels.

Due to its mega-richness in biodiversity, geographical proximity and strong economic ties with China, Southeast Asia (SEA) has long been implicated in this legal and illegal trade (Li and Li, 1998; Li et al., 2000). Countries in the region have functioned variously as sources, transit routes and distributing hubs, as well as destination markets for high-value, endangered species of wildlife fauna (e.g., elephant ivory, pangolin scales) (Krishnasamy and Zavagli, 2020). Especially with countries such as Cambodia and Lao PDR (hereafter, Laos) serving as "hotspots" for wildlife poaching and smuggling, the illegal wildlife trade (IWT)—whilst very lucrative—poses a significant threat to the region's biodiversity, human health and collective security (Sodhi et al., 2004; Hughes, 2017). Moreover, given that the wildlife products trafficked in the region are often illegally sourced from South Asia and Africa, being destined for the mainland Chinese market (UNODC, 2019), this invokes a shared responsibility for China and its SEA neighbors to combat transnational wildlife trafficking.

This paper begins by reviewing the *status quo* of legal and illegal wildlife trading between SEA and China. It then examines the existing legal and policy frameworks in SEA countries and China, and the extent to which they support more efficient criminal justice responses, interagency coordination and intergovernmental cooperation in the fight against the multibillion-dollar illegal trade. This is followed by a synthesis of evidence on the latest developments in regional efforts by China, individual SEA countries and the Association of Southeast Asian Nations (ASEAN), to identify key chokepoints and improve transnational cooperation to tackle wildlife trafficking. In so doing, the paper also considers how proactive and effective China has been in cooperating with its SEA neighbors on this issue. Focusing on the United Nations Convention against Transnational Organized Crime (UNTOC), this paper finally turns to discuss the value of international legal instruments to enhancing China-SEA legal cooperation to disrupt and curtail the transnational illegal wildlife trade.

One caveat warrants note here. Given the difficulty in gaining access to primary data on IWT globally and regionally, this paper draws on available estimates, seizure reports, official statements and media releases, as well as news media sources—some of which may not be very recent (i.e., from 2019 or 2020) due to data limitations—to illustrate the nature and scale of transnational wildlife trafficking between SEA and China.

THE WILDLIFE TRADE BETWEEN SEA AND CHINA

Legal Trade

The legal wildlife trade between SEA and China is substantial and growing in both scale and scope. Analysis of trade records collated from the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) Trade Database revealed that between 1997–2016,[1] approximately 3.8 million CITES-listed, live vertebrates (e.g., amphibians, birds, fish, mammals, reptiles) and 1.4 million whole organism equivalents (WOEs)—mainly comprised of body parts and products (e.g., claws, heads, skins)—were imported into China from SEA. The average annual import volume is 259,695 WOEs, accounting for around 45% of China's legitimate global imports of CITES-listed vertebrates which are estimated at 0.6 million WOEs per year (Jiao and Lee, in press).

This trade is commercially oriented and feeds into five key industries: fashion, traditional Chinese medicine (TCM), food, pets and ornaments, and musical instruments (**Table 1**). Live animals and skins have consistently dominated the trade, with each accounting for 72% and 27% of China's total imports from SEA, respectively. Further, China's sourcing of legal wildlife from SEA has largely focused on a few SEA countries and a handful of reptile species: 79% of its imports from the region were supplied by three SEA countries (Indonesia, Laos, Malaysia), with 88% of the imports made up of ten species [e.g., common water monitor (*Varanus salvator*), Indian rat snake (*Ptyas mucosus*), Siamese crocodile (*Crocodylus siamensis*); **Table 1**].

Over half (60%) of the animals and their derivatives traded from SEA to China reportedly originate from wild and ranching sources. Speaking to an overarching trend which sees wild-caught specimens dominating SEA's wildlife exports to the rest of the world (Nijman, 2010), this presents the risk of illegal, wild-extracted animals being laundered into the legal supply chain prior to export (Lyons and Natusch, 2011; Natusch and Lyons, 2012). Certainly, it is noteworthy how nearly half of the total species found in China's illegal wildlife trade can also be seen in the legal trade (Jiao and Lee, in press). As such, given the large volume of wild-sourced wildlife involved in the legal trade, coupled with the absence of effective regulation of wild harvesting in source countries like Indonesia (China's major supplier of wild-sourced reptile skins in SEA) (Nijman and Shepherd, 2009; UNODC, 2016), this underscores an exigent need for institutional and regulatory innovation to better facilitate information and knowledge exchange of sustainable wild extraction and farming practices, improve source countries' certification schemes, and streamline the implementation of proper licensing and registration to prevent species over-exploitation.

Illegal Trade

With Southeast Asia serving as one of the world's major gateways to the illegal wildlife trade, the regional black-market value of these illicit products is estimated to reach billions of dollars each year (Felbab-Brown, 2011; UNODC, 2013). Even so, the "underground" nature of the trade, combined with data limitations, means that it remains difficult to gauge the full value and magnitude of IWT within the region. Aside from SEA's geographical proximity to China and other consumer markets

[1] CITES Trade Database 1997–2016 (data downloaded in February 2019). Available online at: https://trade.cites.org/(accessed December 23, 2020).

TABLE 1 | Most commonly traded species in China's legal wildlife imports from Southeast Asia during 1997–2016, broken down by live animals and skins (Data source: CITES Trade Database 1997–2016).

Taxa	WOE vol. (%)#	Wild (%)*	Captive (%)*	Source country (%)^	Main uses in China
Ten most imported species in live trade					
Ptyas mucosus	781, 891 (21)	71	23	LA (74), ID (20)	Food, TCM, ornament
Scleropages formosus	611, 291 (16)	–	100	ID (50), MY (44)	Ornament
Crocodylus siamensis	598, 074 (16)	–	98	TH (47), VN (38)	Food, TCM, leather product
Cuora amboinensis	356, 507 (10)	90	6	MY (56), LA (24)	Food, TCM, Pet
Varanus salvator	285, 391 (8)	87	1	LA (94)	Food, TCM, ornament, leather product
Naja	281, 720 (8)	91	8	LA (67), MY (22)	Food, TCM, pet
Heosemys annandalii	209, 595 (6)	77	4	LA (90)	Food, TCM, pet
Heosemys grandis	152, 560 (4)	71	8	LA (73), MY (23)	Food, TCM, pet
Macaca fascicularis	113, 945 (3)	20	80	KH (45), VN (33)	Biomedical experiment
Amyda cartilaginea	71, 529 (2)	100	–	ID (78), MY (22)	Food, TCM, pet
Five most imported species in skin trade					
Varanus salvator	556, 082 (40)	100	–	ID (74), MY (26)	Leather product
Python reticulatus	511, 743 (37)	98	2	MY (85), ID (13)	Leather products, musical instrument
Python bivittatus	116, 718 (8)	3	97	VN (99)	Leather products, musical instrument
Crocodylus siamensis	65, 289 (5)	–	100	VN (42), TH (37)	Leather product
Homalopsis buccata	30, 900 (2)	100	–	ID (100)	Leather product

 # Numbers in parentheses are percentages. In column "WOE vol.," they represent the proportion of the whole-organism-equivalent (WOE) volume of the trade term derived from that species to the total WOE imports of that trade term exported from SEA to China; while in columns "Wild," "Captive" and "Source country," they indicate the proportion of the WOE volume of that specimens reported in that type of source or from that country to the total import volume of that species. The terms and ratios used to convert the heterogeneous types of animal body parts and products into whole-organism equivalents were quoted from the work by "Harfoot et al. (2018)."

**"Wild" category is defined to comprise all records with source code "W" (wild) or "R" (ranched; ranched individuals are either eggs or juveniles taken from the wild and reared in a controlled environment, or progeny from gravid females captured from the wild). The "Captive" category includes all records with source code "C" (captive-bred), or "D" (Appendix-I species bred in captivity in registered operations for commercial purposes), or "F" [born in captivity (F1 and subsequent generations)]. For more information about the source code, please refer to "UNEP-WCMC (2013)."*

^ Cross-reference for ISO code and its correspondent country: KH (Cambodia), ID (Indonesia), LA (Laos), MY (Malaysia), MM (Myanmar), PH (Philippines), SG (Singapore), TH (Thailand), VN (Vietnam). There were no records of trade from Brunei or East Timor to China.

in Asia (e.g., Japan, South Korea), a plethora of other factors have also contributed to this reality, ranging from inadequate legislation and poorly resourced law enforcement to high levels of corruption, endemic poverty, as well as improved transport links within the region (Grieser-Johns and Thomson, 2005; Ngoc and Wyatt, 2013; Brook et al., 2014). Indeed, increased connectivity due to the rapid expansion of the digital economy and physical infrastructure projects, as a result of China's Belt and Road Initiative and other regional initiatives, indicate how the IWT problem may intensify in scale and severity in the near future. Despite the COVID-19 pandemic, which has curbed certain forms of organized crime, transnational criminal entrepreneurs have also become more adaptive in their strategies to evade law enforcement, infiltrate the legal economy and proceed with "business as usual" (UNODC, 2020a).

Owing to unsustainable hunting and poaching, most large animals (> 1 kg) have experienced a precipitous decline in their populations across the SEA region (Harrison et al., 2016). Highly valued species, such as the Chinese pangolin (Challender et al., 2014), Indochinese leopard and tiger (Lynam, 2010; Rostro-Garcia et al., 2016), Javan rhinoceros (Brook et al., 2014), and Burmese star tortoise (Platt et al., 2011) have been extirpated from much of their original range or have even gone extinct in the wild. Crucially, the depletion of the region's wildlife resources has not only transformed the roles of certain SEA countries within the supply chain—Vietnam, for one, has evolved from a regional supplier into a key distribution center (Lin, 2005; Ngoc and Wyatt, 2013; Davis et al., 2019)—but it has also forced poachers, smugglers and illicit traders to target new source areas and alternative species as substitutes. This is exemplified by the increasing occurrence of African pangolin species on the Asian market (Heinrich et al., 2016; Gomez et al., 2016), and how leopard parts have been prescribed as alternatives to tiger parts given their relatively higher availability (Raza et al., 2012).

As noted earlier, China is known as the prime destination for a large share of the wildlife traded illicitly from SEA to the international market (UNODC, 2010). Thailand continues to be among the largest seahorse exporters in Asia, even after its export suspension in January 2016, with most ending up in Hong Kong, Taiwan, and mainland China for TCM uses (Foster et al., 2016, 2019). Bangkok has also become a global trading center for the sale of illegal ivory from Africa (Doak, 2014), as well as illegal tortoises and freshwater turtles smuggled from Africa, South Asia, and Southeast Asia to foreign tourists (Nijman and Shepherd, 2015). Due to its free port status, huge daily cargo throughput, and well-established trade links with both source and consumer countries, Singapore has likewise emerged as a prominent transit hub for the movement of illicitly sourced wildlife commodities, especially via containerized trafficking (Felbab-Brown, 2011; Krishnasamy and Zavagli, 2020).

Considering the land border shared by China and mainland SEA countries, it is unsurprising that this subregion should witness a high-level flurry of illicit trade activity over the past decade. Indeed, the cross-border supply of a variety of illegal wildlife and their derivatives has further contributed to the growth in economic activity seen in the border towns situated between China and its SEA neighbors. These towns have, in turn, evolved into the focal points for the collection, retailing and transshipment of these illicit products. Vietnam has long acted as a critical node in the illicit supply chain between SEA and China (Grieser-Johns and Thomson, 2005), with a large trading network having formed around several Vietnam-China border cities, including Mong Cai and Lang Son on the Vietnamese side (Van Song, 2003) and Dongxing, Pingxiang and Longzhou on the Chinese side (Li et al., 2010).

In Laos' Golden Triangle Special Economic Zone, tiger pelts sourced from Thailand and Malaysia are reportedly sent to Yunnan Province and Fujian Province to tanneries, then smuggled back to the Golden Triangle area where they are sold to Chinese tourists (EIA, 2015). In the border town of Boten, a one-day market survey had recorded around 1,000 wildlife items, including bear parts, pangolin scales and elephant hides, being offered for open sale in outlets run mostly by Chinese nationals (Krishnasamy et al., 2018). Moreover, following China's ban on the domestic commercial processing and sale of elephant ivory and related products in 2017, trafficking networks have since relocated their ivory carving and production from China to Laos and African countries, such as the Democratic Republic of the Congo (CITES Secretariat, 2017a,b).

Similarly, in Cambodia's Tonle Sap Biosphere Reserve, reports had at one point surfaced of a large volume of turtles being harvested unsustainably by local fishermen, sold to village-level dealers and later middlemen in larger cities. These middlemen would then smuggle the turtles to supply urban markets in southern China and Vietnam (Platt et al., 2008). In Myanmar, Kachin State is documented as an important gateway for overland trafficking of pangolins sourced in Myanmar, other SEA countries (Zhang et al., 2017), India, and potentially Africa (Mohapatra et al., 2015; Nijman et al., 2016), as well as for tiger pelts procured in northeast India and Nepal (UNODC, 2010). Accounts indicate how the border town of Mong La, which is located next to the Chinese township of Daluo in Yunnan Province, has become a regional hub for illegal wildlife products, especially elephant ivory, tiger and leopard parts. Most of these products are sold to Chinese customers and then taken back to China via the Daluo port (Shepherd and Nijman, 2007; Nijman and Shepherd, 2014).

With respect to maritime SEA, Indonesia and Malaysia serve as major source countries for illegal wildlife destined for the mainland Chinese and Hong Kong markets. It is estimated that in one year, around 180,000 live Southeast Asian box turtles, substantial amounts of plastrons and carapaces (Schoppe, 2009), between 200,000-450,000 live Asiatic softshell turtles, and 1.2 million tokay geckos (Nijman et al., 2012) were exported in violation of Indonesia's quota control for the international pet, meat and TCM markets. Analysis of seizure reports for Malaysia likewise reveals how the country constitutes a key transshipment center for the trafficking of elephant ivory, Malagasy tortoises, pangolins, and rhino horns from Africa to other parts of Asia—most notably, to Hong Kong, mainland China and Vietnam (TRAFFIC, 2017a,b, 2018, 2019).

POLICY AND LEGAL FRAMEWORKS FOR COMBATING WILDLIFE TRAFFICKING

To deal with the complex and multiscalar challenges posed by IWT, effective legal cooperation and policy coordination are required at both the national and transnational levels. For this to happen, however, a network of concerned and knowledgeable stakeholders at different scales of governance needs to be galvanized, and a cooperative platform established through which their expertise and resources can be pooled for a more cohesive response to wildlife trafficking. Whereas subsequent sections will focus on efforts at interstate cooperation (e.g., between wildlife regulators and enforcers) within the region to disrupt and disconnect cross-border supply chains from source to market, this section takes stock of the key policy and legal frameworks in SEA countries and China pertaining to IWT. It also considers to what extent they collectively contribute to a regulatory regime to curtail the trade.

At the national level, effective interagency coordination between wildlife regulatory and enforcement authorities is crucial. In the Chinese case, for example, formal responsibility for regulating the legal wildlife trade, as well as the prevention, detection and investigation of the illegal trade, is spread across many agencies that come under different ministries. Key ones include the National Forestry and Grassland Administration (NFGA), Forest Police (under the Ministry of Public Security), Bureau of Fisheries (under the Ministry of Agriculture and Rural Affairs), General Administration of Customs and its Anti-Smuggling Bureau, Ministry of Ecology and Environment and local environmental protection bureaus, State Administration for Market Regulation, National Medical Products Administration, and local animal health supervision and inspection stations. In the SEA context, a complex regulatory web is similarly found, with a variety of agencies and actors tasked with implementing and enforcing relevant laws and policies.

Key Developments in Southeast Asia

Across the SEA region, domestic legal frameworks that set out the ownership, management rules, offenses and penalties in the wildlife sector come in different forms. For instance, although most SEA countries have adopted wildlife statutes, Cambodia includes wildlife-related provisions in its 2002 *Law on Forestry*, whereas Vietnam integrates them into ministerial decrees (**Table 2**). Most SEA countries have, moreover, promulgated an array of administrative and ministerial directives, circulars, and orders to support the implementation of major wildlife legislation, as well as customs laws as a supplementary instrument to regulate the trade of controlled wildlife (Broussard, 2017).

Although the consequences of wildlife offenses vary by country, all SEA countries have established regulatory measures pertaining to the killing or hunting, possessing, selling,

TABLE 2 | Key legal provisions for criminalization of wildlife offenses in China and ASEAN member-states.

Country	Key provisions for criminalization of wildlife offenses#	MLA*	Extradition*
Brunei Darussalam	*Wild Fauna and Flora Order 2007* **Art. 47.** Trade in CITES App. I-listed species without a permit or certificate (**5 years**) **Art. 48.** Illegal possession of specimens of CITES App. I-listed species (**5 years**).	×	×
Cambodia	*Law on Forestry 2003* **Art. 97.** Illegal hunting/killing, trading, or exporting of endangered wildlife species (**10 years**). **Art. 98.** Hunting during closed seasons or in protected zones; Illegal hunting/killing, trading, or exporting of rare species; Hunting using dangerous means that has caused serious harm; Illegal possession, processing, stocking, transporting, or importing of endangered species (**5 years**).	×	✓
Indonesia	*Act No.5/1990 Concerning Conservation of Living Resources and Their Ecosystems* **Art. 21.** Illegal catching, injuring, killing, keeping, possession, caring for, transporting, or trading of protected species (dead or alive), including their body parts and derivatives; Illegal transferring of protected species or their body parts and derivatives within or via Indonesia; Illegal taking, destroying, exterminating, trading, keeping, or possession of an egg or a nest of a protected species (**5 years**).	✓	✓
Lao PDR	*Wildlife and Aquatic Law 2007* **Art. 71.** Illegal catching or hunting of species listed in the Prohibition Category; Fishing or hunting using forbidden means that has caused serious harm; Illegal importing, exporting, re-exporting, transporting, or transiting of wildlife species (**5 years)**.	✓	✓
Malaysia	*Sabah Wildlife Conservation Enactment 1997* **Art. 25.** Hunting of species listed in Schedule 1, or hunting in violation of the licensing schemes for species listed in Schedule 2 or 3 (**5 years**). **Art. 33.** Hunting during prohibited period, or in protected areas, or using prohibited methods (**5 years**). **Art. 41.** Illegal possession of species listed in Schedule 1 (**5 years**). **Art. 53.** Illegally bringing in or taking out of the Country, by air, land, or sea, protected species or derivatives thereof (**5 years**). *Sarawak Wildlife Protection Ordinance 1998* **Art. 24 & 29.** Hunting/killing/capturing, selling, offering for sale, importing, exporting, or having possession of, rhinoceros or their derivatives (**5 years**). *International Trade in Endangered Species Act 2008* **Art. 10.** Importing or exporting of scheduled species without a permit (**7 years**). **Art. 11.** Re-exporting or introduction from the sea of scheduled species without a permit (**7 years**). **Art. 12.** Possession, selling, offering/exposing/advertising for sale, or displaying to the public of illegally obtained species listed in the Schedules (**7 years**).	✓	×
Myanmar	*The Protection of Wildlife and Protected Areas Law 1994* **Art. 36.** Killing, hunting, or wounding protected species or seasonally protected species without permission; Illegal processing, selling, transporting, or transferring of such species or their derivatives (**5 years**). **Art. 37.** Killing, hunting, or wounding completely protected species without permission; Illegal processing, selling, transporting or transferring, or exporting of such species or their derivatives (**7 years**).	×	×
Philippines	*Wildlife Resources Conservation and Protection Act 2001* **Sec. 27 & 28.** Illegal killing or destroying of critically endangered species, endangered species or vulnerable species; Illegal trading of critically endangered species (**12 years**). **Sec. 27 & 28.** Illegally trading critically endangered species; Illegal collecting, hunting or possession of critically endangered species or their derivatives; Illegal gathering or destroying of active nests, or nest trees of critically endangered species (**4 years**).	✓	✓
Thailand	*Wildlife Conservation and Protection Act 2019* **Sec. 89.** Illegal hunting of preserved or protected species (**15 years**). **Sec. 89.** Illegally trading preserved or protected species or their derivatives (**10 years**) **Sec. 92.** Illegal possession of preserved or protected species or their derivatives (**5 years**) **Sec. 93.** Importing or exporting of protected species or their derivatives without a license (**10 years**) **Sec. 94.** Illegal transport of preserved, protected or controlled species, or their derivatives (**4 years**)	✓	✓
Vietnam	*Penal Code 2017* **Art. 234.** Illegal hunting, killing, raising, imparking, possession, transporting, or trading of endangered, precious and rare species listed in Group IIB or CITES App. II, or common species, or their derivatives (**12 years**). **Art. 244.** Illegal hunting, killing, raising, imparking, possession, transporting, or trading of animals on List of endangered and rare species, or species listed in Group IB or CITES App. I, or their derivatives (**15 years**).	✓	×
China	*Penal Code 2017* **Art. 151.** Trafficking of rare and endangered wildlife or their derivatives (**Life sentence**). **Art. 341.** Illegal hunting, catching, or killing of rare and endangered wildlife; Illegal purchasing, transporting or selling of rare and endangered wildlife or their derivatives (**15 years**).	n/a	n/a

#*We only included in this table legal provisions with a prescribed maximum penalty for wildlife offences in excess of four-year imprisonment. Singapore was not included because according to its wildlife laws [e.g., Wildlife Act (Chapter 351), revised in 2020], the maximum penalty for wildlife criminal offenses is two-year imprisonment.*
**"✓" and "×" stand for the presence or absence of a bilateral agreement on mutual legal assistance in criminal matters or extradition between China and that SEA country. Data is collected from China Treaty Online Database http://treaty.mfa.gov.cn/Treaty/web/index.jsp (accessed January 29, 2021). China has not signed any treaty on MLA in criminal matters or extradition with Singapore.*

transporting, importing, and exporting of endangered and protected species, in an effort to police their exploitation and movement nationally and across borders (ASEAN-WEN, 2016). Depending on the gravity of the offense, violations may lead to administrative and/or criminal liability. Indeed, all countries in SEA have introduced—whether in their wildlife laws (e.g., Laos), CITES-enabling laws (e.g., Malaysia), or penal codes (e.g., Vietnam)—key provisions for criminalizing serious wildlife offenses with imprisonment and/or monetary charges (**Table 2**).

Notably, recent years have witnessed promising developments when it comes to expanding the scope of existing laws and regulations, imposing heavier penalties for wildlife offenses, and adding aggravating conditions such as the involvement of repeat offenders or organized criminal groups. For example, with Vietnam's amendment of its *Penal Code* in 2017 (Law No. 12/2017/QH14), the Code saw a 40-fold increase in the level of fines for offenses against endangered and rare species to VND two billion (US$86,480), with the maximum jail term also increasing three-fold to 15 years. In March 2019, Thailand enacted the *Wildlife Preservation and Protection Act*. Compared to its 1992 predecessor, the new Act formally brings non-native, CITES-listed species under its protection as "controlled species" and markedly increases the maximum term of imprisonment for infractions from four to 15 years (The Law Library of Congress, 2020; **Table 2**). One year later, Singapore passed a new amendment (Bill No. 15/2020) to its *Wild Animals and Birds Act* (Chapter 351, 2000). Despite the maximum prison sentence for wildlife offenses remaining low (i.e., two years) even with this amendment, the maximum fine has been raised considerably from the original SG$1,000 (US$750) to SG$50,000 (US$37,500). The regulatory scope has also been further expanded to include invertebrate species that are deemed threatened, dangerous or invasive.

At the regional level, ASEAN and its member-states committed in 2019 to meeting their obligations vis-à-vis the UN's Sustainable Development Goals, which include a call to action for governments to clamp down on environmental crime.[2] Alongside its Plan of Action for ASEAN Cooperation on CITES and Wildlife Enforcement (2016–2020), ASEAN has spearheaded some salient multilateral initiatives in this space. Both the ASEAN Working Group on CITES and Wildlife Enforcement (AWG-CITES), and the ASEAN Senior Officials Meeting on Transnational Crime (SOMTC) Working Group on Illicit Trafficking of Wildlife and Timber (WG-ITWT), were established to facilitate information exchange between state authorities and promote interstate cooperation.

The AWG-CITES was created during the 18th Meeting of the ASEAN Senior Officials for Forestry in 2016 by merging the previous ASEAN Wildlife Enforcement Network (ASEAN-WEN) and ASEAN Expert Group on CITES (DENR, 2019). The WG-ITWT was then formed during the 11th ASEAN Ministerial Meeting on Transnational Crime (AMMTC) in September 2017, following its endorsement at the 10th AMMTC earlier in 2015. With the trafficking of wildlife and timber recognized as new areas for transnational crime, the WG-ITWT has served to complement the work of the AWG-CITES in developing a coordinated response to wildlife and timber trafficking. In particular, special attention is directed to strengthening international and regional legal cooperation to crack down on transnational criminal syndicates (ASEAN Secretariat, 2019a). Within this ASEAN operational framework, interagency coordination between ASEAN member-states normally occurs through a national-level, multi-agency taskforce: for instance, the Wildlife Enforcement Network in Thailand and the National Wildlife Management Committee in the Philippines. These taskforces are generally mandated to coordinate law enforcement activities against IWT (ASEAN-WEN, 2016).

But despite the existence of these regional and national coordination networks, a recent assessment of select SEA countries (i.e., Indonesia, Singapore, Thailand, Vietnam) suggests that they have played a limited role thus far in helping to foster a coherent interagency and/or inter-governmental response to IWT (OECD, 2019). Indeed, the use of national multi-agency taskforces to coordinate investigations into and the prosecution of IWT cases remains infrequent at best. Due to a confluence of factors, including high coordination costs, inadequate expertise, and conflicting enforcement priorities, limited information has been exchanged between these national agencies (World Bank, 2016; OECD, 2019). Moreover, the AWG-CITES and its primary interlocutor—that is, the national-level CITES management authorities—continue to lack the capacity and resources to coordinate complex investigations (e.g., joint multi-national investigations or controlled deliveries) into wildlife trafficking, especially those involving transnational organized criminal groups. As a result, IWT cases with a transnational scope do not usually yield successful upstream or downstream investigations.

Furthermore, despite the involvement of anti-corruption and financial intelligence units in the multi-agency taskforces of several SEA countries (e.g., Indonesia, Thailand), investigations into the corruption and illicit financial transactions involved in IWT have rarely been conducted in the region. According to the OECD (2019), the main barriers to the uptake of anti-corruption and "follow-the-money" approaches to IWT can stem from how, for instance, IWT does not feature as a sufficiently high-level, policy priority; the penalty for IWT does not meet the minimum threshold for triggering investigations into alleged corruption; or there is a dearth of expertise, capacity, resources, and political will to undertake parallel financial investigations into IWT-related activities.

Consequently, successful prosecutions continue to be formed primarily on the basis of there being evidence of a wildlife trafficking offense, with evidence for convictions also dependent on the ability of authorities to catch criminals in the act (OECD, 2019). This is not to mention the potential issue of institutional overlap, where the *de facto* intersection of agencies' mandates may result in contradictory, duplicative or obstructive

[2]TRAFFIC. ASEAN commits to strengthening efforts to curb illegal wildlife trade. Available at: https://www.traffic.org/news/asean-commits-to-curbing-illegal-wildlife-trade/(accessed January 29, 2021).

policies. To avoid this problem, the WG-ITWT's work domain needs to be suitably distinct from that of the AWG-CITES in order to enhance their complementarity and reduce overlap (Broussard, 2017).

Key Developments in China

China has a complex regulatory system in place for the protection and management of endangered and threatened species as well as their habitats. This system is comprised of three main tiers of legal instruments: (1) national laws and regulations enacted by the National People's Committee, the State Council and its ministerial affiliates (e.g., NFGA); (2) local laws and regulations promulgated by provincial and other local-level legislative bodies and governments; and (3) legislative and judiciary interpretations and opinions released by the Standing Committee of the National People's Committee, the Supreme People's Court, and the Supreme People's Procuratorate (Cao, 2015, 2016).

The *Wildlife Protection Law* of 1989 (*WPL*; revised in 2016) serves as the backbone of China's wildlife governance framework. It sets out the fundamental mechanisms for the conservation of wildlife species and their habitats, administration of wildlife resource utilization, and the administrative liability and penalties for violations. While the *WPL* prohibits the hunting, catching, sale, and purchase of protected species and their products (including those species in the Special State Protection List and in CITES Appendix I and II), it does allow for exemptions pertaining to the utilization of protected species for a specified range of purposes (e.g., scientific research, captive breeding, epidemic monitoring, public exhibition, heritage conservation, or other special purposes). But to ensure that such exempted uses and trades are monitored and do not adversely impact the survival of wild populations, the *WPL* establishes various regulatory schemes such as business registration, quotas control, licensing, and special marking. Infringement of these prohibitive or restrictive measures can result in administrative sanctions, including the confiscation of wildlife contraband and illegal proceeds, license revocation, and fines of up to ten times the contraband's market value (e.g., *WPL*, Article 48). Acts causing serious harm are also considered criminal offenses under Articles 151 (wildlife trafficking), 340 (illegal fishing) and 341 (illegal hunting, catching, killing, purchasing, transporting, or selling) of the *Penal Code*. Criminal penalties may range from fines or property forfeiture, to fixed-termed imprisonment and a life sentence (**Table 2**).

In terms of domestic policy coordination, new interagency platforms have been created at both the central and local levels in recent years to strengthen the capacity of Chinese wildlife law enforcement officers. In December 2011, the National Interagency CITES Enforcement Coordination Group (NICE-CG) was established as a liaison mechanism to enhance the coordination among responsible government authorities in implementing CITES (NFGA, 2011). The NICE-CG consists of 12 departments from nine ministries, including the Department of Customs Control and Inspection, among others. The Department of Wildlife Conservation, which also hosts China's CITES Management Authority, acts as its coordinating body. Since its initiation, the NICE-CG has convened six annual joint meetings, through which representatives from member agencies are brought together to discuss and identify priority areas for CITES implementation, opportunities for multi-departmental joint law enforcement operations, and training programs for capacity-building (State Council, 2016). By December 2013, all 31 provinces (including municipal cities and autonomous regions) had established their own interagency CITES enforcement coordinating offices (CITES Secretariat, 2018).

In November 2016, another high-level interagency coordination platform—the Inter-ministerial Joint Meeting (IJM) on Combating Illegal Wildlife Trade—was formed with the approval of the State Council (NFGA, 2017). As of July 2020, some 27 ministerial departments are listed as members, with the NFGA designated as the coordinating agency. Joint meetings are held annually to analyze evolving trends in the illegal wildlife trade, review progress made and the major challenges faced by wildlife law enforcement, and set out the key tasks of each member agency (NFGA, 2019). Notably, in July 2020, policy priorities identified during the 3rd Inter-ministerial Joint Meeting included, *inter alia*, enforcing the decision passed by the Standing Committee of the National People's Congress on the total ban on consuming terrestrial wildlife as food (including both wild-caught and captive-bred sources); strengthening the monitoring and tracking of the online sale of illegal wildlife; and building a national platform for public reporting of wildlife offenses (NFGA, 2020). In this way, the IJM platform constitutes an enhanced version of the NICE-CG, one that covers a broader range of IWT issues and features a greater number of participating agencies that have high institutional rank.

This decentralized assemblage of biodiversity legislation and related policy actors notwithstanding, significant implementation and enforcement challenges remain within the Chinese regulatory system. A number of factors can be attributed to this state of affairs. For instance, despite efforts to mainstream and integrate environmental concepts such as "ecological civilization" (*Shengtai Wenming*) into policy practice, the Chinese government continues to prioritize economic values over ecological ones. Especially with the COVID-19 pandemic, economic recovery has yet again become the foremost policy preoccupation for the Chinese leadership. This may be further exacerbated by the "two-masters dilemma," whereby local forestry and environmental protection departments are often accountable less to their central ministries and more to the local governors who decide on their budget and staffing needs—and who traditionally care more about local economic growth targets than environmental sustainability (Li, 2007). This creates perverse environmental incentives on two levels: first, it has meant that the above-mentioned *Wildlife Protection Law,* as a pivotal piece of biodiversity legislation, is more concerned with the "rarity, particularity, and economic value" of a species as opposed to its value to the ecosystem (Yu and Czarnezki, 2013). Second, by focusing on the economic value of species, this arguably encourages a neoliberal outlook that treats the wildlife trade as a lucrative revenue source for the state and other non-state actors.

Aside from bureaucratic rivalry (the Ministry of Ecology and Environment is known for being one of the country's weaker ministries), funding shortages, and a lack of qualified personnel (Li, 2007; Wang and McBeath, 2017), concerns have also been raised over the vague language used in Chinese laws (McBeath et al., 2006). This results in not only unclear lines of authority, but equally unclear guidelines for how these laws are to be interpreted and implemented at the national and provincial levels. A notable example is the problematic interpretation of the term "other special purposes," which has allowed for the commercial farming and trade of protected species since the early 1990s (Sun, 2016).

As previously mentioned, alongside other exempted purposes, the *WPL* (both 1989 and 2016 versions) contains a licensable category for the utilization of state protected species stipulated as "other special purposes." But while this category should have in principle excluded any utilization for "economic purposes," as wildlife farming for economic purposes could have negative impacts on species conservation given the lack of means to distinguish between captive-bred and wild-caught specimens (Tensen, 2016), its inclusion has given rise to adverse unintended consequences. By inscribing economic purposes into the licensable scope, the 1991 *Measures for the Management of Licensing for Domestication and Captive Breeding of Wildlife under Special State Protection*—an NFGA-promulgated regulation for implementing the *WPL* that is still in effect today—had opened up a backdoor to the commercial farming of protected species and trade in farmed specimens. It is in this way that greater harmonization of Chinese domestic laws with the global legal and policy language, as reflected in UNTOC, could assist with enhancing China's domestic enforcement as well as creating a more solid basis for regional cooperation.

COOPERATION BETWEEN CHINA AND SEA TO TACKLE THE ILLEGAL WILDLIFE TRADE

Cooperation between China and SEA countries on environmental protection and non-traditional security issues has expanded considerably and become more formalized since 2002. Particularly in the areas of CITES implementation and combating wildlife trafficking, China has noticeably become more proactive in its cooperation with SEA countries over time. This has resulted in the establishment of bilateral and multilateral agreements, hosting of regional fora, organization of workshops and training sessions, as well as participation in transnational law enforcement operations. The effectiveness, and limitations of each of these mechanisms are discussed below.

Multilateral Agreements at the ASEAN Level

China and ASEAN's deepened cooperation on IWT and transnational crime has been pursued through a variety of institutional mechanisms and platforms that supplement the "ASEAN Plus China" arrangement. These include, for instance, the ASEAN Plus Three (APT) mechanism, which includes China, Japan and South Korea, and the East Asia Summit. Especially since the creation of the ASEAN-WEN in December 2005, several multilateral agreements and joint statements that directly target wildlife trafficking, or which acknowledge it as a major transnational crime threat within the region, have been signed between China and ASEAN. Notably, in November 2014, 18 countries—including China and ASEAN member-states—adopted the "Declaration on Combating Wildlife Trafficking" at the 9th East Asia Summit in Nay Pyi Taw. The Declaration recognized the severe and multifaceted repercussions caused by the illicit trade of wild fauna and flora, as well as the imperative need for a competent interagency response. Participating countries had then agreed to take action through, *inter alia*, regular dialogs, harmonization of relevant laws to support evidence exchange and criminal prosecution, and development of national interagency taskforces to strengthen interstate cooperation among source, transit and destination countries (CITES Secretariat, 2014).

Within the ASEAN Plus China and APT frameworks, cooperation on transnational crime issues (which includes wildlife trafficking) is largely conducted through the annual consultations held between the ASEAN Ministerial Meeting on Transnational Crime and China (AMMTC + China) and the Plus Three format (AMMTC + 3), as well as through affiliated Senior Officials Meeting on Transnational Crime. Work plans are developed every five years to serve as a principal guide for priority action areas. In September 2017, at the 5th AMMTC + China Consultation, China and ASEAN renewed their "Memorandum of Understanding (MOU) on Cooperation in the Field of Non-traditional Security Issues." As part of this agreement, both sides committed to developing practical measures to strengthen national and regional capacities for dealing with different types of transnational crime. These measures included sharing information on relevant legislative frameworks, intelligence sharing, personal exchange and training, as well as cooperation in such areas as evidence gathering, tracing of criminal proceeds, and the apprehension and investigation of criminal fugitives (ASEAN Secretariat, 2017).

Although the illegal wildlife trade was not explicitly listed among the transnational crime types prioritized in this MOU, inroads have since been made to incorporate wildlife trafficking into the purview of the AMMTC + 3. Adopted at the 18th APT Foreign Ministers Meeting in August 2017, the "APT Cooperation Work Plan (2018–2022)," for one, stressed the need to expand and deepen cooperation to address emerging forms of transnational crime, including trafficking of wildlife and timber (ASEAN Secretariat, 2018). In November 2019, at the 10th AMMTC + 3, the delegates reaffirmed their commitment to strengthen APT cooperation to prevent and combat transnational crime as articulated in the APT Cooperation Work Plan (ASEAN Secretariat, 2019b).

Regional Fora, Workshops, and Training Sessions

China has been providing substantial logistical support for capacity-building activities at the regional level—on occasion at the behest of SEA governments—through the organization and hosting of multilateral fora, workshops, and trainings with SEA countries. Although it is difficult to fully gauge the effectiveness of these efforts—building capacity is usually incremental and requires a longer timeframe—the fact that China has taken the lead in many of these initiatives is noteworthy in itself. Back in July 2012, for instance, China hosted the inaugural technical consultation meeting between NICE-CG and ASEAN-WEN in Nanning, Guangxi Province. Over 60 law enforcement officers from China and ASEAN member-states, as well as representatives from international organizations, were present to discuss pathways to enhance collaboration between the two largest wildlife enforcement networks in Asia. Recommended joint activities included information-sharing, public awareness-raising, and demand reduction (TRAFFIC, 2012).

Another example of collaboration took place in April 2016, when China's CITES Management Authority co-hosted a field mission with its Vietnamese counterpart and Laos' Department of Forest Inspection. The trip had frontline enforcement officers from the three countries visiting TCM markets and border ports that were believed to be key staging points in the region's main wildlife trafficking routes. The mission was intended to improve on-the-ground understanding of wildlife trafficking, exchange enforcement experiences, build relationships and encourage future cooperation by establishing direct communication protocols among the law enforcement agencies in the three countries' border provinces (WCS, 2016). This was then followed up with China-Lao and China-Vietnam training seminars, which focused on improving the direct contact mechanism for border enforcement agencies. Crucially, these exchanges would result in agreements to develop pilot communication schemes between the prefectural forestry police in Xishuangbanna and forestry inspection departments in Laos' northern provinces (TRAFFIC, 2016), as well as between the Chinese anti-smuggling office and forest police in Guangxi and their counterparts in adjoining Vietnamese provinces (NFGA, 2016).

2016 is thus an important year for regional cooperation. In the same year, the China-ASEAN Forestry Cooperation Forum was launched during the 13th China-ASEAN Exposition in Nanning. The forum adopted the "Nanning Proposal for China-ASEAN Forestry Cooperation," which identified five priority areas of cooperation, with the fourth being the conservation of wild flora and fauna and prevention of transboundary wildlife trafficking (Zhang, 2016). The momentum continued with the fourth Regional Dialogue on Combating Trafficking of Wild Fauna and Flora in 2017, which expanded upon three preceding dialogs on preventing the illegal logging and trading of Siamese rosewood. China pledged to join up with ASEAN, through offering training support, in regional efforts to curb the illegal wildlife trade (CITES Secretariat, 2017c).

These developments paved the way for the "Plan of Action for Nanning Proposal (2018–2020)," which was formally endorsed at the 21st ASEAN Senior Officials Meeting on Forestry in August 2018 (NFGA, 2018). As part of efforts to implement the Nanning Proposal, the China-ASEAN Wildlife Conservation Workshop was held in Sichuan, with some 20 participants from ASEAN member-states attending the training sessions and exchanging details on their respective wildlife laws as well as practices for controlling IWT (Eaaflyway, 2018).

Transnational Law Enforcement Operations

Considering the large number of seizures and arrests made by Chinese law enforcement each year, China's track record in cracking down on wildlife offenses domestically and intercepting illegal shipments at national borders appears consistent and promising. For example, official data reveals how between 2007 and 2016, Chinese forest police had handled a national total of 246,000 forest and wildlife-related criminal cases and two million administrative cases, leading to the apprehension of 3.9 million offenders and confiscation of 57.6 million animal individuals (NFGA, 2008–2017). Crucially, since 2010, China's wildlife enforcement units, including the CITES Management Authority, forest police and customs, have actively participated in a series of regional and international law enforcement operations with ASEAN-WEN and individual SEA countries. These joint operations have yielded significant seizures of illegal wildlife products and led to the detainment of hundreds of wildlife criminals. The most notable were "Operations Cobra I, II and III." Taking place between 2013 and 2015, the series was aimed at dismantling organized wildlife trafficking syndicates. Over the course of these operations, China played a leading role in proposing and co-organizing cross-continental crackdowns, sending its elite officers abroad to join international coordination teams to facilitate intelligence-sharing, as well as coordinating and conducting follow-up investigations and prosecutions (WCO, 2013, 2014; CITES Secretariat, 2015). Operation Cobra II, carried out between the end of 2013 and early 2014, also saw the first-ever, China-Africa sting operation, which resulted in the eradication of a major ivory trafficking racket and the extradition of a Chinese national from Kenya to China (WCO, 2014). However, as discussed below, the momentum from these joint operations is yet to be adequately built upon at the regional level in SEA.

Even though China and SEA countries have clearly taken considerable steps to boost their domestic interagency responses and regional engagement to tackle wildlife trafficking, especially in the last decade, cooperation among them on IWT remains limited in both scope and effectiveness. Despite the high-level commitment from both sides to ending wildlife trafficking, political will is yet to translate into a sustained and systematic course of action, with efforts largely concentrated in the policy and capacity-building domains. Current progress appears to have stagnated, for example, at the stage of exploring possible roadmaps for a communication mechanism between frontier wildlife law enforcement agencies in China and its SEA neighbors. Furthermore, China's abiding interest would seem to lie more with releasing policy agreements with ASEAN, hosting conferences and training workshops—that is, regional confidence-building measures. China's leadership in these areas—whilst pivotal to advancing its partnership with the ASEAN community—thus remains disproportionate to its prominent role as the region's largest end-user market of illicit wildlife products. This begs the question: how can China step up its leadership in this area and translate its regional institution-building efforts into a more impactful approach to dealing with IWT?

Greater traction is needed with regard to joint law enforcement operations and legal cooperation, more broadly, given how difficulties in investigating and prosecuting offenders in overseas jurisdictions continue to undermine efforts by the region's governments to combat wildlife trafficking. As revealed by court verdicts on criminal cases of wildlife trafficking,[3] an oft-seen practice of wildlife trafficking from SEA to China is one where organized criminal groups and offenders based in SEA countries (e.g., Vietnam)—some of whom may be Chinese immigrants or businessmen with contacts back in China (ACET, 2019; van Uhm and Wong, 2019)—would use Chinese social media (e.g., WeChat) to reach out to potential Chinese buyers. Once an order is received, they will prepare the illegal goods and arrange skilled smugglers to move the goods in circumvention of customs border checkpoints to designated places in Chinese border cities (e.g., Nanning). Contracted Chinese intermediaries are then either paid to handle the domestic transfer to buyers, or will buy up the goods and manage the sale themselves. In many of these cases, only the easily replaceable Chinese transporters and vendors are at risk of getting caught, whereas the ringleaders and criminal syndicates stationed in SEA countries are more likely to remain at large, perpetuating these supply chains.

STRENGTHENING LEGAL COOPERATION TO COMBAT WILDLIFE TRAFFICKING THROUGH INTERNATIONAL LEGAL TOOLS

Cooperation to fight IWT will necessarily have policy, regulatory and operational dimensions, and can take place at all points along an illegal chain of custody from prevention, interdiction to prosecution (Elliott, 2017). Disrupting illicit supply chains, therefore, requires that major countries of supply, transit and demand collaborate to dismantle the criminal networks that operate these supply chains across borders. In this section, UNTOC is leveraged as a framework for deepening China-SEA legal cooperation—and one that also suggests the utility of international legal instruments to combating transnational wildlife trafficking.

At present, the international legal regime for addressing IWT is fragmented. Although a substantial body of treaties, agreements, and declarations has emerged since the 1970s to better protect the environment and endangered wildlife (Trouwborst et al., 2017), none of them contain specific measures for the prevention and suppression of wildlife trafficking (Elliott, 2017). Existing international rules, obligations, and principles relevant to wildlife trafficking have arisen from multiple areas of international law, including international trade, environmental protection and conservation, organized crime and corruption, and animal welfare (UNODC, 2012; Slobodian, 2014; Lelliott, 2020). UNTOC is one such instrument that offers provisions applicable to tackling IWT. Indeed, in the Resolution under which UNTOC was adopted, the UN General Assembly affirmed how the Convention constitutes "an effective tool and the necessary legal framework for international cooperation" to fight the trafficking of endangered species of wild fauna and flora and other criminal activities (UN General Assembly, 2000).

In addition to the seven specific offenses stipulated by UNTOC and its three attached Protocols, the Convention also applies broadly to serious crimes committed by a transnational organized criminal group (Article 3.1).[4] According to the Convention, "serious crime" refers to an offense that is punishable in domestic law by "a maximum deprivation of liberty of at least four years or a more serious penalty" [Article 2(b)]. A crime is "transnational" when it is committed or prepared in more than one state, or committed in one state but involves criminal groups operating in other states, or causes substantial transboundary consequences (Article 3.2). "Organized criminal group" refers to a structured group of three or more people working in concert over a period of time to commit serious crimes for financial or material benefits [Article 2(a)]. Such structured groups do not need to have "formally defined roles for its members, continuity of its membership or a developed structure" [Article 2(c)]. As such, the Convention adopts a broad definition of organized criminal group, covering both loose networks of individuals connected by trade relationships or contracts, and highly integrated groups with more formal hierarchies and stable memberships (Boister, 2016; UNODC, 2016).

In many cases, wildlife trafficking between SEA and China would fall within UNTOC's remit for three main reasons. First, China and all ASEAN member-states are parties to the Convention; and except for Singapore, all countries have written into their domestic legislation a maximum prison penalty in excess of four or more years for wildlife trafficking (**Table 2**). This fact constitutes an important precondition for invoking UNTOC provisions. Second, SEA-China wildlife trafficking involves the illegal acquisition and movement across borders of wildlife products, which can cause far-reaching and adverse impacts on biodiversity, public health (i.e., zoonotic infectious diseases), and regional security. Third, while actors involved in IWT supply chains vary considerably in type (e.g., opportunistic, professional), numbers, and with the structures of the network within which they operate also subject to change depending on the species being traded or the presence of a legal market (Phelps et al., 2016; 't Sas-Rolfes et al., 2019), organized crime elements are known to have penetrated many transboundary wildlife trafficking operations (van Uhm, 2016; van Uhm and Nijman, 2020). More importantly, as noted above, UNTOC's conceptualization of an organized criminal group lends itself to a flexible definition that encompasses organized and corporate criminal groups that exhibit a high degree of

[3]China Judgements Online. Available online at: https://wenshu.court.gov.cn/(in Chinese) (accessed January 29, 2021).

[4]United Nations Convention against Transnational Organized Crime and the Protocol Thereto. Full text available online at: https://www.unodc.org/unodc/en/organized-crime/intro/UNTOC.html (accessed January 29, 2021).

organization and continuity, but also "disorganized criminal networks" made up of opportunistic individuals (e.g., harvesters, processors, intermediaries, smugglers, vendors, launderers) who are connected by fluid relationships of illegality (Wyatt et al., 2020). Against this definition, modern-day wildlife trafficking networks would qualify as organized criminal groups (Strydom, 2016; UNODC, 2020b).

The United Nations Convention against Transnational Organized Crime is thus highly applicable as a practical framework for tackling the illegal wildlife trade between SEA and China, especially with respect to overcoming the difficulties in investigating and prosecuting upstream perpetrators located in source and transit countries. Given China's striking track record in seizures and arrests (NFGA, 2008–2017), it is critical that China promptly and regularly shares intelligence (e.g., records of electronic communication and financial transactions) with law enforcement authorities in source and transit countries, in order to facilitate investigative efforts at following financial and other evidence trails for the prosecution of upstream offenders and organized crime groups in IWT supply chains. It is in this regard that UNTOC offers a host of tools that China and SEA could employ to bolster their cooperation in criminal justice and law enforcement to disrupt and dismantle IWT. These tools include general law enforcement cooperation and exchange of information (Article 27, 28); joint investigations (Article 19) and the use of special investigative techniques (e.g., controlled deliveries, electronic surveillance, undercover operations) (Article 20); international cooperation in confiscation (Article 13); formal mutual legal assistance (MLA) (Article 18) and extradition (Article 16). Certainly, the prompt sharing of information about the smuggling routes, concealment methods and false identities used by criminal groups is what renders early interception and seizure of illegal shipments possible.

The appropriate use of controlled deliveries can, moreover, help to track the route of trafficked wildlife to identify role players and ultimate beneficiaries connected with the criminal activities (INTERPOL and CITES, 2007). MLA in criminal matters also allows for the reciprocal provision of assistance in the servicing of judicial documents and gathering of admissible evidence for use in court cases. With respect to extradition, extraditing wildlife offenders from SEA to China for trial could, in principle, produce a stronger deterrent effect given how China currently has the harshest penalty for wildlife trafficking (i.e., life sentencing). Of course, any extradition agreement requires not only a deep level of legal cooperation but also mutual trust between the countries involved. In practice, agreeing on extradition terms between Southeast Asian governments and China is thus likely to be less than straightforward. However, even if a requested state were to refuse the extradition of an alleged offender to China (i.e., on the grounds that the offender is a national of their country), the request itself could still serve to reinforce the state's obligation under UNTOC [Art. 16(10)] to refer the case to competent authorities to initiate an investigation and, if applicable, prosecution of the alleged offender.

At the fifth Session of the Conference of the Parties to the UNTOC in 2010, UNODC's former Executive Director Yury Fedotov had expressed concern over how the Convention was used by only 12% of its member-states to ground international cooperation to fight organized criminal groups.[5] Owing to the lack of a review mechanism and the limited application of UNTOC to tackling IWT, limited evidence currently exists on how effective UNTOC is (Boister, 2016). Despite repeated calls to bring wildlife trafficking that involves transnational organized criminal groups within UNTOC's remit (e.g., UNESC, 2013; UN General Assembly, 2015; UNEP, 2016), the Convention remains underutilized (UNODC, 2020b). This is reflected in the low level of international cooperation on MLA and extradition in relation to wildlife trafficking. For example, Malaysia received only three MLA requests from foreign countries and had no outgoing requests during 2015–2016 (UNODC, 2017a). There has also been no reported use of MLA treaties or controlled deliveries in cross-border investigations to prosecute wildlife trafficking in Indonesia, Singapore, Thailand, and Vietnam (OECD, 2019). Moreover, certain SEA countries (e.g., Indonesia, Malaysia, Myanmar) have challenged the legitimacy of UNTOC as a legal basis for international cooperation on extradition (UNODC, 2008). As for China, MLA requests issued by the Ministry of Justice have increased only slightly from eight in 2011 (MOJ, 2012) to 24 in 2017 (Statista, 2020).

Although there is yet to be a systematic review of the challenges that constrain the use and utility of UNTOC vis-à-vis SEA-China legal cooperation on IWT, this paper posits that obstacles are likely to include: limited resources, weak rule of law in relevant countries, government corruption (Elliott, 2017), a lack of suitable guidelines and protocols for the content and scale of cooperation (UNODC, 2017b), gaps in the coverage of nationally protected species that result in the priotitization of indigenous species protection (Broussard, 2017), as well as discrepancies in the definition of "organized crime groups" and the penalty threshold for serious crimes. Indeed, it warrants note how the legal definition of organized criminal group still varies considerably between SEA countries and China, specifically in terms of the threshold for the minimum number of group members and minimum prison terms. For instance, Malaysia's *Penal Code* 2013 defines organized criminal group as a group consisting of two or more people for the commission of offenses carrying imprisonment of at least ten years (Article 130u), whereas Singapore and Thailand employ a definition that is more in line with UNTOC. In contrast, China refutes the presence of typical organized criminal groups within its territory. Instead, its *Penal Code* 2017 (Article 294) develops a new concept termed "organizations with underworld characteristics" to describe criminal organizations that have a relatively large number of gang members with clearly defined roles (e.g., organizers, leaders, core group members), and which pursue economic gains through the repeated commission of organized crimes or other illegal activities with violence, threats or other means (Chin and Godson, 2006; Cai, 2017).

[5]Yury Fedotov. International cooperation: the key to halting organized crime. Conference of the Parties to the United Nations Convention against Transnational Organized Crime and its Protocols, Fifth Session, Vienna, October 2010. Available online at: https://www.unodc.org/unodc/en/about-unodc/speeches/2010-10-18.html (accessed January 29, 2021).

CONCLUSION

Tackling the SEA-China illegal wildlife trade undoubtedly necessitates a concerted effort among the major centers of supply, demand and trade involved in global wildlife trafficking (Esmail et al., 2020). Considering the scale, complexity, and severity of the IWT problem in Asia, a multifaceted response is required of the Chinese and SEA governments—individually and collectively. In this way, it is not sufficient to focus only on tackling market demand for contraband wildlife products or cracking down on illegal smuggling rings. Here, the chief objective of any coordinated, interstate effort within the IWT domain should also be to disrupt and dismantle the criminal networks that underpin the cross-border supply and trade of protected wildlife. Following this, the paper argues that China and the ASEAN community should seek to leverage the cooperation outlets offered by UNTOC and use these to supplement existing bilateral and multilateral arrangements. More specifically, it posits two specific areas wherein China and its SEA neighbors could focus on to improve their legal cooperation.

First, China should proactively act in accordance with UNTOC [e.g., Article 18(4), (5)] to share with SEA countries information critical to combating IWT, even when the data has not been explicitly requested. For rapid and secure data-sharing, the use of systems such as CENcomm,[6] developed by the World Customs Organization, could be promoted among customs authorities, while the creation of direct cross-border communication mechanisms between other frontline operational units should also be prioritized. Second, the harmonization of domestic criminal laws and procedures across countries and in line with UNTOC should be undertaken, specifically with respect to the definition of what constitutes an organized criminal group and the penalty threshold for serious environmental crimes. Third, beyond UNTOC, it is crucial that China, individual SEA countries and ASEAN as a whole continue to advance bilateral and multilateral agreements for MLA, extradition (which presently exists between China and only half of SEA countries; **Table 2**), and other forms of legal cooperation. Here, bilateral agreements that address wildlife offenses whose maximum penalty imposes less than four-year imprisonment could serve to supplement UNTOC provisions that apply to serious crimes only. Equally important is for these countries to work together to develop detailed guidance on how such legal cooperation is to happen, with national contact officers clearly designated and law enforcement procedures streamlined.

With the COVID-19 pandemic having raised awareness and concern across the region about the health security implications of possible zoonotic diseases, transnational cooperation to help strengthen local interagency coordination and the rule of law in China and Southeast Asia is imperative to dismantling the illegal wildlife trade—as well as to protecting the region's imperiled biodiversity.

AUTHOR CONTRIBUTIONS

YJ and PY did the data collection, analysis, and writing. All authors did the study design and manuscript revisions and reviewed and approved the final manuscript.

FUNDING

This work was supported by research grants from Sun Yat-sen University (20wkpy08) to YJ, from the National Talent Research Program in China (grant nos. 41180944 and 41180953) and the European Commission Grant ENV/2018/160130/2 to TL, and from the Australian Research Council (DE180100603) to PY.

ACKNOWLEDGMENTS

We thank Sarah Wilson for helping us with data compilation, and three reviewers for their constructive feedback.

[6] World Customs Organization. Customs Enforcement Network Communication Platform (CENcomm). Available online at: http://www.wcoomd.org/en/topics/enforcement-and-compliance/instruments-and-tools/cen-suite/cencomm.aspx (accessed January 29, 2021).

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

frontiers in Ecology and Evolution

METHODS
published: 03 March 2021
doi: 10.3389/fevo.2021.587896

To Trade or Not to Trade? Using Bayesian Belief Networks to Assess How to Manage Commercial Wildlife Trade in a Complex World

Elizabeth L. Bennett[1]†, Fiona M. Underwood[2,3]† and E.J. Milner-Gulland[4]*

[1] Wildlife Conservation Society, Bronx, NY, United States, [2] Independent Statistical Consultant/Researcher, Taunton, United Kingdom, [3] National Trust, Swindon, United Kingdom, [4] Department of Zoology, University of Oxford, Oxford, United Kingdom

Edited by:
Krithi K. Karanth,
Centre for Wildlife Studies, India

Reviewed by:
Nicolas Salliou,
ETH Zürich, Switzerland
Divya Vasudev,
Wildlife Conservation Society, India

***Correspondence:**
Elizabeth L. Bennett
lizbennettwcs@gmail.com

† *These authors have contributed equally to this work*

Specialty section:
This article was submitted to Conservation and Restoration Ecology, a section of the journal Frontiers in Ecology and Evolution

Received: 27 July 2020
Accepted: 15 February 2021
Published: 03 March 2021

Citation:
Bennett EL, Underwood FM and Milner-Gulland EJ (2021) To Trade or Not to Trade? Using Bayesian Belief Networks to Assess How to Manage Commercial Wildlife Trade in a Complex World. Front. Ecol. Evol. 9:587896. doi: 10.3389/fevo.2021.587896

International commercial trade in wildlife, whether legal or illegal, is one of the greatest threats to multiple species of wildlife today. Opinions on how to address it are deeply divided across the conservation community. Approaches fall into two broad categories: making the trade illegal to protect against any form of commercial trade or allowing some or all of the trade to be legal and seeking to manage it through sustainable trade. The conservation community is often deeply polarized on which is the better option. We posit that a way to choose between these options is by considering species-specific attributes of biological productivity, management context, and demand. We develop a conceptual framework to assess which option is more likely to result in successful conservation of a species. We show how to construct a Bayesian Belief Network (BBN) to model how these attributes (1) interact to affect the sustainability of the species' population and (2) vary under different trade management regimes. This approach can support scientifically based decision-making, by predicting the likely sustainability outcome for a population of a species under different trade management regimes, given its particular characteristics and context. The BBN allows identification of key points at which conservation interventions could change the potential outcome. It also provides the opportunity to explore how different assumptions about how humans might respond to different trade regimes affects outcomes. We illustrate these ideas by using the BBN for a hypothetical terrestrial mammal species population and discuss how the BBN can be extended for species with different characteristics, for example, those that can be stockpiled or when there are multiple products. This approach has the potential to help the conservation community to assess the most appropriate regime for managing wildlife trade in a transparent, open, and scientifically based way.

Keywords: Bayesian Belief Networks, commercial wildlife trade, resolving controversies, decision support tools, terrestrial mammals

INTRODUCTION

Setting the Scene

International commercial trade in wildlife, whether legal or illegal, is one of the greatest threats to wildlife today (Butchart et al., 2010; Nijman, 2010; Duckworth et al., 2012; Challender et al., 2015; Eaton et al., 2015). It affects multiple species, from timber and ornamental plants, to corals, to marine and terrestrial vertebrates. In spite of the threat that trade poses to the species, their ecosystems and the benefits that flow from them, opinions on how to address this threat are deeply divided across the conservation community. A key question is how to conserve a species when it is in international trade, but that trade is not sustainable.

We focus here on terrestrial mammals harvested from the wild for international commercial trade, although the general principles apply to other taxa. Terrestrial mammals are traded internationally for food and as pets, and their parts are traded for ornamental use (e.g., ivory, claws, teeth, musk), clothing (skins, furs), and traditional medicines (e.g., tiger bones, bear gall bladders, pangolin scales). Some 915 species of terrestrial mammals are listed on CITES Appendix I or II, so are in trade and deemed to require management; approximately 40% of these are on Appendix I, so considered threatened with extinction unless all international commercial trade is prohibited (data extracted from CITES, 2019).

We consider wildlife trade to be unsustainable if harvested populations, taken in aggregate across the species' range, show a consistent decline in numbers, are reduced to densities where they are vulnerable to local extinction, and populations no longer fulfill their ecological and socioeconomic roles (adapted from Bennett and Robinson, 2000). Unsustainable trade, by definition, threatens the survival of the target species, and also the biodiversity of their habitats, since mammals hunted for trade are often keystone species which act as pollinators, dispersers, browsers, and ecosystem engineers (e.g., Waldram et al., 2008; Blake et al., 2009; Estes et al., 2011; Ripple et al., 2014). Increasingly, intact forests with their full faunal communities and ecological functions are also seen as crucial to tackling climate change (Bello et al., 2015; Peres et al., 2016; Berzaghi et al., 2019). Many traded species are important resources for local people, and their loss may threaten the livelihoods of some of the world's poorest and most marginalized people (e.g., Cooney et al., 2015). For very high value species, illegal international trade may be linked to organized crime, and present security threats to local communities and regional governance (Wyler and Sheikh, 2013; Duffy and Humphries, 2016).

Approaches to Conserving Species in Demand From Trade

Approaches to conserving species in demand for commercial trade fall into two broad categories; making the trade illegal to protect against any form of commercial trade (domestic and/or international), and allowing some or all of the trade to be legal and seeking to manage through sustainable trade, either local, international or both. As a particular species becomes increasingly threatened by trade, the conservation community is often deeply polarized on which is the better option, especially for high profile, charismatic species (e.g., Walker and Stiles, 2010; Wasser et al., 2010; Roe et al., 2014; Biggs et al., 2017; Felbab-Brown, 2017; Moyle, 2017).

Proponents of a sustainable commercial trade argue that wildlife will only be conserved if it has a legitimate economic value, to mitigate against converting natural habitats to farmland (e.g., Stiles, 2004), to give incentives to local people to conserve wildlife (Bulte et al., 2003; Child, 2012; Biggs et al., 2013; Cooney et al., 2015), and so that the proceeds of high-value sales can support conservation efforts that benefit the species concerned, and other species, and offset the costs of enforcement (Child, 2012; Biggs et al., 2013; Di Minin et al., 2014). Further, sustainable trade to meet high levels of demand is proposed as a way to overcome negative cycles of increasing prices in underground markets that can occur with restricted legal trade, with resulting poaching and violence ('t Sas-Rolfes, 2000; Challender and MacMillan, 2014).

In addition to ethical concerns (e.g., Pastor, 2010), opponents of trade argue that the presence of any markets creates demand that cannot be met sustainably (Maisels, 2012; Lusseau and Lee, 2016). If legal supplies are limited, this increased demand might spill over into an illegal market, especially if consumers cannot easily distinguish between legal and illegal products. Further, the presence of legal markets potentially makes smuggling and sale of illegal goods easier because illegal supplies can masquerade as legal ones. Corruption-enabled laundering of illegitimate items into legitimate markets also means that protection of the species across parts or all of its range is challenging (Gabriel et al., 2012; Bennett, 2015).

The pro-trade and anti-trade proponents are often deeply entrenched in their views, partly due to underlying differences in philosophy (Roe et al., 2014) and values (Biggs et al., 2017), making discussions surrounding CITES Conferences of Parties, for example, often extremely heated, with little room for compromise (e.g., McGrath, 2013; Kahumbu, 2015).

Assessment of the relative merits of each approach is hampered by the fact that, for terrestrial mammals, both are currently largely failing (Felbab-Brown, 2017). Indeed, it is rare to find an example of a species of terrestrial mammal with any level of commercial demand whose wild population has been stable or increasing over the past 20 years. Compared to many other plant and animal taxa, productivity of mammals is relatively low, especially of the larger species with low reproductive rates and long maturation times (Robinson and Redford, 1986; Read and Harvey, 1989). If such species face high levels of commercial demand for lethally harvested products, conservation is challenging, whichever strategy is employed. This is especially true for high-value species whose illegal trade often involves organized crime networks, facilitated by high levels of corruption (Wyler and Sheikh, 2013). Indeed, circumnavigating wildlife trade regulations is often characterized as high profit and low risk (Goncalves et al., 2012; Wyatt and Cao, 2015). Agencies responsible for wildlife management around the world are notoriously under-staffed and under-funded (Bennett, 2011), and the absence of strong institutional structures gives the opportunity for over-exploitation (Fischer, 2010).

Examples of trade bans leading to stable or increased populations of terrestrial mammals are scarce, and causation is often hard to attribute given that species generally face multiple, interacting threats. The fur trade was clearly the major threat to many species of big cats, and has declined greatly since they were listed on Appendix I of CITES in 1975 (IUCN, 2000), and hunting for trade is no longer their primary threat (e.g., Caso et al., 2008; Goodrich et al., 2015), with the possible exception of the snow leopard in parts of its range (McCarthy et al., 2017). Full legal protection and a CITES Appendix I listing of the giant otter (*Pteronura brasiliensis*) allowed the species gradually to recover in the Peruvian Amazon (Uscamaita and Bodmer, 2010). Trade bans are not always successful, however. The announcement of trade bans can stimulate trade prior to their coming fully into effect as people anticipate the ban (Rivalan et al., 2007), and can subsequently send trade underground rather than stopping it (Rosen and Smith, 2010). All international commercial trade in the Sunda pangolin (*Manis javanica*) and Chinese pangolin (*Manis pentdactyla*) has been banned since 2000 when CITES established zero export quotas for both species and subsequently listed both species on Appendix I; yet between 1996 and 2014, the status of both on the IUCN Red List of Threatened Species went from Least Concern to Critically Endangered, almost entirely due to illegal hunting feeding into international trade due to the combination of lax enforcement and corruption (Challender et al., 2019a,b).

Examples of sustainable international trade in terrestrial mammals leading to conservation of the target species are also scarce. International trade in fur-bearing animals from the US and Canada is well managed, and the current strict management program has contributed to the recovery of various species from historical unregulated trade (White et al., 2015). The best documented example of a single population of a species being conserved under a sustainable trade regime is skins from collared (*Tayassu tajacu*) and white-lipped (*T. pecari*) peccaries from the Peruvian Amazon, used in high-end gloves and shoes in Europe (Bodmer and Puertas, 2000; Bodmer and Fang, 2016); the impact of such trade on the species in other parts of their range is unclear but is probably not great since demand for skins in international markets is limited, and largely supplied by legal trade. Both of these examples involve intensive management and monitoring at multiple levels, with highly controlled hunting and trade, and rigorous monitoring programs along the trade chain including, in the latter case, a sophisticated chain of custody program. Other examples of long-term successful conservation of species in trade are scarce. One case previously deemed a success was the vicuña (*Vicugna vicugna*). Vicuña wool is in demand for high-end trade, and by 1994, over-hunting had reduced their numbers to about 5,000 animals. This resulted in all trade being banned under CITES. Programs of live-shearing by local communities for sale to international markets were then introduced, with local communities regarding the species as a valuable local resource, enabling them to benefit from trade. This led to successful conservation of some populations of the species, and their being downlisted to CITES Appendix II; by 2010, numbers had increased to more than 200,000 animals (McAllister et al., 2009; Lichtenstein, 2011). However, since then poaching has increased significantly because the open markets allowed the laundering of wool from illegally hunted animals since hunting is cheaper and easier than live-shearing, and hunters threatened local communities who anyway were only gaining a small percentage of the end-market price The situation was compounded by porous international borders and weak legislation (Nuwer, 2015). Hence, although the species' status has been lowered to "Least Concern" by IUCN, conservation programs and tight control of the ongoing legal wool trade at local, national and international levels are deemed essential for the species' continued viability (Acebes et al., 2018). Although this example is one in which animals do not need to be killed for their products to be traded, there are not many other situations in which live-harvesting of products to supply legal trade is possible. This is because the acquisition of most products (e.g., bones and tusks) leads to the death of the animal or, in the case of pets, removal from the wild. There are a few other instances, e.g., rhino horn, where live-harvest is possible; in these cases productivity over the life time of the animal can be much greater ('t Sas-Rolfes and Fitzgerald, 2013).

One core reason why neither approach has been unambiguously successful in conserving species is that both trade bans and management of a regulated trade depend on high levels of management along the trade chain, especially if biological productivity is low and demand is high. Bans require the ability to prevent hunting, trafficking and illegal sales of wildlife along trade chains. Various localized examples show that strict site-based protection can result in successful conservation of species demanded in trade (e.g., Linkie et al., 2015; Global Initiative against Transnational Organized Crime, 2020), although such examples are rare. Sustainable trade requires transparent management and rigorous, long-term monitoring to ensure that offtakes are truly sustainable, and management capacity at all points that can easily distinguish legal, sustainably sourced items from unsustainably or illegally sourced ones. At all parts of the trade chain, the presence of organized crime presents a further management challenge, especially in the context of high levels of corruption. Such criminals are more likely to be involved in trades in items with high individual values, but those could be either species for which there is no legal trade (e.g., rhinos), or ones with potential parallel legal and illegal trades (e.g., musk deer).

In this paper, we posit that there is way to choose between the two options; by disaggregating the issue, we can develop a framework to assess which approach is more likely to result in successful conservation of any particular species. We first describe three categories of attributes of species and their management, and how these might be expected to affect the outcome of either legalizing or banning trade, as reflected in biological sustainability at the species level. We then introduce a modeling framework which would enable users to explore how these attributes interact to produce different outcomes for the two options. Recognizing that these attributes require joint consideration (Cooney et al., 2015), we use a Bayesian Belief Network (BBN) (McCann et al., 2006). This both recognizes the interactions between attributes, and allows identification of key points at which conservation interventions could change the potential outcome. We show how this framework could be used to support scientifically based decision making, by predicting the likely outcome in terms of the sustainability of a population of a hypothetical traded species under different trade management regimes.

Our approach does not model how human behavior will change in response to different management regimes within the BBN. Much of the controversy around the wildlife trade concerns how humans will behave in response to particular decisions and circumstances (Walker and Stiles, 2010; Roe et al., 2014; Biggs et al., 2017). Given that we are building a decision support tool, we did not want to hard-wire human behavior into the model, because this then builds in the controversies, rather than enabling users to step back from them. Instead, our approach makes it possible to explore how outcomes could differ depending on the assumptions being made about human behavior. For example, does a species population remain sustainable if we assume that consumer preferences change when a ban is implemented? What happens if consumer preferences do not change? The model allows the testing of such questions, and many more.

Over time, we hope that the model will be applied to different species with various types of trade structure, since solutions have to be customized to specific conditions (Felbab-Brown, 2017). As that happens, the model itself will inevitably evolve to incorporate other attributes, with different emphasis on those attributes of most importance to the species under consideration. Finally, we suggest next steps for operationalizing this model.

KEY SPECIES ATTRIBUTES AND THEIR RELEVANCE TO MANAGEMENT OPTIONS

The attributes relevant to management of a species in demand for commercial trade are complex, inter-related and influence each other. IUCN (IUCN, 2000) categorized attributes relevant to sustainable use into productivity, management control, and demand. We tweak those categories into: biological productivity, management context, and demand.

Different species in trade vary greatly according to these attributes (**Figure 1**). Hedgehogs are not in demand for trade, are subject to negligible management, and have a relatively high productivity. By contrast, peccary skins are traded, they also have relatively high productivity, management of the trade from the Peruvian Amazon is intense and of a high standard, and demand for the skins in international trade is relatively low (Bodmer and Fang, 2016). This combination of attributes means that trade is sustainable (Bodmer and Puertas, 2000; Bodmer and Fang, 2016). Productivity of vicuna wool is also relatively high since the animals do not have to be killed to acquire it, yet management in some areas is failing, and demand for the wool relatively high. Under this combination of attributes, trade overall is becoming unsustainable (Nuwer, 2015). Productivity of ivory from African elephants is extremely low (Maisels, 2012; Lusseau and Lee, 2016), management to prevent poaching and trafficking is also low across much of the species' range, and demand for ivory over the past ten years has been extremely high (UNEP et al., 2013). That combination of attributes has led to unsustainable trade and major declines in elephants across large parts of their range, though not all Maisels et al., 2013; Thouless et al., 2016; CITES, 2017). North American bobcat and lynx are killed for their furs, but as cats they are relatively fecund, and management is sufficiently good that exploitation remains sustainable (White et al., 2015). Productivity of both Chinese and Sunda pangolins is low, management along the trade chain extremely poor, and demand for meat and scales very high; the result has been catastrophic declines of both species (Challender et al., 2019a,b).

Any species could be situated within **Figure 1** and its location will change as different policies affecting management or demand are enacted. For a species with low biological productivity and high demand, improving management should lead to a more sustainable future for a species. In comparison, if productivity of the traded item is high and demand is low, management might not need to be so intense for the species to be sustained. This characterization is useful in gaining a first insight into how different species might perform, and which species are most at risk, but it does not assist decision makers in determining whether a regulated trade or a ban is likely to be more effective at ensuring long-term conservation of the species. That requires a probabilistic comparison of the two approaches within a modeling framework, which allows for: (1) investigation of how changing any attribute feeds through the system to affect the potential outcome; and (2) understanding which of the attributes are most important for ensuring sustainable management of the species populations across their range.

MODELING APPROACH

We propose that construction of a modeling framework would allow for an objective discussion around management options. A challenge in doing this is that data for many species on some or all of the attributes are poor, and also people's views on what are the most important determinants of outcomes differ, e.g., whether enforcement or local community involvement is more critical to effective site-based management. So a framework is needed which is flexible enough to include these different views and can incorporate uncertain knowledge. This framework should be applicable to a wide range of different species threatened by unsustainable trade. It should also be transparent and easy to visualize the results, allowing users who might have divergent views to explore different policy options and see their likely outcomes.

Here we demonstrate how a Bayesian Belief Network (BBN) may provide an appropriate modeling framework for describing the interactions between the different attributes of the wildlife trade, for comparing different management strategies for traded wildlife, and how these strategies might impact the sustainability of a given species' population. We describe the key components of a BBN and how it could be applied to understanding the wildlife trade. The BBN we present is for illustrative purposes and

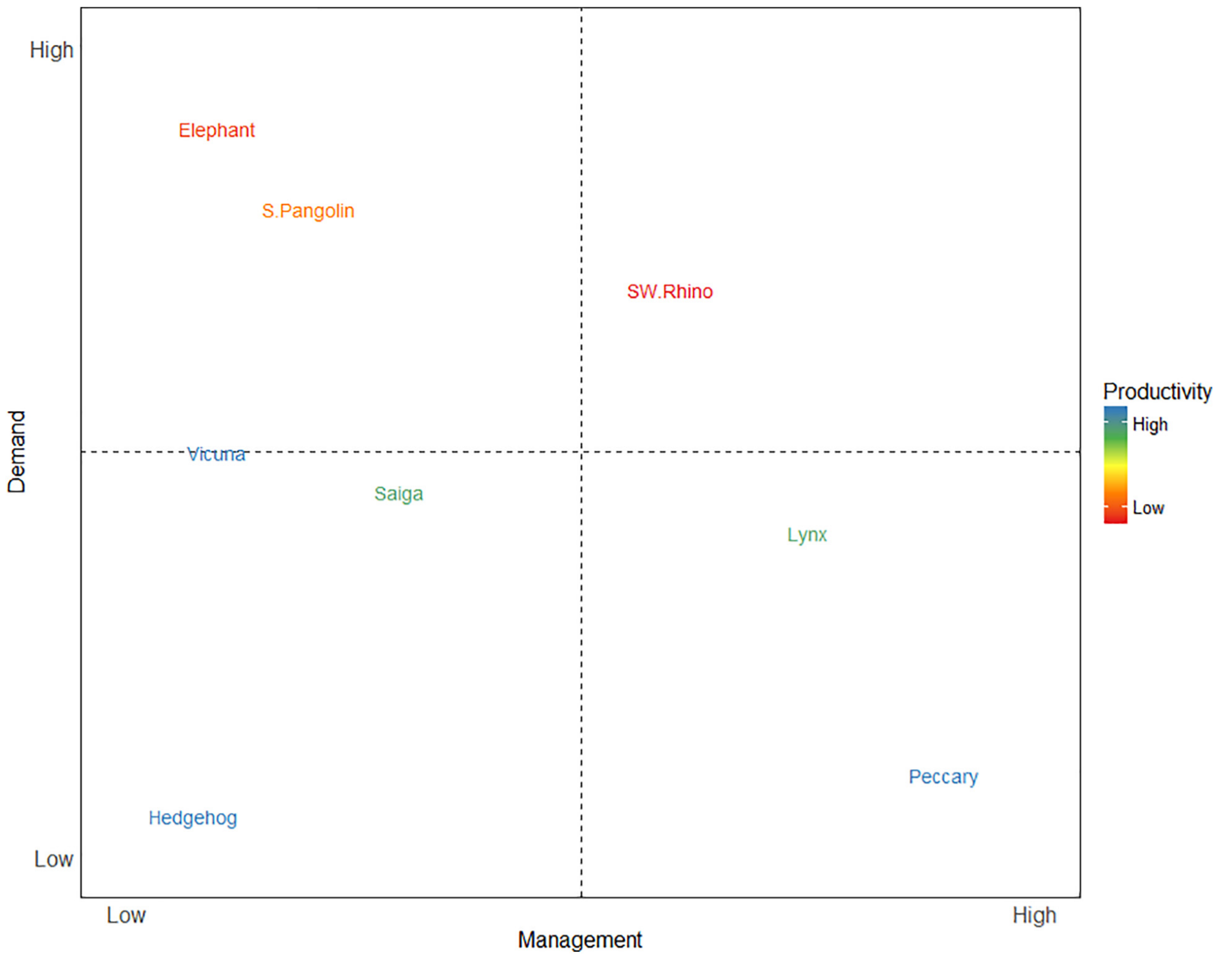

FIGURE 1 | Productivity, demand, and management for different species (S. pangolin = Sunda pangolin; SW rhino = southern white rhino). Species are likely to have a more sustainable future if the demand is low and the management effectiveness is high, but the relative importance of these, hence which policies should be adopted, depend on productivity. This figure does not help in determining whether a trade ban or managed legal trade will be more effective at improving species sustainability. It does highlight which species are most likely to need help—those in the top left corner with low productivity. Please note, these results are illustrative and qualitative.

does not capture all of the subtleties of actual scenarios. Neither does it include any real data because at this initial stage we wish to present a general concept and framework for consideration, rather than focusing on the potentially distracting specifics of any one species or set of species. Hence, we demonstrate its basic purpose and outline, then discuss how such a tool could be developed in practice and applied to specific cases.

Bayesian Belief Networks are simplified models that capture probabilistic relationships between variables (Cowell et al., 1999; Jensen, 2001; Aguilera et al., 2011). They have been applied to problems in natural resources management (Cain, 2001; McCann et al., 2006; Castelletti and Soncini-Sessa, 2007; Zorilla et al., 2009) and risk assessments of wildlife populations (Marcot et al., 2001; Pollino et al., 2007). Koen et al. (2017) used a BBN to understand rhino poaching in Kruger National Park. They have also been proposed as a strategy for understanding the illegal ivory trade (Burn et al., 2003; Martin et al., 2012). BBNs are particularly useful for contentious and data-poor situations, because they are relatively easily visualized and so are a good foundation for participatory modeling in which the effect of differing assumptions about attribute identities, values and interactions can be explored by knowledgeable researchers and practitioners (Düspohl et al., 2012; Saliou et al., 2017).

Structure of the BBN

The first step is to build the structure of the BBN. This requires identification of the different variables in the model, the values that they can take, and indicates which variables are related to each other (but not how). The different variables in a model (e.g., population density, illegal offtake, and demand) are represented in a BBN as **nodes**. The actual nodes can be modified as the BBN for any one species and type of trade is developed, so this is illustrative of the general approach. Each node can take several

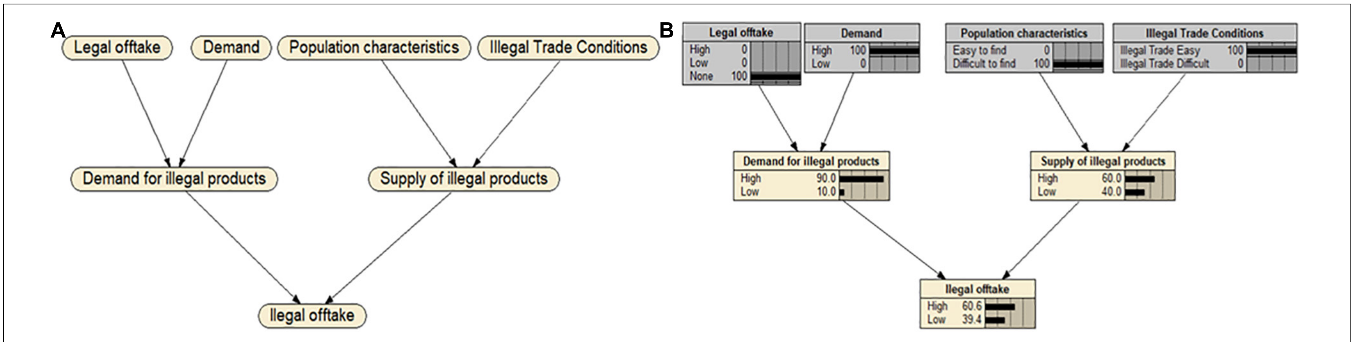

FIGURE 2 | Example of a small BBN which could form part of the BBN for the illegal wildlife trade. **(A)** The relationship between different nodes. **(B)** The states of each node and the probability of being in each state. The gray boxes show findings—where the states of the nodes are set. Here, there is a 60.6% chance that Illegal offtake is high when there is **no** *Legal Offtake*, *Demand* is **High**, *Population* is **Difficult to find,** and *Illegal trade conditions* are **Easy**. These are illustrative probabilities only. The Basic Model section provides further reasoning for this BBN.

values—known as **states**. A node might have only two states; e.g., in **Figure 2**, the node *Illegal Offtake* might only take the values high and low, or it could be a continuous variable with an infinite number of states. Dependencies between the different nodes are represented by directed **edges**. For example, the arrow from the nodes *Illegal Demand* and *Illegal Supply* to *Illegal Offtake* indicates that these first two nodes have an influence on *Illegal Offtake.* Illegal offtake could be the point at which illegal supply and illegal demand curves intersect and the nodes describe these curves and their intersection. The node *Illegal Offtake* is then described as a child of its parents: *Illegal Demand* and *Illegal Supply*. Cyclical relationships are not allowed as they are logically impossible, although it is possible to represent feedbacks using a dynamic BBN where for example offtake in one timestep is a function of demand in the previous timestep. The nodes, their states and the directed edges represent the structure of the BBN. This structure is also known as a directed acyclic graph (DAG) or graphical model (Pearl, 1985).

Quantifying the Relationships in the BBN

The relationship between nodes, as indicated by the directed edges, may be deterministic or, more usually, specified by a Conditional Probability Table (CPT). Each child node has a CPT that describes the conditional probability that the node is in a particular state, given the states of all its parent nodes. The CPT for the child node depends only on its parents and no other nodes in the BBN; not even its grandparents. For example, in **Figure 2** if *Illegal offtake*, *Illegal supply* and *Illegal demand* each only have two states—high and low—then the probability that *Illegal offtake* is high is 0.20 if *Illegal Supply* is high and *Illegal demand* is low. The full set of conditional probabilities for this example is given in **Table 1**. The CPTs do not need to know about the state of grandparent nodes, for example *Illegal Trade Conditions* or the probability that overall *Demand* is high. This powerful property of BBNs, known as **conditional independence** (Jensen, 2001), makes it possible to construct complex BBNs out of many small sub-models, because only the direct relationships between children and their parents need to be quantified.

Building the BBN

Constructing a BBN is a trade-off between providing enough detail to capture the main features of the trade, and not becoming too detailed and unwieldy. Typically BBNs are constructed by thinking about outcomes of interest—in this case whether a population is sustainable—and then identifying the variables (parent nodes) that influence these outcomes. This becomes an iterative process as the parents of these variables are then identified. The BBN's construction can be informed by a series of conceptual models built at different scales or different groups of experts and stakeholders Cain (2001).

Bayesian Belief Networks work best when nodes each have small numbers of parents, and, unless they are continuous, when nodes have few states; otherwise it can be difficult to define the CPTs, or the BBN may become intractable (as highlighted by Marcot et al., 2001).

Developing a working BBN would require engaging a group of experts to refine our provisional model (shown in **Figure 3**). Koen et al. (2017) describe a process by which BBNs could be developed and built by experts. For our BBN, experts would, for example, assist in: (1) clarifying the structure of the model, the main linkages and those about which there is debate; (2) identifying strategies for obtaining the CPTs to quantify the relationships between these different components; and (3) validating the BBN

TABLE 1 | Example of a Conditional Probability Table (CPT) for the node *Illegal Offtake*.

Illegal supply	Illegal demand	
	High	**Low**
High	0.90	0.20
Low	0.30	0.00

*The table shows hypothetical values of the probability that Illegal Offtake is **High** given the states of the nodes Illegal Supply and Illegal Demand. These CPTs could be based on expert judgment, data, or from economic models of supply and demand. Using economic models, the State **High** for Illegal Supply could suggest a particular relationship between quantity and price of products. The relationship may be different when Illegal Supply is **Low**. Similarly, there may be different demand curves depending on whether Illegal Demand is **High** or **Low.***

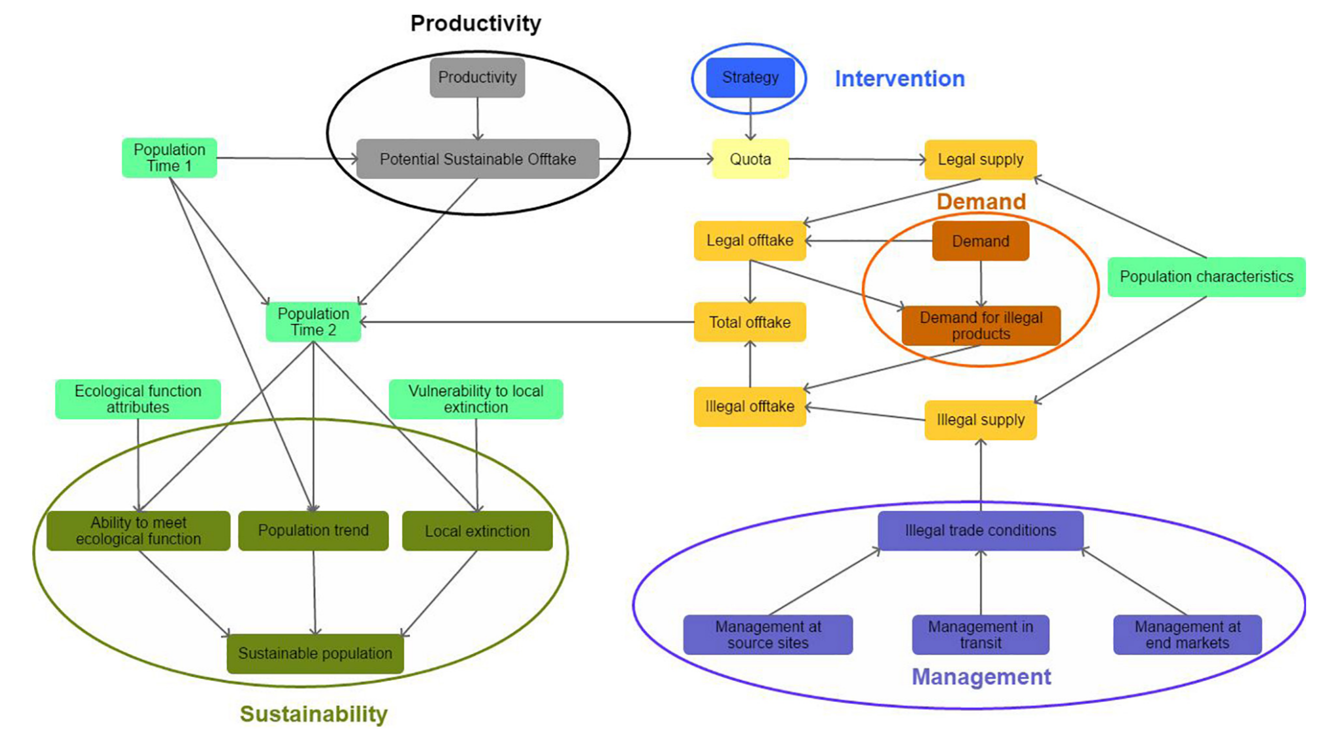

FIGURE 3 | BBN representing the relationships between productivity, demand and management on the sustainability of the population. Nodes describing biological characteristics are colored bright green and nodes colored bright yellow describe supply and offtake.

to ensure that it realistically reflects trade in the particular species concerned.

A variety of strategies can be used to obtain the CPTs. Because of conditional independence, different parts of the model can be constructed using different data sources and types of information. Analysis of primary data might provide insights into some components of the model (Halls et al., 2002; Underwood et al., 2016), while the scientific literature may provide information on other links (Johnson et al., 2014). Where there are data and knowledge gaps, which might suggest future research priorities, consultations can elicit the CPTs from experts (Cain, 2001; Ticehurst et al., 2011). As an example, Koen et al. (2017) used a combination of expert knowledge, scientific literature and data sources to populate the CPTs of their BBN.

Once a model has been constructed and tested, the CPTs for a given species can be updated as new information becomes available, using BBN learning (e.g., Neapolitan, 2004). This might be particularly useful when there is limited current information for a particular species and more information arrives over time.

Using the BBN

Once the CPTs have been specified, probabilistic inference can be used to "interrogate" the BBN to answer different questions. That is, given the state of one or more nodes, known as **findings**, the probabilities of the states of all other nodes in the network can be calculated. There may be one or more nodes of particular interest, often called **target** nodes. Like findings, target nodes can fall anywhere in the BBN. Three different types of questions can be asked. The first is **predictive reasoning**—the likely outcomes of a child node given the states of parent nodes with no ancestors. In **Figure 2B**, an example of predictive reasoning is given, showing the probability of high and low illegal offtake for a species that is difficult to obtain and for which there is high demand, no legal trade and it is easy to trade the species illegally. **Diagnostic reasoning** is the converse - what is the most probable state of preceding nodes given the known state of a node with no children. For example, using the small subnetwork in **Figure 2**, what combination of legal offtake, demand, ease of obtaining the species and illegal trade conditions is best in order for illegal offtake to be low? A third type of question is **sensitivity analysis**—for example, whether the probability of high levels of illegal offtake changes more when the amount of legal trade changes or when the ease of illegal trade changes.

MODEL

Basic Model

Figure 3 is a representation of how our framework might look for a single species, traded for a single purpose, and for which there is no stockpiling of the traded products. The aim of this BBN is to model how an intervention (in this case, implementation of either a sustainable trade regime or a ban) might affect a population. In a simple model, this could be the total population of the species as a whole, but it might be necessary to model individual populations, especially for species with broad distributions if management varies greatly across their range. The BBN is dynamic because it considers the size of the population prior to the intervention (*Population_T1*) and then models the change in the population numbers due to the intervention to give the population in the next timestep (*Population_T2*). The effect of the intervention on the population is measured by our definition of sustainability—specifically what is happening to the population trend, whether the population is vulnerable to local extinction, and whether it fulfills its ecological functions. All three outcomes are affected by the size of the population after the intervention (*Population_T2*) and its other characteristics.

It is important to recognize that the timesteps in this BBN are not the same as those in many standard models that represent system dynamics (such as a population model or harvesting model, in which annual timesteps may be used to represent population change over time, and therefore infer the sustainability of harvesting). In our BBN, the nodes and links represent a cumulative understanding of the system's dynamics (e.g., the trend in population size), in order to infer sustainability for decision-making purposes. The second timestep represents what happens to the sustainability of the system as a result of an intervention (such as a trade ban), enabling comparative analysis of policy scenarios. The BBN could be extended to include further time-steps, iterating this process, to investigate, for example, the impact of different sequences of interlinked policy interventions. These further timesteps therefore would refer to time-periods over which the sustainability outcomes of given intervention(s) are being considered. They could be short-term, such as a year, or long-term, such as several decades, depending on the speed of system change in response to interventions and the resolution of the relevant datasets.

The change in population size between the two time periods due to the intervention is captured by the relationship between *Total Offtake* and *Potential Sustainable Offtake*. The latter is a function of *Productivity* and *Population Size*, assuming that the population is otherwise stable and not affected by major habitat loss or environmental pressures such as drought. *Total Offtake* is a combination of both *Legal Offtake,* where relevant, and *Illegal Offtake* (assuming that other sources of human-induced mortality, such as problem animal control or habitat loss, are accounted for in productivity estimates, or modeled as separate components or nodes in a more complex model). Both legal and illegal offtake can be modeled as a function of the supply of and demand for goods.

One approach to legal supply is to set a quota determined by potential sustainable offtake which depends on productivity and the current population. Legal supply also depends on other population characteristics, which determine how easy it is to harvest individuals (the catchability). For example, if the quota is high but catchability is low (for example, because the species is cryptic), then supply will be lower. In our simple example, we assume that demand is first met from legal sources, then any unmet demand becomes a demand for illegal goods.

Beyond the biological productivity of the species, the supply of illegal goods depends mainly on illegal trade conditions. The occurrence and scale of illegal trade depends on management at source sites, transit routes and markets. For example, if demand is high but management along the trade chain is good, it is difficult for illegal goods to be obtained, transported and sold and illegal offtake will be low. Hence, management regulates the supply of illegal products.

Using predictive reasoning, the BBN could answer a question such as: for a species with a small population, low productivity, high demand, good management and a trade ban in place, what is the probability that the population can be maintained sustainably? Diagnostic reasoning could be used to answer a question such as: what is the best configuration of productivity, management structure, demand and trade regulation that would allow a population to be managed sustainably?

More generally, questions combining predictive and diagnostic reasoning can be asked, making it possible to investigate:

(1) the changes to the sustainability of the population under either a ban or regulated trade, given the current management structure, demand and biological productivity of the species;
(2) the best strategy for sustaining the population, given its biological productivity and current management structure and demand;
(3) the best configurations of productivity, current management and demand for maintaining sustainable populations under either a ban or regulated trade.

Components and Extensions of the Model

Although the model that we present here is tentative and preliminary, it captures our key proposition: that by considering the mechanisms by which productivity, demand and management interact, we can investigate how different conditions affect the sustainability of the population and the relative effectiveness of a ban or managed trade for a particular species. Many aspects of the model shown in **Figure 3** would need further expansion for it to allow anything other than the most basic type of enquiry. For example, the BBN models a species rather than a product, since it is the conservation of the species that is the primary management goal. The model described above considers a single species which is traded for a single purpose. To model a species traded for multiple purposes, (e.g., pangolin meat and pangolin scales) and/or by different consumer groups, which might therefore also potentially follow different trade routes, the BBN would need separate nodes for each product and/or consumer group and/or transit route which then combine to a species-level node for offtake. More generally, the BBN can capture information about different source populations, varying degrees of management along different parts of a trade route and different consumption patterns in more or less detail, depending on the spatial and temporal resolution at which the model is to be used.

The model could also include other threats that act on the species, or be extended to include drivers of productivity, management and demand. This can be important because it is often these underlying threats and drivers, rather than the implementation of a ban or regulated trade, that conservation bodies can influence and that ultimately will influence the outcome. As such it helps to be able to understand the relative importance of different drivers. To illustrate this, we here describe some potential drivers of productivity, management and demand and how they would be represented as ancestors of these nodes in the BBN.

Total Productivity

The base level of biomass productivity [measured in kg of the traded product(s)] varies greatly with habitat; in comparison to tropical grassland and savannah habitats, for example, tropical forests have a very low potential productivity of mammal biomass/km^2 (Robinson and Bennett, 2004). Within this, the productivity of individual species is a function of their life history, and of the history of exploitation in a given site. If a species occurs in multiple different locations, underlying productivity may vary between locations due to different ecologies or exploitation histories, potentially requiring a BBN that incorporates multiple locations in order to draw species-level conclusions.

Productivity also depends on whether the animal has to be killed to obtain a traded item. If the species can be live-harvested (e.g., for wool and horn), productivity (in terms of biomass per individual) may be higher. A white rhino can produce eight times as much horn in its lifetime if the horn is live-harvested periodically than if the animal is killed for a one-time harvest ('t Sas-Rolfes and Fitzgerald, 2013).

Expanding the BBN to recognize drivers of productivity could include parent nodes for carrying capacity and the rate of population increase. The total standing population is a function of population density and geographic range and these could, potentially be included as parent nodes of the population size node. These parameters would relate only to that part of the population that can be traded.

Management Context

The management context is critical in determining the ability to manage legal supplies and control illegal ones. Weak management at any point in the trade chain potentially undermines both regimes of no trade or regulated trade. For example, management at sites where trade is permitted might be good, but if management at sites where trade is not permitted is poor, illegal trade can still occur, based on animals sourced from these other sites. As such, the BBN may need separate nodes for different source sites, transit routes and end markets.

Various attributes could be included in the model to represent the quality of management. These could include the capacity of the management agency (e.g., government or non-government agency, local community, and private landowner). Alternatively, the model could use a composite measure of capacity as captured in tools such as Protected Area Management Effectiveness (PAME) (Coad et al., 2015). Along the trade chain, whilst in transit, the primary management responsibility generally lies with customs agencies. At the market end of the trade chain, in many countries, the legal responsibility for enforcement often lies not with the wildlife authorities, but with transportation or urban authorities whose training and focus on wildlife management is negligible (Bennett, 2011).

In our example BBN, a first set of nodes could describe whether managers have:

(1) the legal mandate to manage—for example, whether local communities have clear legal ownership rights over the wildlife resources at sites;
(2) the capacity to manage – including the funding, technical skills, equipment, staffing levels and leadership needed to operate.

A second set of nodes could describe how effectively management can operate both legally and in general, given the mandate and resources. These factors describe the environment within which managers are operating and can apply to specific sites or to countries or regions. For example:

(1) Legal effectiveness. Without a legal framework such as the presence of appropriate legislation, a functioning judiciary and prosecution process, there is no ability to enforce a ban or manage a legal trade. Thus, two source sites from different countries might fall under the same legal mandate to manage the site, but if the legal framework is not in place, their mandate is not meaningful;
(2) Management effectiveness. Management effectiveness depends on the environment within which agencies are operating, especially the levels of governance and corruption. Corruption among government officials charged with implementing wildlife-related legislation plays a major part in facilitating illegal wildlife trade (Elliott, 2007; United Nations Office of Drugs and Crime [UNODC], 2010; Milliken and Shaw, 2012; Bennett, 2015; Smith et al., 2015; Wyatt and Cao, 2015; Felbab-Brown, 2017), both for species for which all commercial trade is illegal, and also those with a managed legal trade with the potential for illegally obtained items to be laundered into a legal market (Bennett, 2015). Thus, two source sites could have the same management capacity and the same legal mandate in countries with the same legal framework but could function very differently because of differing levels of corruption. Levels of corruption could be represented by the World Governance Indicators (World Bank, 2011). Other variables describing the socio-economic environment within which management is operating, such as GDP, inequality, and levels of poverty and alternative livelihood opportunities, may also be relevant here.

These nodes would share children with variables describing the capacity for management and the presence of a legal mandate to provide overall measures of management ability to control illegal trade.

A further set of attributes which affects the ability of management to control the illegal trade relates to properties of the product itself and how easy it is to identify. Specifically:

(1) Is it distinguishable from similar products from different species? If products look similar but have different legal status, it is difficult for managers to ensure that illegal products are not passing along the trade chain. This could be included in the BBN by including a node that represents

the ease of identifying the species, or product. One parent of this *Ease of identifying species* node could be the legal status of other similar products in trade.

(2) Geographic range: For species with large geographic ranges spanning many countries, the challenge for management is greater if items from unsustainable or illegal sources are to be prevented from entering trade chains with sustainable, legal ones. Species with broad geographic ranges might have larger total populations hence more able to support a sustainable trade (Cooney et al., 2015), but ensuring that all of that trade is from legal and sustainable sources over a wide area is challenging. Thus geographic range might have an influence on the effectiveness of trade route management in addition to its effect on potential sustainable production.

Additional attributes might be specific to source, transit or end markets. For example, at source sites it might be important to include a node that describes whether local communities benefit in some way from the wildlife and wild lands, whether through some regime of sustainable offtake, or from non-consumptive uses such as tourism. Management of transit routes could potentially include a node that describes the number of potential trade routes – whether egress from a site is only through one mountain pass, or across multiple highly porous borders. Distance from a porous international land border could potentially be a node to describe ease of management at markets.

Demand

Many different factors affect the level of demand for a species. Three key factors are:

(1) Consumer preferences. These can be positive - an item is preferred because it is fashionable, prestigious, and/or fulfills cultural needs. They might also be negative, if the item is socially unacceptable. Rarity of a species can also affect consumer preferences; some species are in demand because of their extreme rarity, and can fetch high prices (Courchamp et al., 2006). Conversely, consumers might prefer to buy common species if they believe that they are not harming the population;

(2) Availability of acceptable substitutes. This determines elasticity of demand (Conrad, 2012). If alternatives are available, then once price goes above a certain level, demand for the species will drop as people seek alternatives. If acceptable substitutes are not available, for example, if buyers seek an item from the wild that has no substitutes because of its extreme rarity or due to the cultural belief in its unique medicinal efficacy, then demand might continue to increase even if prices are extremely high (Verheij et al., 2010; 't Sas-Rolfes and Fitzgerald, 2013);

(3) Wealth in the end-market. A key driver of demand is the degree of poverty or wealth in potential markets. For example, increased per capita spending in China is correlated with increased poaching of elephants in Africa (CITES, 2012).

In the BBN, demand could therefore be separated into three separate nodes describing consumer preferences, availability of alternatives and consumer wealth. The BBN aims to model a species rather than a product, since it is the conservation of the species that is the primary management goal. Thus, if a species is used for multiple purposes, for example pangolin meat and pangolin scales, and/or by different consumer groups, the BBN would need separate nodes for each product and/or consumer group, which then combine to a species-level node for offtake.

Extending the Model to Include Stockpiles

The BBN described in **Figure 3** could be extended to be relevant to species whose trade involves stockpiles of the products. Non-perishable wildlife products can be stockpiled by globally distributed networks of buyers (Eriksson and Clarke, 2015). For mammals, such products include tusks, horns and, to some extent, furs and pelts. Stockpiles can act as a buffer between consumers and biological populations, leading to a time delay between changing demand and offtake. This can lead to a less clear signal between supply and demand. Thus the BBN could be extended to represent a three-time-step process so that the consequences of this buffering can be more easily measured.

Some stockpiles are owned and managed by governments, or other bodies which are registered or legally managed. In theory, at least, there is a clear mechanism by which products from stockpiles enter the trade chain. There is, however, evidence of leakages from government stockpiles entering the trade chain (CITES, 2016). Other stockpiles, sometimes legal sometimes not, are in the hands of private speculators, who keep products as investments in the expectation of future price increases; such increases are highly likely as a species becomes rarer and as it approaches or even reaches extinction (Mason et al., 2012). The BBN would therefore need to differentiate between these different types of stockpiles, the mechanisms by which products enter the trade, and the different ways that this buffers the link between supply and demand.

Modeling Controversies Around the Impacts of Different Interventions

Identifying the appropriate strategy for managing the trade in different species is controversial. A benefit of BBNs is that once one has been set up for a particular species, it is relatively quick to investigate the effect of different strategies on the population, and therefore to explore potential options with a group of stakeholders holding different views. The BBN does not test whether or not a particular hypothesis about the effect of trade or bans on species sustainability is correct. Rather, it provides a framework for examining what would happen under different management options, and evaluates how sensitive the species' sustainability is to different scenarios. For example, what might happen to the populations of a specific species if it is down-listed from CITES Appendix I to CITES Appendix II, given different assumptions about consumer preferences and the resources available for management?

We demonstrate the power of a BBN to explore this and similar questions using a slightly expanded version of our model of a hypothetical traded species (**Figure 4**), including some of

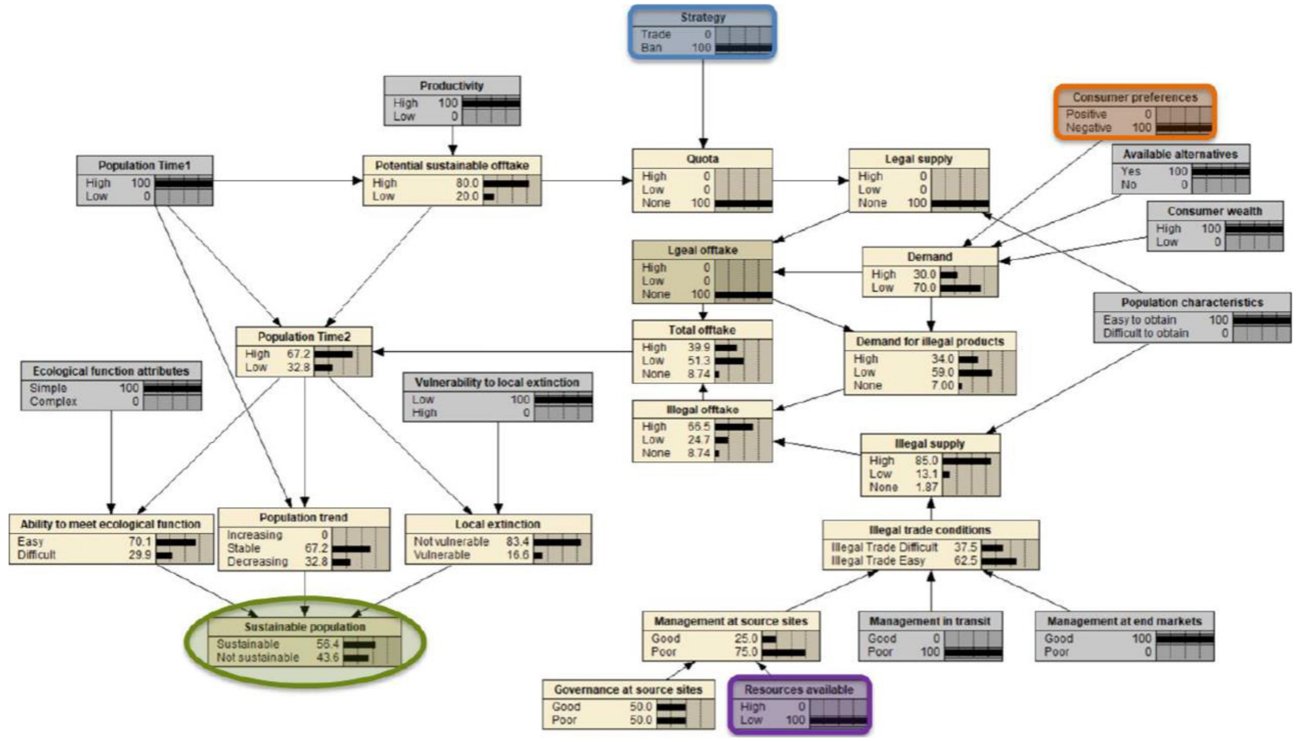

FIGURE 4 | Illustrative expanded BBN from **Figure 3** with additional nodes to represent how some of the drivers of demand and management could be represented in the model. The BBN shows the (hypothetical) probability of a sustainable population for a particular species with a particular set of findings (gray boxes) under a trade ban. Gray nodes are where the state is fixed and known. Yellow nodes show calculated probabilities for each state given the fixed states of the gray nodes. This BBN is a reduced and simplified model, all nodes only have two or three discrete states, only two time periods are included, and all relationships are simple. Note that all probabilities used to construct this BBN and shown in the figure are illustrative only.

the drivers of management and demand. This model shows a species with high productivity, and high population prior to the intervention, where consumer preferences are negative, alternative products are available, management at transit sites is poor, and few resources are available for management at source sites. Given these findings (the gray boxes), probabilities of the states of other nodes are calculated (the yellow boxes). The probability that the population is sustainable under a trade ban is calculated to be 56%.

Figure 5 shows the results from using the hypothetical BBN of **Figure 4** to explore the probability that populations of two different species are sustainable under different trade strategies. The only two interventions considered are regulated trade or a trade ban. For both species, under a trade ban, the probability that the population is sustainable, (given negative consumer preferences and low resources) is 56% (point A in **Figure 5** and as shown in **Figure 4**). If the *Strategy* changes to Trade, but all else remains the same (**Figure 5** point B), for Species 1 the probability that the population is sustainable declines to 35%. For Species 2, however, the probability is the same at 56%. This would suggest that for Species 1, Ban is better than Trade but for Species 2 both strategies are equally good, assuming all else remains constant.

However, disagreements about which is the best strategy are often due to different assumptions, or hypotheses about which drivers are also expected to change when a particular strategy is implemented, e.g., whether allowing legal trade will lead to changes in consumer preferences or availability of resources for management at source sites. For Species 1, **Figure 5** shows that the probability that the population is sustainable is always higher under a Ban than under Trade, irrespective of *Consumer Preferences* and *Resource Availability*. However, for Species 2, to determine how other drivers are expected to change as a result of a change in trading strategy, discussions are needed to identify the best outcome for the species. For example, one hypothesis might be that switching to Trade also leads to positive *Consumer Preference*s. Then the probability that the population is sustainable drops to 35% (**Figure 5** point C). If a further hypothesis is that the effect of switching to Trade also leads to the *Resources Available* for management of source sites increasing from low to high, the probability the population is sustainable increases to 75% (**Figure 5** point D).

Hence, even if different stakeholders disagree about what other changes will occur under a different trade strategy, the BBN could help them agree that it will not affect the overall outcome for the species (as for Species 1). Alternatively, the BBN might indicate that changing the trade regime has no effect on the sustainability of the population but other drivers, reflected in another part of the BBN (e.g., management at sites), are more critical. In other cases, the choice between a ban or legal trade could lead to very different probabilities that the species population is sustainable,

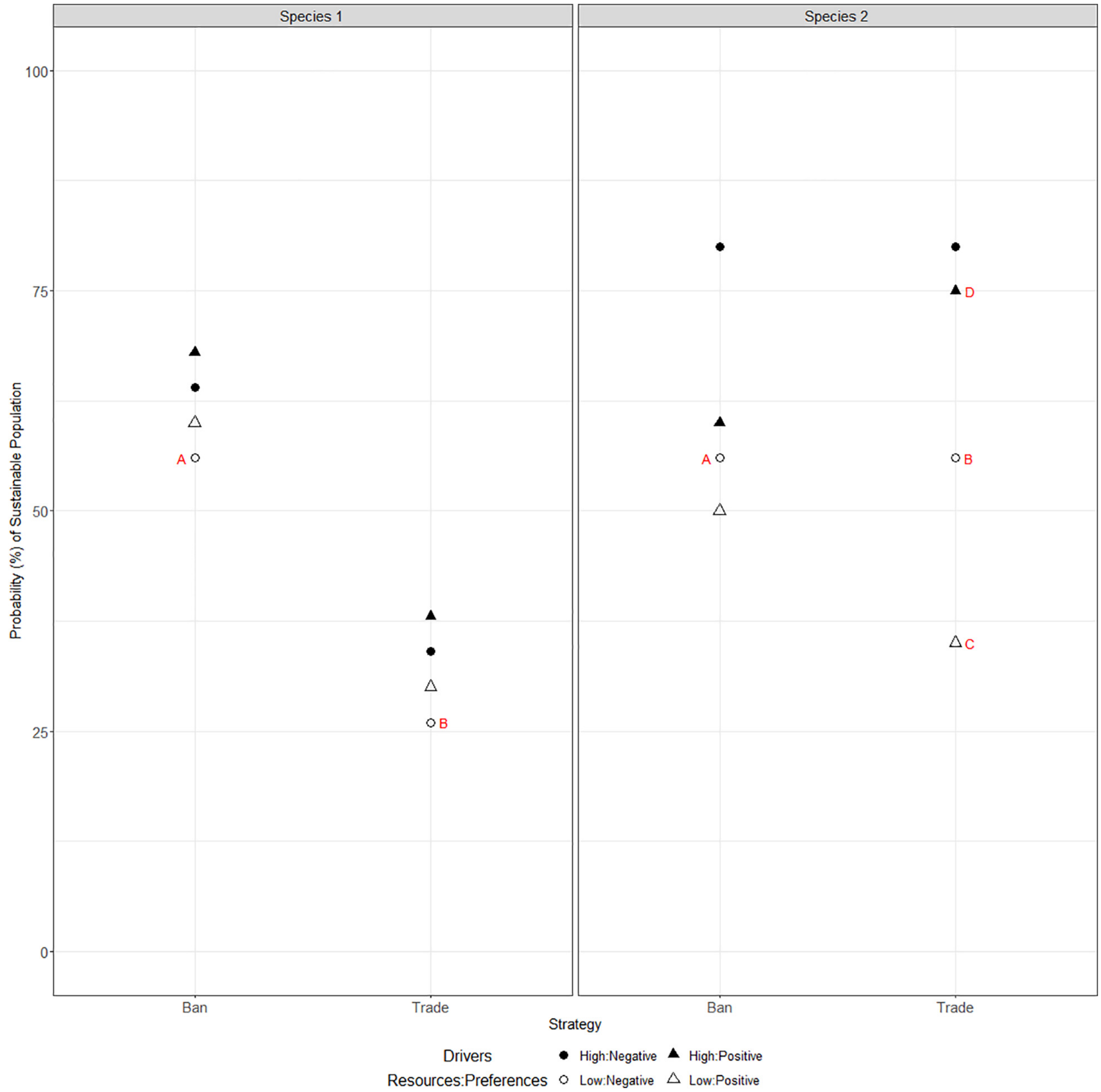

FIGURE 5 | Hypothetical probabilities (as percentage) that two different species are sustainable under two different Strategies (**Ban** or **Trade**), given different combinations of the drivers: *Resource Availability* at source sites either **High** (filled symbol) or **Low** (empty symbol) and *Consumer Preferences* are either **Negative** (circle) or **Positive** (triangle). The probability that either species is sustainable when *Resource Availability* is **Low** and *Consumer Preferences* are **Negative** is point A when *Strategy* is **Ban** and point B when *Strategy* is **Trade**. For species 2, point C shows the probability under **Trade** when *Consumer Preferences* are **Positive**. Under point D *Resource Availability* is also **High**.

depending on beliefs about what else will change as a result of a change in trade regime (as for Species 2). This could suggest that further work, and potentially a more refined modeling approach, are needed to understand which hypotheses are most likely.

Modeling Uncertainty

There are three main sources of uncertainty in a BBN. The first (1) is that relationships between variables are probabilistic—i.e., given the states of a particular set of nodes, outcomes are not predicted with certainty. This is modeled inherently by the BBN. The other two depend on the model components, specifically (2) structural uncertainty—our understanding of which variables and drivers to include in the BBN and how they affect each other (the linkages between nodes) and (3) parameter uncertainty—our knowledge about the values of the CPT that describe the relationships between nodes.

In some cases, controversy might arise around these model components. For example, views on the importance (reflected in the CPT values) of each of the parents of the *Demand* node (**Figure 4**) might differ. In this case, one would examine how changing the CPTs affects the outcomes of interest. This might suggest that further research is needed to obtain better evidence about what the CPTs should be. Alternatively, it might indicate that changing the CPTs in this part of the BBN network does not materially affect the outcome, so is not a research priority.

One constraint of a BBN is that the CPTs do not have estimates of uncertainty attached to them. Thus although BBNs can be used to better understand and model complex problems, identify knowledge gaps, prioritize future research and evaluate management options (Johnson et al., 2014), they would need to be complemented by other approaches if the uncertainties in the probabilities need to be captured for decision making. Strategies for estimating these uncertainties have been proposed (Van Allen et al., 2008; Donald and Mengersen, 2014), but they are not currently available in standard BBN software. This current limitation on BBNs does not, however, undercut the value of the general approach of constructing a BBN and exploring it to investigate the relationships between species productivity, different aspects of management and demand, in order to assess impacts of different policy decisions on the sustainability of species' populations.

DISCUSSION

Discussions around whether or not a particular species should, or should not, be subject to a sustainable trade are often divisive, and the contrast between the approach and even the language of the pro- and anti-trade proponents in the literature is great. Both are concerned about the implications of unsustainable trade for conservation, but the pro-trade literature focuses on empowering and incentivizing local communities and benefiting source countries (e.g., Cooney et al., 2015), and the anti-trade literature on increasing enforcement and supporting criminal justice systems (e.g., Wyatt and Cao, 2015).

Models can help to move us beyond such entrenched value-based assumptions to a scientific discussion, giving another way to look at an issue (Addison et al., 2013; Biggs et al., 2017). Models do not provide definitive answers, but provide a framework that can help resolve difficult issues by identifying assumptions, and estimating probabilities of success for alternative actions based on the best available information (Starfield and Beloch, 1991; VanderWerf et al., 2006). BBNs are a potentially powerful tool for presenting and investigating problems and communicating solutions, because they make it possible to explore the consequences of different decisions (Uusitalo, 2007; Korb and Nicholson, 2010). Most importantly, they provide a transparent basis for a logical discussion and dialog between proponents of different viewpoints (Bromley et al., 2005). All interested parties can examine the values of the different attributes for a particular species, the structure of the BBN and the CPTs, and jointly see the potential outcomes of a particular course of action. For example Henriksen et al. (2012) demonstrated how BBNs could be used as a way of communicating and engaging with different stakeholders about groundwater management in Spain.

We have described a broad framework to capture how the outcome for a species population of a particular strategy (ban or sustainable trade) is determined by the interaction of three components: biological productivity, management context and demand. We have shown how this framework can be turned into a BBN to allow us to examine the likely outcome for the population of a species in demand in trade if we implement a program of sustainable use, or a partial or total trade ban, given the current attributes of the species, management context, and demand attributes. The BBN can be used to assess which strategy is more likely to succeed in conserving a species, given the particular characteristics of that species and the context. It can also help us to examine what needs to be changed to make a particular trade regime succeed in conserving the species, or whether other drivers which might respond to a change in trade regime could impact the outcome for a species. If the BBN shows that under current conditions, populations are unlikely to be sustainable under either trade bans or a sustainable trade regime (as is currently the case for many species), the model can help to identify what needs to change to result in a successful outcome for each approach. Furthermore, the BBN can be used to assess whether particular assumptions about how human behavior responds to particular trade regimes impact on the outcome.

This is the first attempt to construct a BBN to assess the impact of different options for managing wildlife trade on species populations. The BBN presented here is simple, to convey the basic principles involved. It could potentially be used for any species in a relatively quick-and-dirty way, by setting appropriate values for the nodes (e.g., productivity low, management low, and demand high). A more complex BBN could also be built to reflect the biological and trade characteristics of an individual species. The former might be useful for general discussions about the trade, while the latter might be useful for those trying to manage a particular species. An operational BBN for use on a real species would need to be constructed through expert debate and a consultative process.

The current model was developed for terrestrial mammals, but the basic principles can be applied to any other taxonomic group. Hopefully, this approach could help the conservation community to move beyond the rancor which can typify debates, and instead allow us to assess the most appropriate regime for managing trade in species of both conservation and commercial value in a transparent, open and scientifically based way.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

AUTHOR CONTRIBUTIONS

EB was primarily responsible for the wildlife trade literature review and providing species-specific examples and information. FU was primarily responsible for the model literature review and developing the BBN. EM-G brought the group together and provided critical thinking to improve the manuscript throughout. All authors contributed to the article and approved the submitted version.

FUNDING

EB was funded by the Wildlife Conservation Society and a Biodiversity Fellowship at the Interdisciplinary Centre for Conservation Science, University of Oxford. EM-G was funded by the Oxford Martin Programme on the Illegal Wildlife Trade.

ACKNOWLEDGMENTS

We thank Bob Burn and John Robinson for discussions and comments on drafts of the paper, and to the two reviewers for their comments.

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

ORIGINAL RESEARCH
published: 12 March 2021
doi: 10.3389/fevo.2021.608057

Exploitation Histories of Pangolins and Endemic Pheasants on Hainan Island, China: Baselines and Shifting Social Norms

Yifu Wang[1], Nigel Leader-Williams[1] and Samuel T. Turvey[2]*

[1] Department of Geography, University of Cambridge, Cambridge, United Kingdom, [2] Institute of Zoology, Zoological Society of London, London, United Kingdom

Overexploitation is a critical threat to the survival of many species. The global demand for wildlife products has attracted considerable research attention, but regional species exploitation histories are more rarely investigated. We interviewed 169 villagers living around seven terrestrial nature reserves on Hainan Island, China, with the aim of reconstructing historical patterns of hunting and consumption of local wildlife, including the globally threatened Chinese pangolin (*Manis pentadactyla*) and Hainan peacock-pheasant (*Polyplectron katsumatae*), from the mid-20th century onwards. We aimed to better understand the relationship between these past activities and current consumption patterns. Our findings suggest that eating pangolin meat was not a traditional behaviour in Hainan, with past consumption prohibited by local myths about pangolins. In contrast, local consumption of peacock-pheasant meat was a traditional activity. However, later attitudes around hunting pangolins and peacock-pheasants in Hainan were influenced by pro-hunting policies and a state-run wildlife trade from the 1960s to the 1980s. These new social norms still shape the daily lifestyles and perceptions of local people towards wildlife consumption in Hainan today. Due to these specific historical patterns of wildlife consumption, local-adapted interventions such as promoting substitute meat choices and alternative livelihoods might be effective at tackling local habits of consuming wild meat. Our study highlights the importance of understanding the local historical contexts of wildlife use for designing appropriate conservation strategies.

Keywords: China, conservation, game meat, Hainan peacock-pheasant, hunting, pangolin, social norm, wildlife trade

OPEN ACCESS

Edited by:
Yan Zeng,
Institute of Zoology, Chinese Academy of Sciences (CAS), China

Reviewed by:
Hari Prasad Sharma,
Tribhuvan University, Nepal
Andres Garcia,
National Autonomous University of Mexico, Mexico

****Correspondence:***
Yifu Wang
yw393@cam.ac.uk

Specialty section:
This article was submitted to Conservation and Restoration Ecology, a section of the journal Frontiers in Ecology and Evolution

Received: *18 September 2020*
Accepted: *22 February 2021*
Published: *12 March 2021*

Citation:
Wang Y, Leader-Williams N and Turvey ST (2021) Exploitation Histories of Pangolins and Endemic Pheasants on Hainan Island, China: Baselines and Shifting Social Norms. Front. Ecol. Evol. 9:608057. doi: 10.3389/fevo.2021.608057

INTRODUCTION

Unsustainable harvesting of wildlife, in particular hunting for meat consumption, has been recognised as one of the major causes of global biodiversity loss (Bennett and Robinson, 2000; Corlett, 2007; Benítez-López et al., 2017; Grooten and Almond, 2018). Many different motivations underlie hunting for meat consumption, from meeting subsistence protein needs to a demand for luxury dishes. Drivers and patterns of wildlife exploitation also vary across cultures and geographic regions (Fa et al., 2003; Sandalj et al., 2016). In particular, biodiversity in regions with very high human population densities, such as China, is often under intensive pressure from exploitation and other human activities (Zhang and Yin, 2014; USAID Wildlife Asia, 2018). As a result, many hunting-induced population declines and regional extinctions have been documented in China across a diverse range of species (Greer and Doughty, 1976; Thapar, 1996; Rookmaaker, 2006; Turvey et al., 2015a), and further population collapses of formerly widespread and abundant species, such as the Chinese giant salamander (*Andrias davidianus*) and yellow-breasted bunting (*Emberiza aureola*), continue to occur due to extensive and unsustainable demand for the wild meat market (Wang et al., 2004; Kamp et al., 2015; Cunningham et al., 2016). Exploitation of wildlife in China has occurred throughout recent history, but has escalated rapidly during the past few decades (Cunningham et al., 2016). Historical patterns of wildlife consumption, and the extent to which such patterns might have become modified during recent periods of socio-cultural change, are therefore important to understand when designing conservation management strategies for species threatened by overexploitation (Huber, 2012; Duffy et al., 2016).

Pangolins (Family Manidae) are recognised as international conservation priorities. They are heavily trafficked for consumption, and have also been identified as potential intermediate hosts in the COVID-19 pandemic of 2020 (Choo et al., 2020; Zhang et al., 2020). The enormous volumes of pangolins seen in wildlife trade has led to recent revision of their IUCN Red List status, with the Chinese pangolin (*Manis pentadactyla*), Sunda pangolin (*M. javanica*) and Philippine pangolin (*M. culionensis*) now listed as Critically Endangered, and the five other pangolin species listed as Endangered or Vulnerable (IUCN, 2020). China is one of the main destination markets for international pangolin trade due to demand for meat, body parts, and scales. Much research attention has been focused on the international trade of pangolin products and hunting of pangolins in source countries, mainly in Africa (Challender and Hywood, 2012; Soewu and Sodeinde, 2015; Cheng et al., 2017; Ingram et al., 2019). Conversely, hunting pressure on native pangolin populations within demand countries such as China has been relatively neglected (Yang et al., 2007; Xu et al., 2016).

The Chinese pangolin was formerly distributed widely across central and southern China. However, it has declined severely during recent decades, making evidence-based conservation of its remaining populations an important goal (Wu et al., 2004; Yang et al., 2018). This population decline has resulted in China uplisting the species from Class II to Class I protection status under national wildlife protection law in 2020 (SFGA of China, 2020). However, due to their cryptic and nocturnal habits and their low population densities across a wide geographic range, estimating current pangolin population size and distribution is challenging, and few studies have attempted to estimate population densities, abundance or trends using standard census techniques. In contrast, social science approaches offer some promise for gaining evidence on these population parameters to guide conservation. One such study was conducted in 2015 on Hainan Island, China's southernmost province, where rural household interview surveys suggested that a small pangolin population might still persist within the island's remaining tropical forests (Nash et al., 2016). It is therefore urgent to (i) assess levels and drivers of potential exploitation of surviving pangolin populations on Hainan, and better understand the socio-cultural context within which local people interact with pangolins, and (ii) inform conservation interventions to reduce exploitation and demand at the community level.

Collecting conservation-relevant data on sensitive behaviours using social science methods is often difficult, due to interviewee reticence in reporting accurate information on potentially illegal activities (Nuno and St. John, 2015; Hinsley et al., 2019; Jones et al., 2020). However, whereas absolute baselines on human-wildlife interactions are difficult to obtain, it is still possible to detect differences in the timing or magnitude of reported interactions with different exploited species that occur within the same landscapes, thus providing a relative between-species signal for use in conservation planning (Turvey et al., 2015b). Rural subsistence communities in Hainan are known to exploit and consume other threatened and protected species in addition to pangolins (Gaillard et al., 2017; Gong et al., 2017; Xu et al., 2017). In particular, galliform birds are hunted for food across China (Liang et al., 2013; Zhou et al., 2015; Kong et al., 2018; Chang et al., 2019). The island's Endangered endemic pheasant, the Hainan peacock-pheasant (*Polyplectron katsumatae*), is a Class I Protected Species that also occurs within remaining tropical forests across Hainan, and is threatened by illegal hunting and habitat destruction. The peacock-pheasant population is thought to have declined rapidly since the 1950s, with an estimated population loss of almost 80% compared to historical levels (Liang and Zhang, 2011). As pangolins and peacock-pheasants share similar threats, protection status, and inferred distributions across Hainan, they may constitute a useful species pair for assessing reported patterns of hunting and consumption.

We conducted semi-structured interviews in Hainan to establish a new baseline on past and present hunting practices associated with pangolins and peacock-pheasants in low-income subsistence communities across the island, including targeted interviews with hunters, consumers, restaurants, and wild meat dealers. Our results demonstrate different patterns and perceptions of hunting and consuming of these species, associated with policy changes in recent decades and their conflict with local traditions. These findings can guide evidence-based conservation planning for these protected species by informing local-adapted interventions based upon understanding of historical behaviour patterns.

MATERIALS AND METHODS

Interviews

We conducted household interviews from November 2016 to April 2017 around seven terrestrial protected areas in Hainan: Bawangling, Diaoluoshan, Jianfengling, Wuzhishan and Yinggeling national nature reserves, and Jiaxi and Limushan provincial nature reserves. All of these reserves contain monsoon forests that represent potential pangolin and peacock-pheasant habitat. However, recent baseline distributions and local occurrence data for both species are unavailable. The reserves are all surrounded by numerous low-income rural communities mainly comprising Li and Miao ethnic minorities. Local people often utilise resources collected inside the reserves (Fauna and Flora International China Programme, 2005; Turvey et al., 2017). We sampled villages identified by local guides that were within walking distance of reserves, in which inhabitants were known to hunt wildlife within nearby forests and were also open to be interviewed by outsiders. We conducted interviews in 3–13 villages adjacent to each reserve, covering 42 villages within four administrative counties (Baisha, Ledong, Qiongzhong, and Wuzhishan) in total (**Figure 1**).

We conducted between 1 and 11 interviews per village. We initially identified interviewees through introductions by local guides, then used snowball sampling to identify subsequent potential interviewees who might hunt or hold hunting knowledge (Newing, 2010). Most interviews were conducted with village inhabitants on a one-to-one basis; a small number of interviews were instead conducted in groups, during which no attitudinal or demographic questions were asked. Rangers and reserve staff were also interviewed when available and were not asked about their perceptions on current hunting behaviour. Villagers younger than 18 years old were not interviewed, only one interviewee was interviewed per household to ensure independence of responses, and both males and females were interviewed. No maximum sample size was set for interviewees in each village. We explained that we were conducting anonymous interviews to understand people's perceptions and knowledge about hunting, obtained verbal consent before all interviews, and informed respondents they could stop at any time. Cotton towels (about 0.2 USD each) were given as gifts to increase participation rates and show gratitude for the interviewee's time. The choice of gift was given careful consideration, and aimed at being useful but not too expensive for interviewees, so that motivation to participate would not be mainly due to receipt of the gift. Research design was approved by the Department of Geography Ethics Review Group, University of Cambridge (#1503).

We used an anonymous questionnaire to collect data on interviewees' reported hunting experiences, intentions, and attitudes, with a specific focus on the hunting of pangolins and peacock-pheasants. We also collected basic demographic data on interviewees' age, gender, ethnic group, income level and education level. However, we did not record names or other personal information that could identify individuals. The questionnaire consisted of a series of multiple-choice and

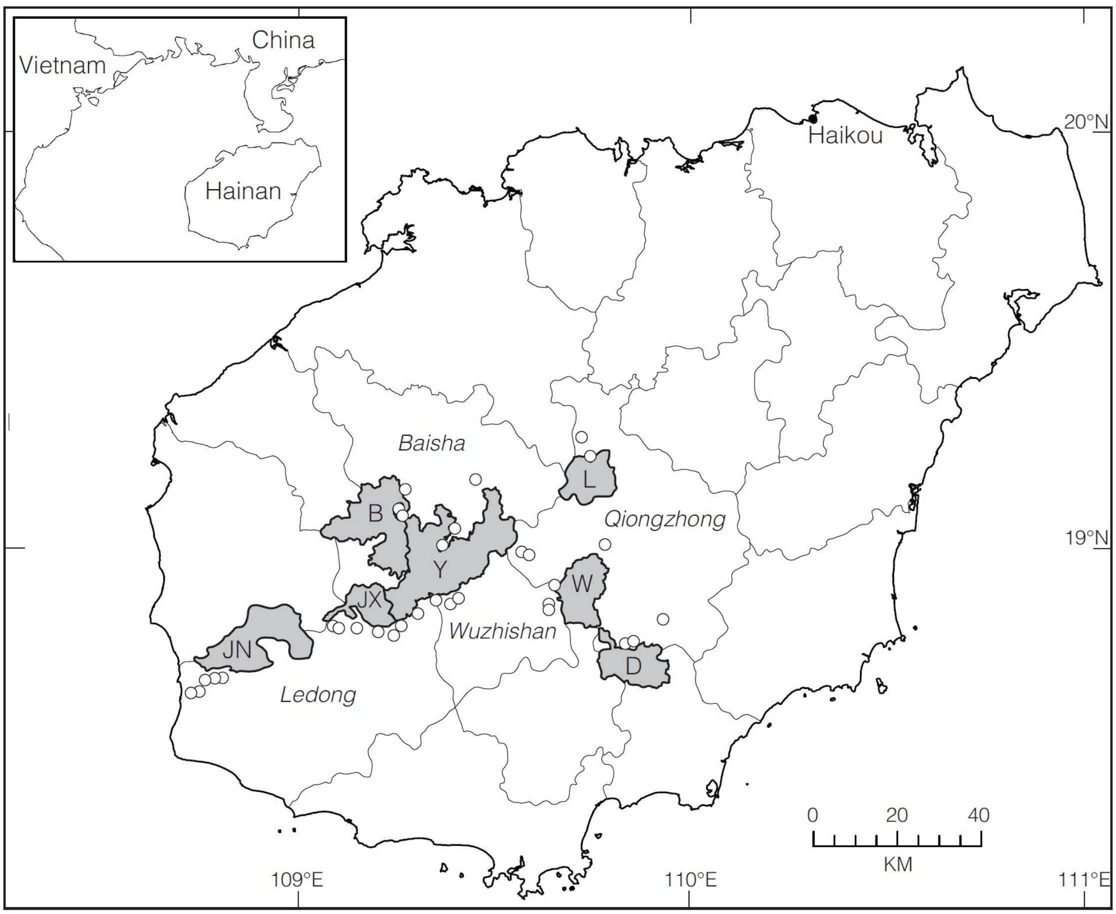

FIGURE 1 | Locations of 42 villages around nature reserves in Hainan included in this study.

open-ended questions that took up to 30 min to complete (see **Supplementary Material**). Part of the questionnaire design was based on the Theory of Planned Behaviour, and aimed to investigate people's attitude towards hunting (Ajzen, 2002, 2006). Specifically, we used Likert scales and multiple-choice questions to determine interviewees' experiential and instrumental attitudes towards hunting (i.e., whether they feel hunting benefits themselves or others), injunctive and descriptive social norms (i.e., whether people around them approve and/or practice hunting), and perceived behaviour control (i.e., whether they are capable of hunting and whether they feel hunting is a self-willing behaviour). We also asked about hunting practices during the previous 2-year period and about future intention to hunt, and whether interviewees held utilitarian values about nature (Gamborg and Jensen, 2016). In addition to asking about hunting wildlife in general, we also asked specifically about hunting of pangolins and peacock-pheasants, and interviewees' knowledge of these two species. We validated whether interviewees could recognise pangolins and peacock-pheasants by showing pictures to aid identification (sourced from pangolins.org and arkive.org), and further asked them to provide descriptions of key morphological characters (e.g., scales on pangolins; eyespot-patterned tail feathers of peacock-pheasants). All interviews were conducted by the first author in Mandarin, and answers were recorded in Chinese. The majority of interviewees spoke Mandarin, but some older people spoke only Li and Miao languages, and interviews were carried out with translation assistance provided by bilingual local guides.

We also conducted additional targeted interviews with professional hunters, potential wild meat selling restaurants, wild meat consumers and wild meat dealers, with potential interviewees accessed through social networks and introduced by trusted middlemen. Because recruitment rates were expected to be low, we did not set a maximum sample size, and results are presented in a descriptive manner. High confidentiality was assured for these interviewees to encourage participation; we did not ask about any demographic variables, and interview questions mainly focused on interviewees' personal hunting, selling, or consuming behaviours.

Analyses

We used binomial general linear models (GLMs) to identify factors that correlated with interviewees' self-reported hunting behaviour (with self-reported hunters defined as interviewees who said it was "possible" or "largely possible" that they would go hunting in the future, and/or who admitted to hunting during the previous 2-year period). The maximal model included 16 variables: respondent age, gender, education, ethnic group, occupation, annual income, county, nearby reserve, and eight other variables associated with the Theory of Planned Behaviour (Ajzen, 2002, 2006). We used stepwise selection (*stepAIC*) to find the best-performing model with the lowest Akaike information criterion (AIC). We standardised variable coefficients in the final model using *beta* to identify the most influential factor. We used two additional binomial GLMs, built following the same procedure, to determine potential demographic predictors for interviewees who reported knowledge about pangolins or peacock-pheasants. We also conducted Spearman rank correlations and z-tests to investigate knowledge distribution patterns among interviewees. All analyses were performed in RStudio under R version 3.5.2 (RStudio Team, 2015). Answers to open-ended questions on interviewees' knowledge about pangolins or peacock-pheasants were analysed using thematic analysis; responses were coded into different categories, then grouped into themes to reveal general patterns (Gavin, 2008; Newing, 2010). Price data were inflated to prices in 2017 in Chinese yuan using the consumer price index (National Bureau of Statistics, 2020).

RESULTS

We conducted interviews with 169 individuals or groups in 42 villages, including 34 rangers and reserve staff, 131 villagers, and four villager group interviews (group sizes ranging between 4 and 10 villagers) (**Table 1**). We also successfully interviewed one active professional hunter, three wild meat dealers, five restaurant owners, and four wild meat consumers across Hainan. The locations of these 13 interviewees remained confidential and were not recorded.

Most interviewees expressed negative attitudes toward hunting, although a relatively high proportion agreed that hunting was an enjoyable activity (**Table 2**). Most interviewees also reported that hunting was an uncommon activity, with only 16 out of 131 interviewees (12.2%) considering that hunting was frequently or sometimes practiced. Self-reported hunting behaviour was also uncommon, and only 13 interviewees (10%) self-identified as active or potential future hunters. GLM

TABLE 1 | Number of interviewees grouped by reserve and administrative county.

Nearby nature reserve	Baisha	Ledong	Qiongzhong	Wuzhishan	Total
Bawangling	5 (3 villages)				5
Diaoluoshan			16 (3 villages)		16
Jiaxi		20 (5 villages)			20
Jianfengling		26 (7 villages)			26
Limushan			20 (3 villages)		20
Wuzhishan			2 (1 village)	40 (7 villages)	42
Yinggeling	15 (4 villages)	6 (2 villages)	8 (4 villages)	11 (4 villages)	40
Total	20	52	46	51	169

TABLE 2 | Attitudes toward hunting held by interviewees on Hainan (N = 131).

Statement	Totally agree	Largely agree	Neutral	Largely disagree	Totally disagree	Do not know
Hunting provides more advantages than disadvantages to people	12.2%	3.1%	4.6%	12.2%	**62.6%**	5.3%
Hunting provides more advantages than disadvantages to nature	2.3%	5.3%	6.9%	16.0%	**55.7%**	13.7%
Hunting is an enjoyable activity	24.4%	7.6%	14.5%	5.3%	**38.9%**	9.2%
People around you support hunting	1.5%	1.5%	6.9%	14.5%	**66.4%**	9.2%

The highest percentage answer for each question is highlighted in bold.

results showed that age and perceived local supportiveness for hunting were significantly correlated with self-reported hunting behaviour, with self-reporters tending to be younger and feel that people around them supported hunting (**Table 3**).

Although hunting was reported as uncommon, seven out of 169 interviewees (4.1%) specifically reported having hunted either pangolins or peacock-pheasants since 2010. Five interviewees reported pangolin hunting incidents that occurred during 2014 or 2015 outside or within Jianfengling and Yinggeling reserves. For example, one interviewee from a village outside Jianfengling Reserve described how he had heard of a villager in an adjacent village catching and eating a pangolin that was found in cropland. Hunting of peacock-pheasants was described by one interviewee near Jianfengling Reserve as "frequent" and "occurring every year." Another interviewee said that he often went to Nanle Mountain inside Yinggeling Reserve to hunt peacock-pheasants and other birds because he thought that this area was not protected. Hunting of other species was also reported without prompting during interviews, and several captive wild animals and hunting gear (snap traps and cage traps) were observed in villages during fieldwork, providing evidence of ongoing local hunting activities (**Figure 2**). Three interviewees also mentioned the "turtle rush," a period of intensive local collecting of the golden coin turtle (*Cuora trifasciata*), a species highly valued in the pet trade.

Our open-ended questions asked for knowledge about the two target species. A total of 121 interviewees (71.6%) provided information about pangolins, whereas only 77 interviewees (45.6%) provided information about peacock-pheasants, representing a statistically significant difference (z-test, $P < 0.001$). The relative amounts of different reported categories of knowledge also differed significantly between the two species (Spearman rank correlation, rho = 0.0340, $P = 0.917$)

TABLE 3 | Results for GLM investigating predictors of self-reported hunting behaviour with lowest AIC value (AIC = 45.074).

Variables	Std. Estimate	Std. Error	*z* value	*P* value
(Intercept)	0.0000	0.23756	4.712	< 0.00001
Age	**−0.2189**	**0.01008**	**−2.617**	**0.00997**
Gender	−0.1172	0.07916	−1.433	0.15434
Hunting is an enjoyable activity	−0.1612	0.01503	−1.806	0.07328
People around you support hunting	**−0.1896**	**0.02964**	**−2.145**	**0.03387**
Capacity to hunt	−0.1459	0.09836	−1.753	0.08210

Predictors significant at $P < 0.05$ are highlighted in bold.

(**Figure 3**). GLM results revealed that the only predictor to be significantly correlated with whether interviewees reported pangolin information was age (N = 147, SE = 2.4, z = 3.8, $P < 0.001$; see **Supplementary Material** for full results), with older interviewees more likely to report information. Conversely, three predictors were significantly correlated with whether interviewees reported peacock-pheasant information (N = 147; county: Wuzhishan, SE = −1.6, z = −2.4, $P < 0.05$; age: SE = 1.2, z = 2.7, $P < 0.01$; occupation: state-enterprise employees, SE = 1.7, z = 2.9, $P < 0.01$; see **Supplementary Material** for full results), with older interviewees, interviewees not from Wuzhishan County, and interviewees working for state-owned enterprises more likely to report information.

There was a significant difference between the number of respondents reporting exploitation-related knowledge (i.e., trade and price, hunting, consumption, use as medicine, and ornamental use) for pangolins and for peacock-pheasants (98 reports for pangolin and 20 reports for peacock-pheasants; z test, $P < 0.0001$). Even non-hunters were found to be very familiar with pangolin exploitation. Indeed, these exploitation-related topics were all reported more frequently than any other categories of knowledge about pangolins, such as ecological or behavioural characteristics. The most frequently reported pangolin knowledge category was knowledge about trade and price, reported by 64 interviewees (52%). The second most frequently reported knowledge category was knowledge about hunting, reported by 61 interviewees (50%), which described hunting frequency or specific hunting techniques including looking for pangolin tracks, using dogs to track down pangolins, or smoking pangolins out of their burrows. Conversely, knowledge about peacock-pheasants focused more on behaviour (30 reports), habitat (26 reports), or physical biology (25 reports) rather than hunting (16 reports) or trade (0 reports) (**Figure 3**).

We did not obtain reports of historical hunting or trade from earlier than the 1960s. This might reflect the age limit of our interviewee sample, but might also be due to local beliefs mentioned by several interviewees (n = 6), in which pangolin hunting and utilisation was disapproved of in the past. Local myths regarded seeing a pangolin during the daytime as an omen representing either extreme fortune or bad luck (Katuwal et al., 2016), thus giving pangolins a more symbolic role in local culture rather than merely representing food items. This belief is apparently associated with the rarity of seeing these nocturnal animals during the daytime, combined with the reported local idea that pangolins feed on bones of the dead, also mentioned by Liu (1938).

Interviewees' extensive knowledge on hunting and trading pangolins came from changing practices during the second

FIGURE 2 | Captive wild animals and hunting gears observed in villages during fieldwork. **(a)** Black-breasted leaf forest turtle (*Geoemyda spengleri*); **(b)** female silver pheasant (*Lophura nycthemera*); **(c)** Pallas's squirrel (*Callosciurus erythraeus*); **(d)** crested serpent eagle (*Spilornis cheela*); **(e)** snap traps; **(f)** cage traps. Photo credit: Yifu Wang.

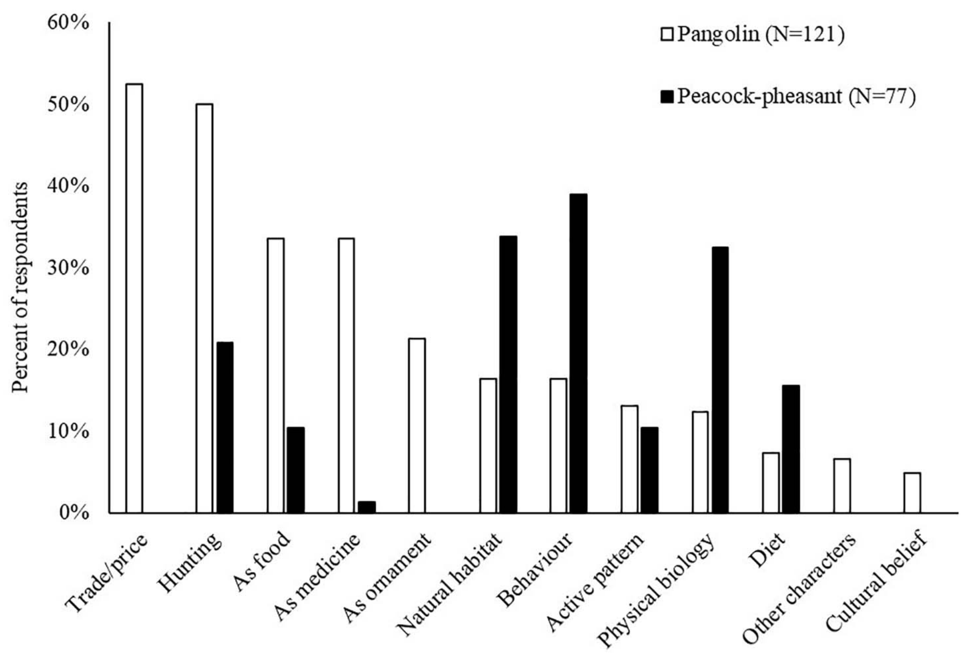

FIGURE 3 | Percentage of interviewees providing different categories of knowledge about pangolins and peacock-pheasants. Note that respondents may provide knowledge on more than one category.

half of the 20th century; 49 out of 121 interviewees (>40%) provided hunting or trade information specifically from the 1960s to the 1990s, with a peak of reported hunting during the 1980s. Interviewees described that pangolin hunting was directly supported by the Chinese government through legal commercial trade during this period, as state-owned supply and marketing cooperatives would purchase pangolin scales from locals for relatively high prices, as also reported by Wu et al. (2004).

Hunting activity declined in the 1990s for two reasons: hunting was officially banned, and Hainan's pangolin population had reportedly declined heavily by this period. The pangolin hunting period reportedly started and ended slightly later in more remote communities (i.e., those with reduced road access). Conversely, professional hunters reported that peacock-pheasants were never a main target species in Hainan due to their low body weight (around 0.5 kg per adult bird), meaning that they could not be sold for a high price. Instead, harvest of peacock-pheasants was mostly by-catch and/or for personal consumption.

These direct quotes from three interviewees illustrate the extent of hunting during the peak period and the subsequent collapse of the pangolin population:

> "*A village could catch a few hundred pangolins in total in one month back in the 1980s. I caught more than 20 myself.*"

> "*Hunting and government purchasing started in 1976. Around that time, a local could catch more than 30 in one month. I caught more than 20 in 1985.*"

> "*Lots of villagers searched for pangolins in the mountains during the 1990s, but they found only one or two per month at that time.*"

Information provided about pangolin trade included data on historical prices of whole pangolins and pangolin scales, which show an increase in price from the 1970s, a decline in the 1990s, and a more recent further increase (**Figure 4**). Professional hunters, wild-meat dealers and consumers also confirmed to us that the recent price of a whole pangolin was 2,000–3,400 yuan/kg (280–490 USD/kg).

None of the interviewed restaurant owners admitted to selling pangolin or peacock-pheasant products, but did confirm that they sold farmed wildlife species such as bamboo rats (*Rhizomys* spp.) and porcupines (*Hystrix brachyura*). These species and other wild animals from unknown sources, including passerines, squirrels and other rodents, and small carnivores, were also common in local markets, whereas pangolins and galliform birds were much rarer according to restaurant owners. This was consistent with information provided by consumers, who reported buying whole pangolins from markets that were then cooked in restaurants rather than buying dishes directly in restaurants. Both consumers and dealers reported that buying pangolins from markets took place under conditions of strong trust between buyers and sellers, with unknown buyers requiring guarantees from up to seven trusted middlemen.

The four interviewed consumers provided different reasons and scenarios for eating pangolin dishes. One consumer particularly liked the taste of pangolin meat and, since pangolins were rare and expensive, often invited business friends and colleagues to socialize for work when pangolins were available. Two consumers ate pangolin dishes at their workplaces during meals to which they were invited by other people, who ordered pangolin dishes to show respect to their guests due to the species' high price and rarity. The fourth consumer regularly enjoyed eating wild meat dishes and considered that holding a wild meat party was a way to maintain friendships and social connections. According to this consumer, pangolins were consumed for their potential health benefits, but due to their high cost, the consumption was not frequent.

DISCUSSION

Our results provide a new baseline to understand patterns, levels, and socio-cultural drivers of local hunting of pangolins and other conservation-priority species in Hainan Island, China. Unsurprisingly, direct questioning of rural interviewees provided

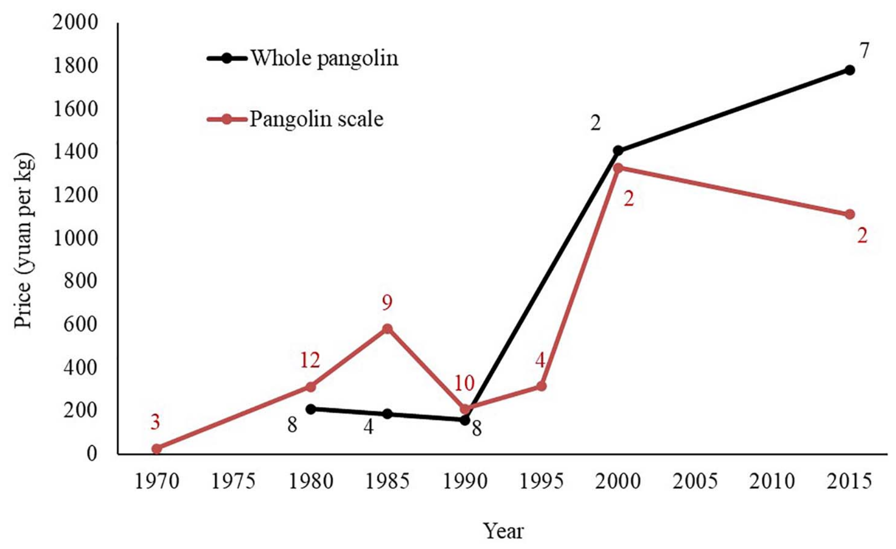

FIGURE 4 | Historical price of whole pangolins (black line) or pangolin scales (red line) reported by interviewees. Data are grouped into 5-year time bins, indicated on the *x* axis by the first year of each respective time bin. Mean reported prices are given for each time bin; numbers associated with each data point show the number of prices reported for that period.

relatively low levels of self-reported hunting, a result consistent with previous findings (Van Der Heijden et al., 2000; Nuno and St. John, 2015). However, interviewees still provided substantial information about hunting of pangolins, peacock-pheasants and other wildlife, and local demand for wild meat. These findings indicate that Hainan's biodiversity faces continuing pressures that threaten its future. Enforcement and management agencies have made efforts to reduce regional wildlife hunting and consumption behaviours, and our results suggest that some of these behaviours (notably pangolin hunting) were more common in the past compared to today. However, observed decreases in hunting may have been driven by population declines rather than effective enforcement, and remaining illegal wildlife hunting and consumption needs to be tackled urgently. Our study provides a new understanding of hunting and consumption that can contribute important insights for identifying potential solutions, and also includes crucial baselines of historical change that further aid conservation planning.

Hainan's rich biodiversity has constituted an important resource for local communities for millennia. Even pre-modern regional human interactions with many vertebrate species were unsustainable on Hainan, leading to numerous prehistoric and historical extinctions (Turvey et al., 2019), and escalating natural resource use has placed increasing pressure on regional biodiversity (Chau et al., 2001; Gong et al., 2006; Xu et al., 2017). However, although historical accounts indicate that pangolins have been exploited for food and medicine on Hainan since at least the early 20th century (Allen, 1938; Liu, 1938), data from our study suggest that local myths reduced hunting for consumption, thus keeping hunting pressure relatively low and stable until the Chinese government promoted a nation-wide state-run commercial trade of pangolins from the 1960s (Wu et al., 2004). This is also supported indirectly by the heavy pangolin harvests reported in the 1960s–1980s followed by the sudden decrease in offtake in the 1990s. If hunting pressure had been high before the mid-20th century, local pangolin populations may not have been sufficiently abundant to support such a high harvest load, and the subsequent decline in harvests would also not have been so drastic. This pattern of recent historical change in hunting intensity of pangolins contrasts with peacock-pheasants, which appear to have been hunted more than pangolins in the past because there were no cultural taboos restricting such behaviour. Conversely, peacock-pheasants did not experience an increase in hunting pressure driven by changes in state policy.

Cultural taboos play an important role in regulating a wide range of local behaviours and support sustainable interactions with biodiversity across many cultures and social-ecological systems (Colding and Folke, 2001; Wadley and Colfer, 2004). However, as demonstrated by the increased acceptability of hunting pangolins in Hainan, such taboos can be eroded easily by rapid societal change or outweighed by monetary incentives, and are often hard to restore following their disruption (Golden and Comaroff, 2015; Katuwal et al., 2016). State-encouraged hunting during past decades has also changed the nature of specific human-wildlife interactions and has driven severe population declines and extirpations in other Chinese species, such as tigers (*Panthera tigris*) (Coggins, 2003; Kang et al., 2010).

Patterns of pangolin knowledge, hunting and consumption across Hainan are therefore very different compared to local awareness and interactions with peacock-pheasants as a result of this official policy change. Whereas increased knowledge about both species was positively associated with interviewee age in our analyses, fewer interviewees had knowledge about peacock-pheasants, and knowledge about this species also showed geographic variation and was greater among state-enterprise employees, a category that consists mainly of reserve workers. These results suggest that although peacock-pheasants are known to be hunted (Liang and Zhang, 2011), they have been less of a priority target compared to pangolins, which do not show any variation in knowledge across our entire survey area or across all demographic sectors of our interviewee sample. In addition, interviewees did not provide much information about peacock-pheasant trade as there was little wider demand for this species. However, we note that even though peacock-pheasants might face lower intentional hunting pressure comparing to pangolins, hunting of this species still needs conservation attention due to a lack of knowledge of sustainable off-take thresholds, their probable low population size, and potentially high by-catch rates (e.g., from snares) as suggested by our interviewee data. As one of the most threatened galliforms in China, this species is also at potential risk of becoming valued due to its rarity, a main driver of consumption of luxury wildlife dishes (Sandalj et al., 2016; Shairp et al., 2016; Cardeñosa, 2019).

From an historical perspective, hunting first became formally regulated in China in 1989 when the first wildlife protection law was enacted, and hunting of pangolins, peacock-pheasants, and many other wildlife species was banned through their listing as Protected Animals (SFA of China, 1989). Hunting in general is also prohibited within the seven protected areas included in our survey, which were established from the 1970s to the 2000s (Ministry of Ecology and Environment of China, 2012). The rapid change in government policy did not lead to a sudden end in hunting or trade of wildlife products, and our results show that the price of pangolin products increased substantially during the 1990s. This economic change might reflect not only pangolin population decline, but also the shift from a controlled price to a market price where supply capacity would have a greater impact on economic value (Gale, 1955; Courchamp et al., 2006).

Our data also show that shifts in attitudes towards hunting and consuming wildlife are still ongoing. Although the majority of interviewees reported negative attitudes towards hunting, many still enjoyed hunting. These results suggest either that levels of subsistence or economic hunting were underreported in our study, or that recreational hunting remains popular (Phelps et al., 2016). Indeed, enjoyment and recreational value are major drivers of local hunting in many other parts of rural China (Chang et al., 2019). Recreational use of wildlife was also highlighted in our wild meat consumer survey in which wild meat parties with friends were mentioned as a frequent and important event. It is also interesting to note that hunting is often phrased as a solitary activity. In contrast, wild meat parties are a social activity, and need to be considered separately from recreational wildlife meat consumption.

Furthermore, several responses in our study demonstrate that understanding of current conservation regulations is incomplete.

For example, some hunting activities were not considered to constitute "hunting" by interviewees, such as the "turtle rush" that overharvested golden coin turtles and many other reptile species (Gong et al., 2006; Gaillard et al., 2017). Several interviewees were also unclear about which areas were protected, or appeared unconcerned about openly discussing hunting protected species outside reserve boundaries as if protected animals were only protected in reserves. These observations might suggest the lack of using appropriate language when communicating with locals, and highlight potential future directions.

There are some unavoidable limitations in our study design. Illegal behaviours such as hunting are likely to be sensitive to direct questioning. Specialist interview techniques have been developed to attempt to overcome this problem (Hinsley et al., 2019; Jones et al., 2020), but restrictions such as sample size, design and analytical complexity, and time constraints prohibited application of these techniques in this study. Although some previous studies have obtained valuable results about sensitive behaviours through the use of direct questioning techniques (Kroutil et al., 2010), we assume that some interviewees are likely to under-report personal hunting behaviours, while over-reporting is much less likely. However, 10% of our interviewee sample admitted to recent hunting or to being potential hunters. This is not a low percentage given the known pressures from hunting that face many highly threatened species in Hainan (Gong et al., 2006; Liang et al., 2013; Xu et al., 2017). This figure can be treated as a minimum estimate, and probably underestimates the real number of hunters in our study. We also note that our use of snowball sampling rather than random sampling might conceivably have led to preferential selection of interviewees who were more likely to discuss hunting and hunting-related knowledge, thus making it difficult to infer wider levels of hunting across rural Hainan from our data. However, overall our findings suggest that there is a continuing and urgent need to tackle hunting as a threat to biodiversity in Hainan.

Other points highlighted in our results might be helpful for tackling ongoing hunting pressure in Hainan. Firstly, self-reported hunters tended to believe that people around them supported hunting. However, our results also indicate that most interviewees held negative attitudes towards hunting. We acknowledge that some interviewees might have misreported their true opinions on hunting during interviews. However, conservation mitigations could focus on this reported difference between perceived and actual social norms to encourage desired behaviour change, a well-studied concept that has been applied in many areas beyond wildlife conservation (Zhang et al., 2010; McDonald et al., 2014). Secondly, we suggest that the terminology associated with hunting, and regulations associated with hunting and protected areas, need further clarification through improved local educational activities to reduce misunderstanding and the perpetuation of unwanted behaviours. Lessons should be learned from this historical policy change and how it failed to convey these terminologies clearly, to avoid similar loopholes in future.

Consumption of wild animal products has also been impacted by the rapid changes in hunting policy. Such change can lead to different social norms related to consuming of different species. The change in pangolin exploitation pattern revealed in our study and the contrasts with that of peacock-pheasants support this conclusion. As the result, strategies to change wildlife consumption behaviour in Hainan should not focus solely on the conservation status or threats of species of concern, but also on the social associations that these species provide to consumers, whether it is recreational use or health benefits. Appropriate conservation mitigations should thus include encouraging suitable substitutes, and helping to establish new social norms (Clarke et al., 2007; Drury, 2009).

Our study highlighted that conservation interventions should build upon the understanding that current patterns of wildlife exploitation and consumption could be a legacy of past policy changes and shifting social norms. Due to the current COVID-19 pandemic, regulations on trading and consuming wild animal products have now become much tighter in China (National People's Congress of China, 2020). The corresponding policy change means that species traditionally common in trade, such as bamboo rats and porcupines, can no longer be traded. A new social norm needs to be established. Indeed, our fieldwork was conducted before the COVID-19 outbreak, providing a baseline for future studies on the impact of these new policy shifts on local hunting and wildlife consumption behaviours. On the other hand, ongoing hunting practices in rural areas of Hainan and other parts of China require extra management attention, as human interactions with threatened wildlife species might pose threats not only to biodiversity but also to public health. Various bans on hunting and consuming wild animals have been established since 1989 and intensively recently to cope with the COVID-19 pandemic. However, changing public behaviours by implementing bans is just the first step (Ribeiro et al., 2020; Zhu and Zhu, 2020). Establishing and accepting such new social norms and adhering to desired behaviours is the final goal, and understanding the history of how social norms have changed can provide valuable insights for current management.

DATA AVAILABILITY STATEMENT

The datasets presented in this article are not readily available because original raw data will not be shared with a third party as part of the ethics requirement. Requests to access the datasets should be directed to YW.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Department of Geography Ethics Review Group, University of Cambridge. Written informed consent for participation was not required for this study in accordance with national legislation and institutional requirements.

AUTHOR CONTRIBUTIONS

YW, NL-W, and ST all contributed to the initial design of the project, data analysis, revising the first draft, and the approval of the final submission. YW collected data and wrote the first draft. All authors contributed to the article and approved the submitted version.

ACKNOWLEDGMENTS

We thank volunteers from Hainan Blue Ribbon Volunteer Organization, Hainan Laotao Volunteer Organization, Ledong Xinlianxin Volunteer Organization, Hainan Forestry Administration, Hainan Forestry Research Institute (Tongshi Branch), and Jianfengling National Nature Reserve for help with surveys in Hainan. We give special thanks to all anonymous respondents who participated in surveys, and people who helped with social network access to respondents. We also thank Heidi Ma and Helen Nash for help with project coordination and questionnaire design.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fevo.2021.608057/full#supplementary-material

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

frontiers in Ecology and Evolution

POLICY AND PRACTICE REVIEWS
published: 17 March 2021
doi: 10.3389/fevo.2021.652103

Promotion of *in situ* Forest Farmed American Ginseng (*Panax quinquefolius* L.) as a Sustainable Use Strategy: Opportunities and Challenges

Hong Liu[1,2*†‡], *Eric P. Burkhart*[3,4†‡], *Vivian Yi Ju Chen*[5] *and Xi Wei*[6]

[1] Department of Earth and Environment, Institute of Environment, Florida International University, Miami, FL, United States, [2] Fairchild Tropical Botanic Garden, Miami, FL, United States, [3] Shaver's Creek Environmental Center, Petersburg, PA, United States, [4] Department of Ecosystem Science and Management, Pennsylvania State University, University Park, PA, United States, [5] Department of Marketing and Logistics, Florida International University, Miami, FL, United States, [6] Department of Geography, Centre for Geo-computation Studies, Hong Kong Baptist University, Kowloon Tong, Hong Kong

OPEN ACCESS

Edited by:
Yan Zeng,
Institute of Zoology, Chinese Academy of Sciences (CAS), China

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James McGraw,
West Virginia University, United States
Jennifer Chandler,
West Chester University,
United States

***Correspondence:**
Hong Liu
hliu@fiu.edu

†These authors have contributed equally to this work and share first authorship

‡ORCID:
Hong Liu
orcid.org/0000-0002-7814-5512
Eric P. Burkhart
orcid.org/0000-0002-8870-1340

Specialty section:
This article was submitted to Conservation and Restoration Ecology,
a section of the journal
Frontiers in Ecology and Evolution

Received: 11 January 2021
Accepted: 22 February 2021
Published: 17 March 2021

Citation:
Liu H, Burkhart EP, Chen VYJ and Wei X (2021) Promotion of in situ Forest Farmed American Ginseng (Panax quinquefolius L.) as a Sustainable Use Strategy: Opportunities and Challenges. Front. Ecol. Evol. 9:652103. doi: 10.3389/fevo.2021.652103

The cultivation of wild-harvested plant species is one strategy to achieve species conservation while meeting continued demand. A limitation to this approach for species used in Traditional Chinese Medicine, however, is that products produced under *ex situ* artificial agricultural conditions are often not a perfect replacement for their wild-collected counterparts, so demand for wild-harvested materials persists. This situation applies to American ginseng, an internationally protected species by the Convention on International Trade of Endangered Species of Wild Fauna and Flora (CITES) since 1975. In this paper, we trace the trade the history and conservation need for American ginseng in North America, including a summary of the development and evolution of *in* and *ex situ* cultivation methods. We report results from a preliminary survey of product labeling of American ginseng sold online in China and adjacent regions and provide recommendations for promoting forest farmed ginseng to consumers as a sustainable use strategy. We suggest that the use of CITES's new "human assisted" production category amongst trade partners, coupled with "green" product certification and e-commerce platforms, provides a new opportunity to encourage consumption of wild-cultivated rather than wild ginseng in east Asia, and the continued development of ginseng forest farming and supply transparency mechanisms in the eastern United States.

Keywords: agroforestry, CITES, green products, non-timber forest product certification, plant conservation, Traditional Chinese Medicine, semi-wild

INTRODUCTION

Over-exploitation is among the greatest threats to species' survival (Maxwell et al., 2016). The cultivation of wild over-harvested species is a common strategy to meet continued demand and achieve species conservation at the same time (Abensperg-Traun, 2009; Anderies, 2015; Challender et al., 2015). It is often assumed that cultivation alone can alleviate wild harvesting pressure and help conserve species. However, a recent review found that there is limited evidence to validate this assumption with commercial cultivation only generating a conservation benefit for a handful of the 193 threatened species studied (Liu et al., 2019). This review found that cultivation operations may be motivated by market forces, but may be promoted by various NGOs, or government agencies if species conservation and social equalities are among the purposes of the cultivation operations. Cultivation operations structured to meet market demand only are not likely to generate conservation benefits, regardless of how large the operations are and how long a species has been under cultivation. One reason is that for many species, such as traditional medicinal plants, products cultivated under completely artificial conditions are not a perfect replacement for wild collected counterparts; therefore, demand for wild-harvested products persists despite the existence of mature artificial cultivation.

Nevertheless, there are cases in which cultivation has generated or is likely to generate conservation benefits, including the implementation of semi-wild cultivation approaches, in which populations planted in native wooded areas can be harvested (Burkhart, 2011; Liu et al., 2019). These cultivation operations can be seen as a hybrid between commercial cultivation and population restoration because farmers can adopt harvesting regimes that enable the population to persist and reproduce, as reported for selected medicinal (Ashton et al., 2014; Liu et al., 2014) and ornamental plants (Vovides et al., 2010; Menchaca Garcia et al., 2012; Ticktin et al., 2020). While these semi-wild cultivation operations hold promise for sustainable use, they should be considered experimental at this stage. However, it is nevertheless important to recognize these potential pathways exist and that they hold the promise to realize the dual goals of conserving plant resources while concurrently supporting local livelihood and social equity.

In this paper, we examine the opportunities and challenges associated with promoting *in situ* forest-based semi-wild cultivation as a mechanism to achieve sustainable use of American ginseng (*Panax quinquefolius* L., hereafter ginseng). We place our study within the context of evolving and emerging opportunities for product promotion in Asia where greater than 95% of wild ginseng is consumed. We first offer background on the trade and conservation needs surrounding ginseng in the United States of America (USA, hereafter US), followed by a discussion of the opportunities and challenges associated with ginseng forest farming in the eastern United States. We then examine ginseng product labeling in Mainland China and adjacent regions (e.g., Hong Kong China), the role of Convention on International Trade of Endangered Species of Wild Fauna and Flora (CITES) in ginseng conservation and trade, and conclude by offering recommendations intended to encourage consumption of forest farmed rather than wild ginseng as a conservation and sustainable use strategy. In offering this suggestion, we are not implying that continued trade monitoring and regulation are unnecessary; rather, we recognize that ginseng forest farming, and the consumption of wild-cultivated ginseng products, may offer sustainable use benefits not realized by a CITES-driven regulatory approach alone.

BACKGROUND

Trade History and Wild Exploitation

Collection of wild ginseng in North America for Asian consumer markets began during the early 1700s following an exchange by Jesuit missionaries (Carlson, 1986; Wang, 2007). In 1716, the Jesuit priest Joseph Francois Lafitau, with help from the Iroquois tribes, recognized ginseng in the vicinity of Montreal, Canada from botanical descriptions of the Chinese relative Asian ginseng (*Panax ginseng* C.A. Mey.) provided by Jartoux in 1714. Commercial exports from Canada to China commenced the following year and by mid-century populations were already declining or extirpated from over-collection near Montreal where the species was first "discovered" (Benson, 1987).

Export and harvest records indicate nearly continuous commercial exploitation of wild ginseng in eastern North America during the past 300 years (Carlson, 1986; United States Fish and Wildlife Service (USFWS), 2020). Export statistics reveal that over 13.7 million kg of ginseng root was exported from the United States during 182–1899 (**Figure 1**), for example. This would have been comprised entirely of wild root since there are no reports of commercial cultivation before the late 1800s (as discussed in section "Cultivation as a Sustainable Use Solution"). During the twentieth century, about half the volume of the previous century (roughly 7 million kg) was exported, and in the first two decades of the 21st century only 500,000 kg was reported to United States Fish and Wildlife Service (United States Fish and Wildlife Service (USFWS), 2020). Harvest amounts of wild ginseng have not exceeded 250,000 kg/decade after the year 2000, which is less than 1/10 of the historic peak in the late 1800s. All these statistics do not account for the quantity marketed and utilized domestically which would not have been recorded in export or, more recently, harvest records.

The long trade history associated with ginseng suggests that the exploitation of wild ginseng throughout eastern North America during the past three centuries has resulted in significant impacts to the species in the wild. United States vary widely in export quantities (**Figure 2**) and while year-to-year export volume can reflect socio-economic conditions rather than availability (Schmidt et al., 2019), the gradual and significant declines in export volumes are likely indicative of declining wild populations —especially when coupled with contemporary botanical field observations (McGraw et al., 2013; NatureServe, 2021). Ginseng is presently listed as "vulnerable" in the United States and out of 33 states where ginseng occurs as an indigenous forest species, seven consider the species to be "critically imperiled" (S1); four "imperiled" (S2); fourteen "vulnerable" (S3); and eight "apparently secure" (S4) (NatureServe, 2021). The species has been listed as "endangered" in Canada since 1999, with exports of wild ginseng prohibited altogether (Ontario Ministry of Agriculture and Food (OMAFRA), 2005; NatureServe, 2021).

Species Biology and Vulnerability

Destructive root harvests exert the most negative impacts on population dynamics among the various types of plant parts

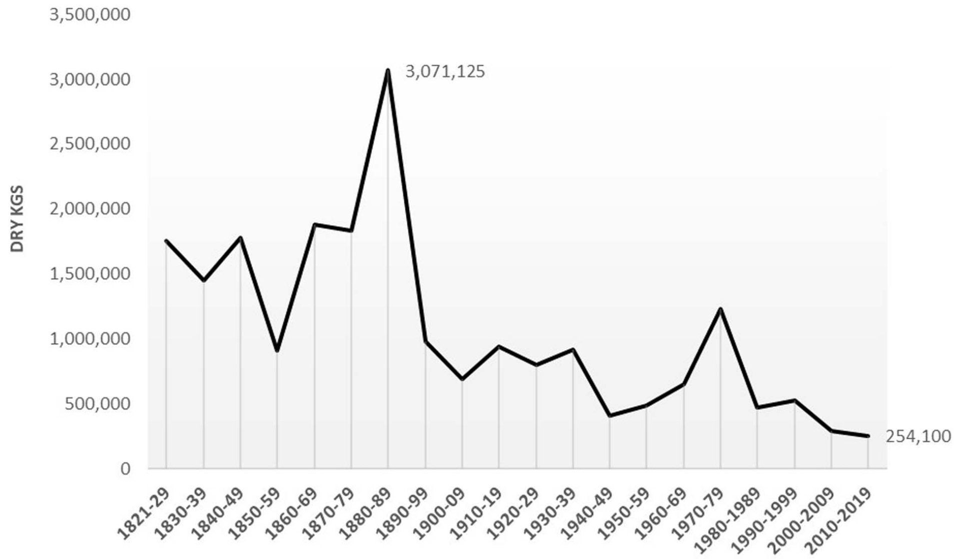

FIGURE 1 | Reported harvest amounts (dry kgs) of wild American ginseng originating from the United States 1821-2019. Data sources: Carlson, 1986; United States Fish and Wildlife Service (USFWS), 2020.

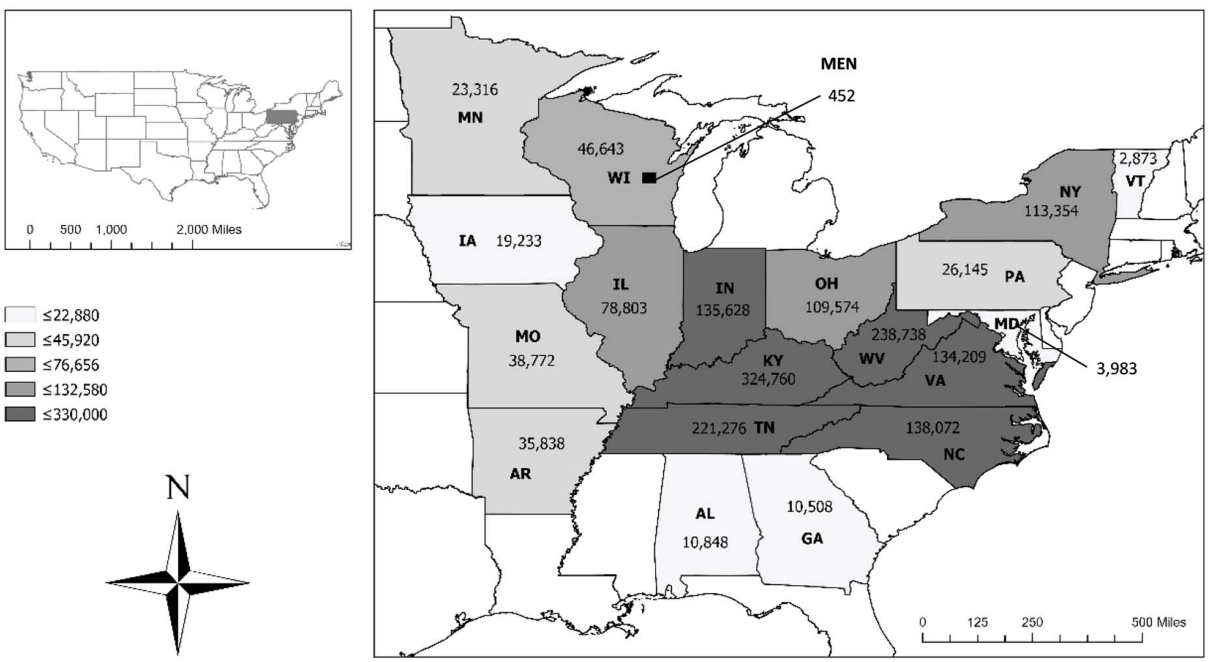

FIGURE 2 | Geographic origins of wild American ginseng harvest exports from the U.S.A. 1978–2019. Shading and labels indicate states with legal export programs. Darker shading indicates greater exports. The year in parenthesis below notes the first year of reported data if different than 1978. Data source: USFWS 2020. State abbreviations: AL = Alabama (1988), AR = Arkansas (1979), GA = Georgia, IL = Illinois, IN = Indiana, IA = Iowa, KY = Kentucky, MD = Maryland, MN = Minnesota, MO = Missouri, NY = New York, NC = North Carolina, OH = Ohio (1980), PA = Pennsylvania (1989), TN = Tennessee, VT = Vermont (1984), VA = Virginia (1980), WV = West Virginia, WI = Wisconsin (1981), MEN = Menominee Nation (2012).

harvested (Ticktin, 2004). With wild ginseng collection, the entire root and attached short rhizome (known as the "neck") are generally taken, resulting in plant mortality. Collector attention to population structure (i.e., growth stages present) and harvest restraint are therefore necessary for continuous, sustained harvests (Van der Voort and McGraw, 2006; McGraw et al., 2013). Even given proper attention, recovery rates can be slow, and years of "rest" between harvests may be required (ibid). On average, about 90 roots, and therefore plants, are required to yield one kg of dry product (Burkhart and Jacobson, 2009; Unpublished data provided by Pennsylvania Department of Conservation and Natural Resources).

Ginseng is a slow-growing perennial herb, requiring at least three growing seasons before reaching reproductive or harvestable stages under cultivation (Ontario Ministry of Agriculture and Food (OMAFRA), 2005) and five or more years in forested habitats (Charron and Gagnon, 1991; McGraw et al., 2013; Davis and Persons, 2014; McGraw, 2020). Regeneration and recruitment occur primarily through seed production and therefore fecundity and seedling survival are important, and often constraining, life history traits. Reproduction is often delayed by years and fecundity is lower in wild plants, in comparison with cultivated plants, which means that wild plants must persist longer in forested habitats to contribute to recruitment (ibid). Moreover, all United States export states have regulations restricting harvest to mature stages, which effectively then inadvertently encourages wild collectors to remove reproductive plants from populations once mature stages are attained, thereby lowering recruitment potential over time (Van der Voort and McGraw, 2006).

In addition to collection for commercial markets, immediate threats to wild ginseng in the United States include loss/degradation of supportive forest habitat types, over-browsing by white-tail deer (*Odocoileus virginianus* Zimmerman), and poaching/theft (McGraw et al., 2013; McGraw, 2020). The last of these, ginseng poaching, is fueled by widespread stakeholder recognition that laws around theft are difficult to enforce and/or successfully prosecute, especially on privately owned lands where jurisdictional boundaries can limit enforcement activities (Pokladnik, 2008; Burkhart et al., 2012). During the past decade, this situation has only gotten worse as United States "reality" television shows (e.g., Appalachian Outlaws, Smoky Mountain Gold) have helped to "normalize" ginseng poaching by unfortunately portraying ginseng diggers, competitive digging, and theft from others as part of a cultural and industry "outlaw" identity (West Virginia Public Broadcasting, 2014).

CITES as a Conservation Mechanism

In the United States, ginseng trade is monitored by both state and federal governments following its 1975 listing in Appendix II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). CITES is an international agreement between governments with the shared goal to ensure that international trade in specimens of wild animals and plants does not threaten their survival (Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), 2021). Appendix II status is reserved for "species not necessarily threatened with extinction, but in which trade must be controlled in order to avoid utilization incompatible with their survival" (ibid).

The United States Fish and Wildlife Service (USFWS), which is part of the Department of the Interior, is responsible for CITES implementation in the United States (Burkhart et al., 2012; Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), 2021). The USFWS has the Division of Management Authority to address policy and permitting issues, and the Division of Scientific Authority (DSA) to deal with scientific issues relating to CITES implementation. Under CITES, ginseng exports must be legal and not detrimental to the survival of the species in the wild. The USFWS has approved export of wild ginseng from the United States on a state-by-state basis since 1978. The DSA relies on individual states' data and determination in making its "non-detriment" determination, as a compliance measure to CITES when approving export of "wild" American ginseng (ibid).

The nineteen approved United States for wild ginseng export (**Figure 2**) have all experienced declines in reported harvest amounts since the species was first listed in CITES in 1975 (United States Fish and Wildlife Service (USFWS), 2019). Accordingly, the question of how effectively CITES is working as a conservation mechanism remains unclear, as is any influence of CITES listing on black market smuggling. At a minimum, a CITES listing elevates the conservation visibility around the species and helps to provide a mechanism for tracking and regulating trade. However, there is disagreement amongst stakeholders as to whether CITES regulations are helping ginseng conservation efforts (Burkhart, 2011; Burkhart et al., 2012; Beyfuss, 2019).

In a case study of CITES implementation in the United States of Pennsylvania, the impact of a CITES-driven "top-down" regulatory approach to wild ginseng conservation was found to be limited (Burkhart et al., 2012). While there was general support amongst stakeholders (e.g., diggers, growers, traders) for conservation efforts, study participants widely shared the belief that many harvest restrictions are not easily enforced—a reality that was externally validated by the fact that law enforcement is often constrained by complex jurisdictional boundaries. Moreover, Burkhart et al. (ibid) found that a lack of public confidence in ginseng conservation efforts stemmed in large part from a perceived failure of natural resource agencies to recognize and stop ginseng habitat loss, serving as justification to adopt critical attitudes toward any government involvement in the trade. Importantly, and relevant to this current paper, is the finding that the most widespread support uncovered for government driven ginseng efforts was involvement of stakeholders as "partners" for *in situ* planting, farming, and restoration.

CULTIVATION AS A SUSTAINABLE USE SOLUTION

Demand for Wild Persists Despite Cultivation

The first attempts to cultivate ginseng in North America began in the late 1800s, following more than a century of wild harvest and trade, in the Appalachian and Mid-Atlantic regions of the United States. One prominent figure during this early period was George Stanton, who started experimental forest beds at his home in Apulia Station, New York around 1885 (Stanton, 1892;

Davis and Persons, 2014). Known in later years as the "Father" of American ginseng cultivation, he investigated both forest- and artificial shade-based horticulture. Stanton's introduction of artificial shading around 1890 was intended to speed up plant development following the observation that ginseng grew very slowly in forest beds. The cultural system he employed featured wooden panels perched upon posts 6-7 feet above raised garden beds to facilitate 70% shade since ginseng is a shade-obligate species. In his pursuit of successful husbandry, Stanton used wild ginseng ecology as his model and attempted to duplicate natural conditions in every respect.

However, it was in Marathon County, Wisconsin that the Fromm brothers perfected the commercial methods still largely used today in artificially shaded field production of ginseng (Polczinski, 1982). Like Stanton, the Fromm brothers developed practices that essentially mimicked the natural requirements for optimum growth and reproduction by carefully observing the occurrence of plants in the wild. The practices they and others adopted included the use of raised beds to provide soil moisture drainage; the application of winter mulches; proper seed stratification to ensure germination; and the construction of lathing to create favorable shade conditions (Van Fleet, 1913; Hardacre, 1974).

Presently, the majority of ginseng is cultivated using these methods in two regions of North America: the upper Midwest United States (Wisconsin) and ON, Canada (Ontario Ministry of Agriculture and Food (OMAFRA), 2005; Ginseng Board of Wisconsin, 2021; Ontario Ginseng Growers Association (OGGA), 2021). Although there are no accurate statistics on production by country, four countries—South Korea, China, Canada, and the United States—are the biggest cultivated producers with a total ginseng root production (fresh weight) of approximately 79,769 tons, which is more than 99 percent of the estimated total world production of 80,080 tons (Baeg and So, 2013). These estimates include all ginseng species known to be cultivated (*P. quinquefolius, P. ginseng, P. notoginseng* Burk*, P. japonicus* C.A. Meyer), however. Artificial shade cultivation (also known as "field cultivation") of ginseng in the North America has supplied export markets and thereby helped conserve wild ginseng by providing an affordable and accelerated alternative to wild. Ginseng cultivation under artificial shade is the primary horticultural arrangement for large-scale production in Ontario, Canada and Wisconsin, United States which are estimated to produce 6,486 and 1,504 tons of ginseng annually, respectively (Baeg and So, 2013). Ginseng farmers utilize artificial shade cropping to mechanize their production and better manage diseases, which in turn shortens the number of years to maturity, increases yields, and reduces labor needs (Ontario Ministry of Agriculture and Food (OMAFRA), 2005; Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA), 2021).

However, the cultural predilections of some Asian consumers, especially within TCM, continue to drive a niche demand for wild ginseng since they are attracted to "wild" labeling and accompanying product characteristics. Ginseng grown *in situ* in forests are likely to possess "wild" traits that are traditionally favored by Asian consumers including taste, shape, color, and texture (Hu, 1976; Guo et al., 1995; Roy et al., 2003). Desirable characteristics include old age, which is demonstrated by a long "neck" (rhizome) with many "neck scars:" transverse "stress rings" on the main body of the root; and variable rhizome branching, with one or more variously shaped tubers attached (Hu, 1976; Upton, 2012; **Figure 3**). By contrast, cultivated ginseng roots tend to be larger, more uniform, younger, and lack many of the subtle characters such as "stress rings."

The market price for wild-appearing ginseng roots is as much as 100 times greater than for artificially shaded field cultivated roots (**Figure 4**; Burkhart and Jacobson, 2009). Such high price premium of ginseng with "wild" traits over products cultivated in artificial shade field have driven continued wild harvests as well as the interest in forest farming in the United States (Davis and Persons, 2014).

Forest Farming and "Wild Cultivation" in the Eastern United States

In the eastern United States, *in situ* forest-based ginseng cultivation was first adopted beginning in the late 1800s (Butz, 1897; Harding, 1912; Hardacre, 1974). The cultivation of crops in an existing forestland understory is referred to, and in recent decades promoted as, "forest farming" in the United States (Gold et al., 2000; Mudge and Gabriel, 2014). Forest farming has been defined as "the integration and management or intentional cultivation of high-value non-wood/timber forest crops such as medicinal and edible plants under the canopy of well-managed forest" (ibid). It is one of five agroforestry practices recognized and promoted by the United States Department of Agriculture National Agroforestry Center (NAC) nationwide (National Agroforestry Center (NAC), 2021). The specific husbandry practices associated with forest farming of ginseng form a husbandry continuum from management *in situ*, using enrichment plantings ("wild-simulated"), to intensive cultivation *in situ* using beds and/or tillage ("woods-cultivated") (Hill and Buck, 2000; Pritts, 2010; Davis and Persons, 2014; National Agroforestry Center (NAC), 2021). Regardless of the approach, ginseng forest farming has the potential to be highly profitable, even at a small scale (Burkhart and Jacobson, 2009; Davis and Persons, 2014). Outside of the United States, ginseng forest farming methods are also being developed and encouraged in rural, mountainous regions within China and South Korea, where it is referred to as "wild-cultivated," "mountain ginseng," "forest-cultivated," or simply "wild" ginseng production (International Federation of Organic Agriculture Movements (IFOAM), 2011).

Because ginseng forest farming has only recently been recognized in the United States, and because of the complexity associated with identifying growers (as discussed under section "Regarding Research"), there have been few efforts to date attempting to track adoption and production. An effort to estimate forest farmer numbers in 1994 estimated the total number of producers in 20 United States at 814 woods-cultivated and 3,334 wild-simulated growers farming 566 total hectares of forestlands (Persons, 1995). In 2000, estimates were again made with a resulting 750 and 3,416 forest farmers suggested, for a total of 818 hectares of woods-cultivated and wild-simulated producers, respectively (Persons, 2000). These estimates are

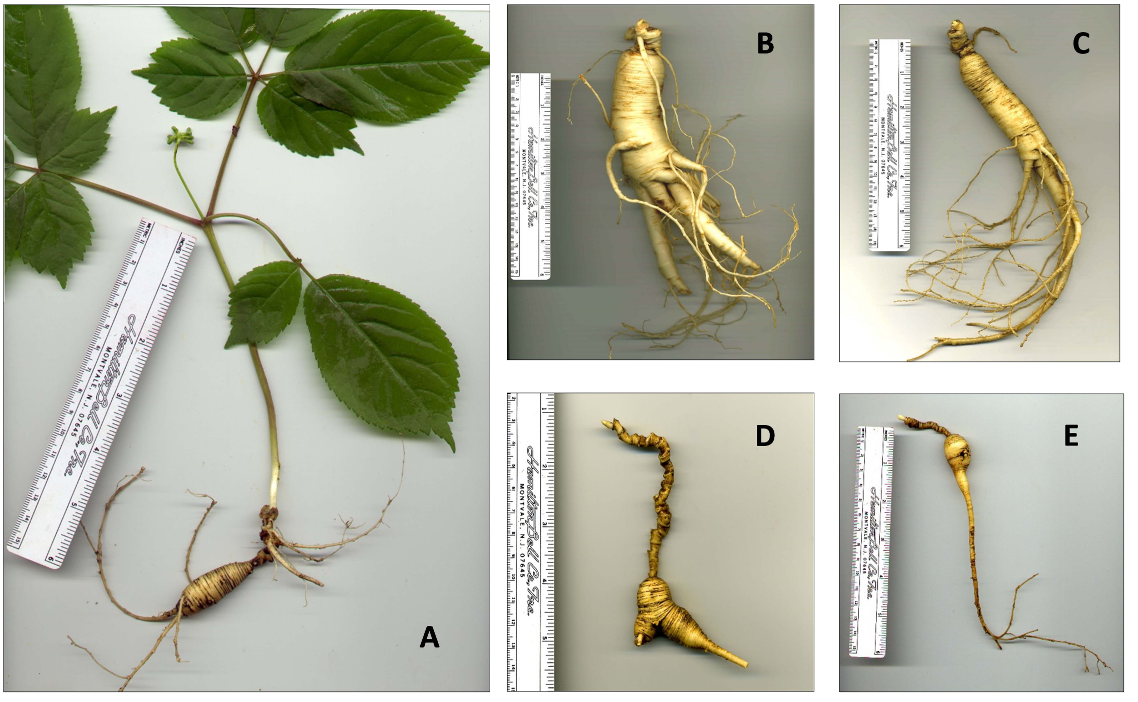

FIGURE 3 | Comparative appearances of different types of American ginseng resulting from different production practices. **(A)** an *in situ* wild-cultivated ginseng plant with top attached is provided for overall scale. Root and attached rhizomes examples include **(B)** cultivated under artificial-shade; **(C)** cultivated under a forest canopy; **(D)** wild; and **(E)** wild-simulated.

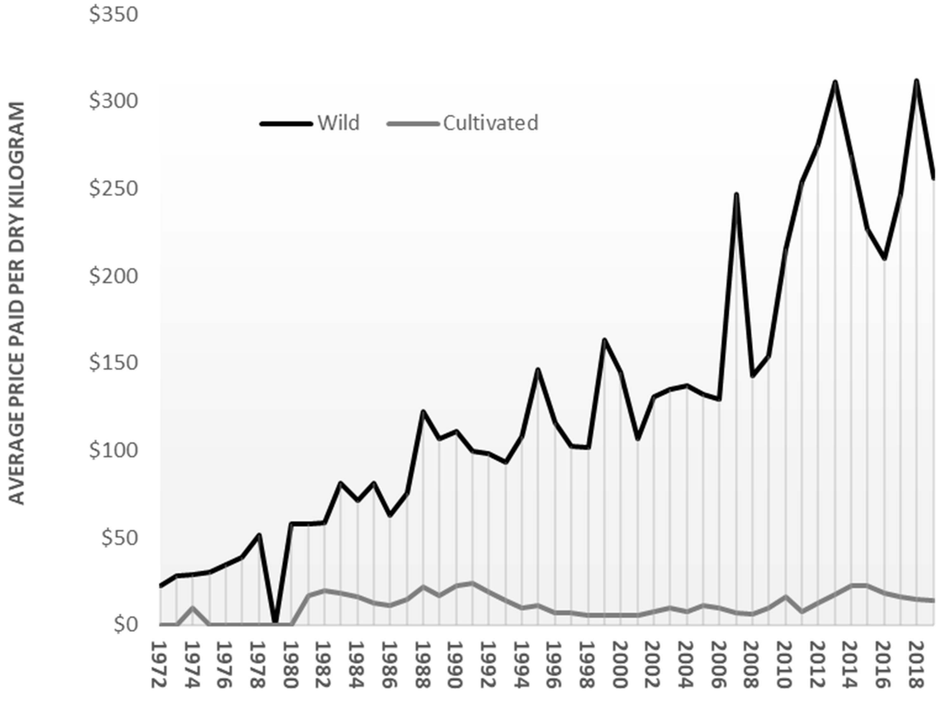

FIGURE 4 | Comparison of the average prices paid for wild versus cultivated American ginseng for the years 1972-2019. (Prices have been sourced from ginseng buyers, producers, publications, and industry experts by EPB).

incomplete, and perhaps even under-representative, as they were compiled by simply querying contacts in each state rather than by examining any type of official industry data (ibid).

Immediate advantages of forest farming are realized by producers through production cost savings. Since ginseng is shade obligate, significant investments in artificial shade structure are necessary when plants are grown in open field settings, with materials and associated labor costs averaging $75,000 (US$) per hectare (Ontario Ministry of Agriculture and Food (OMAFRA), 2005; Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA), 2021). Moreover, ginseng is commonly plagued by fungal diseases under field cultivation which requires frequent and costly use of fungicides (Ontario Ministry of Agriculture and Food (OMAFRA), 2005). Depending on production methods, forest farmed ginseng may not be impacted as much or at all by fungal diseases, by contrast (Davis and Persons, 2014). The cultivation of forest plants *in situ* may therefore eliminate or reduce disease problems and, in turn, the need for pesticide use, thereby facilitating access to "organic" and other niche markets.

Disadvantages associated with forest farming include a slower growth rate, requiring 10 or more years to reach harvestable size, and generally lower yields when compared with field production (Ontario Ministry of Agriculture and Food (OMAFRA), 2005; Burkhart and Jacobson, 2009; Davis and Persons, 2014). In ON, Canada, field production under artificial shade can result in root yields as high as 2,950 kg per hectare (Ontario Ministry of Agriculture and Food (OMAFRA), 2005; Ontario Ginseng Growers Association (OGGA), 2021). By comparison, top yields of 670 kg per hectare are obtained under forest farming production (Burkhart and Jacobson, 2009; Davis and Persons, 2014). Thus, forest farming may be 1/10 as productive as field cultivation when yields alone are considered. These lower yields result from a combination of reduced ginseng biomass production and the heterogenous nature of forest cropping environment which creates both micro-site variation as well as physical barriers (e.g., rocks and boulders, basal tree stems) to cropping. Additionally, forest farmers typically rely heavily on labor for forest-based husbandry activities to minimize site disturbance, which prevents any efficiencies that might be gained through mechanization. *In situ* ginseng farming is also subject to many of the same threats facing wild ginseng populations including targeted theft, wildlife predation, and farming habitat changes resulting from invasive species and/or climate change (Pokladnik, 2008; Davis and Persons, 2014; McGraw, 2020).

Despite these diverse challenges, *in situ* forest farming of ginseng as a conservation strategy can generate direct benefits to ginseng and associated forestland habitats. In particular, the practice of *in situ* enrichment plantings can preserve understory forest biodiversity, and function in wild population restoration or augmentation (Burkhart, 2013; International Union for Conservation of Nature (IUCN), 2013; Chittum et al., 2019). Forest farming offers multiple economic and ecological benefits while also being attractive to forest landowners since the practice has the potential to increase income while maintaining forest integrity (Hill and Buck, 2000). Income derived from forest cultivation is received at shorter intervals than timber, giving private forest landowners more revenue options, enabling them to pay annual taxes and other carrying costs. Facilitating private landowner adoption of forest farming can therefore drive interest in forest stewardship, raise awareness about indigenous forest plants, and positively influence silvicultural decisions (Burkhart and Jacobson, 2009).

PROMOTING FOREST FARMED GINSENG AS A SUSTAINABLE USE STRATEGY

Challenges

Planting Stock Origins and Conservation of Wild Genotypes

The scaling-up of ginseng forest farming as a conservation strategy faces the fundamental challenge of securing adequate planting stock supplies while concomitantly utilizing and protecting wild ginseng genetic resources. Currently, most forest farmers in the United States obtain stock sourced from artificial shade ginseng farms in Wisconsin, which produce seed as a by-product of root production (Ontario Ministry of Agriculture and Food (OMAFRA), 2005; Davis and Persons, 2014; Burkhart et al., 2021). A persistent concern surrounding the planting of this "commercial" stock in forested environments is therefore how this stock might impact remaining local wild genotypes (e.g., United States Fish and Wildlife Service (USFWS), 2019). The introduction of non-local seed may, for example, result in "genetic swamping," or the rapid increase in number of the introduced ecotypes or alleles in a population (Kramer and Havens, 2009). If these introduced ecotypes or alleles have a fitness advantage over the local ecotype, replacement of the local ecotype may occur (Hufford and Mazer, 2003). Concerns about genetic preservation and maintenance in wild plant populations has led to many in the conservation community to recommend using only local seed sources for restoration purposes to preserve local gene pools and to prevent outbreeding depression (Vallee et al., 2004; McKay et al., 2005). However, there is a lack of consensus, and considerable complexity, around this topic, and each species needs to be considered on a case-by-case basis (McKay et al., 2005). For species that have experienced dramatic population declines and fragmentation, inbreeding depression is common across many populations (Angeloni et al., 2011) and mixing local and non-local populations as planting source materials is sometimes recommended to overcome inbreeding depression in restoration (Frankham et al., 2011). This approach may be increasingly attractive as assisted population migration (Handler et al., 2021) may be required for applied plant conservation and restoration efforts under future climate change and extreme climate events (Maschinski and Haskins, 2012; Maschinski et al., 2013). It is presently unclear whether wild ginseng is more at risk of inbreeding or outbreeding depression (Schlag and McIntosh, 2012).

Additionally, for more than a century in the eastern United States, the distribution and genetic composition of wild ginseng have been greatly impacted by human husbandry through harvesting, planting, and "stocking" practices (Burkhart, 2011; Young et al., 2012; Davis and Persons, 2014; Burkhart et al., 2021). The use of non-local stock therefore needs to be considered through the unique and long-term cultural significance of this species, especially on privately owned lands, in which husbandry has resulted in a "middle ground" where plants may no longer be simply wild or cultivated and populations may be comprised of germplasm resulting from decades, lifetimes, or generations of planting activities (Hardacre, 1974; Burkhart, 2011; Burkhart et al., 2021). Research has shown that some forest farmers in the eastern United States may generate and maintain their own genotypes and chemotypes (Schlag and McIntosh, 2013) and such examples could be used to stimulate interest and collaboration by the broader public in conserving and sharing germplasm, as is currently done with other "heirloom" horticultural specialty crops (e.g., Seed Savers Exchange Mission, 2021). Forest farmers should be encouraged to establish any introduced "commercial" stock away from existing wild populations and use existing local, regional, or diverse purchased stock sources wherever possible. Some states (e.g., West Virginia Ginseng Program, 2021) with wild ginseng programs require that state-recognized forest farms be inspected and demonstrated to be free of existing wild ginseng before planting approval is given.

In coming decades, a reliance on non-local genetic stock which is undergoing unconscious selection (Zohary, 2004) through artificial shade culture may prove to be an increasingly important, and limiting, factor impacting ginseng forest farming success. There is an urgent need for the coordinated development of a United States ginseng germplasm conservation, propagation, and restoration/farming network pursuing an *in situ* "ecosystem domestication" approach (Michon and de Foresta, 1996) in which breeding, lineage selection, and maintenance is conducted *in situ* as an alternative to current *ex situ* stock sourcing approaches. By encouraging an "genetic awareness" amongst forest farmers and forest landowners, it may be possible to engage the United States public in longer-term collaborative efforts intended to actively protect and conserve remaining wild germplasm resources, and utilize this stock in future initiatives to scale-up forest farming using local or regionally sourced materials. Indeed, many current ginseng forest farmers in the eastern United States have found that the production of planting stock (e.g., seed, transplants) for sale to other landowners can be more profitable than production for root markets (Davis and Persons, 2014).

A CITES-Driven Lexicon

An immediate challenge confronting ginseng forest farmers is the "cultivated" vs. "wild" binary labeling derived from CITES. The present ginseng trade lexicon under CITES (Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), 2021) is used by many United States on trade paperwork. It identifies "cultivated" plants as "artificially propagated" and in Resolution Conf. 11.11 (Rev. CoP14) defines these as follows:

> Plants grown under controlled conditions from seeds, cuttings or divisions of cultivated parental stock. A controlled condition is defined as a non-natural environment that is intensively manipulated by human intervention. General characteristics of controlled conditions may include but are not limited to tillage, fertilization, weed control, irrigation, or nursery operations. The cultivated parental stock used must have been established in accordance with national and State laws, determined not to be detrimental to the survival of the species in the wild, and managed in such a way as to guarantee long-term maintenance of the cultivated stock.

Any ginseng that does not meet these criteria is "wild" under CITES and at present, *de facto*, by USFWS and State export programs. Burkhart et al. (2021) suggest that this dichotomous lexicon is far too simplistic to account for the breadth of forest farming practices that are being employed to produce roots ultimately sold as "wild." When forced into this dichotomy, forest farmers often choose to report their product as wild, fearing pricing disparities (discussed below), theft, taxation, and disagreement over what constitutes "wild" (ibid).

However, while self-declaring forest farmed ginseng as "wild" can bring higher profit for farmers, it also increases exportation barriers due to CITES restrictions. The complexities and costs associated with applying for export permits also prevents forest farmers from legally selling their products directly to customers in China and east Asia via e-commerce platforms. Additionally, forest farmers often do not have the knowledge or financial resources to apply for CITES permits to sell small amounts of wild-cultivated ginseng internationally (Burkhart, pers. comm. with producers). The burden of applying for CITES export/import permits may be one of the reasons that very few or no vendors sell wild and wild-cultivated ginseng on e-commerce platforms in Hong Kong, China, Singapore, and Taiwan (Arik et al., 2020).

In the online retail market survey mentioned in section "Cultivation as a Sustainable Use Solution," each of the named countries or regions, e.g., Mainland China, Hong Kong China, is an independent CITES entity, with its own national or equivalent domestic laws and authorities to carry out CITES regulations. Even though Hong Kong is part of the China, it has its own CITES related domestic laws, scientific and management authorities (Agriculture, Fisheries, and Conservation Department of Hong Kong, 2020). In addition, while Taiwan is not a CITES signatory authority because it is not a member of the United Nations, it participates in CITES and abides by the rules of this international convention voluntarily (Forestry Bureau of Republic of Taiwan, 2016). Import of ginseng into these countries and regions requires a CITES export permit issued by the authority of the exporting country and a license to import from the import country's managing authority.

Another significant challenge to the forest farming in the eastern United States is that it remains a largely secretive and poorly documented. In eight years of annual surveying of Pennsylvania sellers, Burkhart et al. (2021) found that "wild" exports consisted of a mix of collected, planted (along with various husbandry practices), and forest farmed product. A complex suite of husbandry practices was found to be involved in modern wild ginseng occurrence and these practices obscure and complicate distinctions between "wild" and "cultivated."

Importantly, Burkhart et al. (ibid) also found that attempts by United States to clarify the origins of "wild" ginseng through forest farming terminology in point-of-sale paperwork are often resisted or falsified because sellers harbor concerns regarding buyer-trader pricing and crop taxation. Regarding the former, it is recognized that many buyers pay less for wild-cultivated product even when it is indistinguishable from wild so that they can re-sell for a higher profit margin. Rumors of unfair pricing have resulted in low rates of seller compliance when asked to report forest farming activities in some United States that have worked to implement measures for differentiating wild-cultivated from wild ginseng (ibid).

Forest Farmed Product in Chinese E-commerce

More than 95% of American wild ginseng exports is sold to consumers in Mainland China and adjacent regions where TCM cultural practices are popular (Baeg and So, 2013; United States Fish and Wildlife Service (USFWS), 2013; Arik et al., 2020). To understand the current retail venues in the above regions, as well as in the United States where wild and forest farmed ginseng is produced, we carried out searches on popular e-commerce platforms using the key words "wild American ginseng" and "semi-wild American ginseng" (**Table 1**). To search vendors in Mainland China, we used the most popular e-commerce platform "Taobao.com" and the related Chinese key words "野生花旗参," "半野生花旗参," "野生西洋参," or "野生花旗参" (meaning "wild or semi-wild American ginseng"). To search vendors in Hong Kong and Singapore, we used google.com using the same Chinese keywords. To search vendors in Taiwan, we use the popular internet platforms shopee.tw, momohope.com.tw, and Pchome.com.tw. And finally, in the United States, we used Amazon.com and Google.com for our searches. These searches were not exhaustive but rather exploratory and aimed to identify major e-commerce retailers, and examine any terminology used to describe the product being sold, especially whether there is a presence of any conservation appeals to consumers.

Among the countries and regions studied, the United States had the largest number of vendors (9) selling wild ginseng, mostly distributed in California and New York. All but one had a physical store. Vendors in Mainland China (8), Hong Kong China (4), and Singapore (2) also sold wild or wild-cultivated ginseng. Online vendors in Taiwan sold cultivated ginseng products only and were not included in our analysis. Many well-known traditional vendors of ginseng such as Tongrentang (同仁堂), a famous TCM company, sold cultivated ginseng but surprisingly did not offer wild or wild-cultivated ginseng via e-commerce, even though the company is known to import both types of ginseng (Arik et al., 2020).

The most frequent terms used in e-commerce to promote ginseng in Mainland China and adjacent regions were the following: "Wisconsin," "American imported," "wild forest grown," "authentic from North America," "pollution-free," and "old age." Significantly, messages on sustainability and conservation were mostly absent in accompanying promotional language suggesting that while the socio-economic and environmental benefits associated forest farming of ginseng are understood in the United States, these are not being communicated to the ginseng consumers in Asia who constitute the overwhelming majority of whole-root consumers worldwide.

Hong Kong has been the most significant ginseng trading for decades and is the largest consumer of ginseng in the world (Robbins, 1998; Arik et al., 2020). A significant portion of the wild or wild-cultivated ginseng roots are imported from the United States through local-registered trading companies, priced in Hong Kong, and redistributed to China and adjacent regions. However, given the rapid economic development and maturation of e-commerce platforms in Mainland China in the past 10 years, the importance of Hong Kong for Mainland China as a hub for international goods has been declining as more goods are being traded directly between China and other countries. This is likely to be the case for ginseng, as American based vendors have begun to set up shops on Chinese e-commerce platforms. This change in trading venues and hubs presents new opportunities to create innovative value chains and new ways to promote forest farmed ginseng (Arik et al., 2020).

Opportunities

CITES and Recognition "Human Assisted" Production

Increased transparency is key to the continued expansion of ginseng forest farming and consumer awareness. A clear lexicon around ginseng planting, husbandry, and forest farming would help facilitate a more realistic and dynamic understanding of wild ginseng status and improve conservation and enforcement efforts (Burkhart et al., 2021). USFWS has continued to urge United States to implement measures for differentiating "wild simulated" ginseng from "wild" (United States Fish and Wildlife Service (USFWS), 2019).

A new production category has recently been accepted by CITES signatories referred to as "human assisted" (Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), 2019). This production category is intended to better acknowledge the status surrounding many wild plant species which do not fall "within the definition of 'artificially propagated' and are considered not to be 'wild' because they are propagated or planted in an environment with some level of human intervention for the purpose of plant production" (p. 9, Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), 2019). This new production category creates a pathway for forest farmed ginseng to be recognized as being distinct from both the conventional "cultivated" and the "wild" in commerce.

E-commerce and the Emergence of "Green Products" in China

Despite a relatively late start, e-commerce has been steadily increasing in China along with internet user numbers (Marinova, 2017; The China Internet Network Information Center (CNNIC), 2020). Among the 940 million internet users documented in China as of June 2020, 749 million or nearly 80% of internet users have participated in online shopping (The China Internet Network Information Center (CNNIC), 2020). E-commerce options include species of conservation concern

TABLE 1 | Major wild and semi-wild American ginseng retail online companies in Mainland China, Hong Kong, Singapore, Taiwan, and the United States.

Company	Company Headquarter	Country	Product Type	Product Classification	Positioning		Country of Origin
					Chinese	English	
Hong Kong Yingfeng Trade co., LTD (香港莹锋贸易有限公司)	Guangdong/ Shenzhen	China	root trunk, slice, powder	Age/ Size/ Shape	美国半野生 10 年 10g 参 30 年纯正野生美种野生“	American semi-wild 10-year 10 g ginseng 30-year authentic wild American ginseng	United States (WI)
mohongchun 840322	Jilin/ Baishan	China	root trunk, slice	N/A	无污染天然种植; 自产销; 野生	Pollution free, naturally grown, sold by farmer directly, wild	Changbai Mountain, China
Lanzhirui (1234567890 蓝芝瑞)	Yunnan/ Wenshan	China	Root trunk, slice	N/A	美国花旗参进口野生西洋参粉花旗参西洋参片“ “美国进口花旗参””“天然 无硫 支持药检” “正宗进口花旗参为八年老参 个个均匀饱满”	Imported American ginseng powder and slices; Imported from United States; Natural, sulfur-free, support drug test; authentic imported, 8-year old aged ginseng, evenly plump;	Imported
Shenghongtang (李慧芳 8883 盛弘堂参茸药材海味)	Guangdong/ Guangzhou	China	Root (trunk)	Age (6-year and above), size (3g -30g/ root)	加拿大西洋参整支特级野生粒头整枝; 加拿大进口原皮无熏染 8 年老参 8 年自然无干扰林下生长，自有基地系统种植	Canadian ginseng, top grade wild root trunk; Canada import; no smoke contamination; 8-year aged ginseng; naturally grown under private forest canopy for 8 years.	Canada
Yingzhongtang (kinglover06 益众堂养生)	Guangdong/ Jieyang	China	Root slice	Age (6-year)	加拿大进口泡茶人参片” “特级野生 来自加拿大安大略省 纯天然来自加拿大	Canada imported ginseng slices;came from Ontario Canada; purely natural	Canada (Taylor Ginseng Farm)
Changbaishan Yongbao Store (长白山永宝店)	Jilin/ Baishan	China	Root slice	Age (6 or 8-year)	特级野生北京同仁堂花期参 8 年参老参味浓 纯正洋参 营养丰富	top grade wild Beijing Tongrentang American ginseng 8-year ginseng old aged ginseng with strong flavor; pure western ginseng; nutrient rich	China (Jilin)
Authentic popular goods special sales (正品行货特卖场)	Guangdong/ Guangzhou	China	Root small branches	NA	西洋参须参脚美国花旗参脚进口西洋参根八百光野生西洋参干净新鲜 无硫无添加	Western ginseng small root branches, Imported western ginseng, wild western ginseng; clean and fresh; sulfur-free additives-free	Mainland China
Fukang Traditional Health Supplements Store (富康传统滋补品店)	Guangxi/ Yulin (Global trader certified)	United States and China	Root trunk	Size (0.5/ root)	美国威斯康辛州进口精选野生黑色花旗参,味浓西洋参段, 野山泡参粒头吃参就要吃性价比,入口回甘,参味浓郁	American Wisconsin imported, selected wild; black American ginseng; strong flavored western ginseng root segment; Wild mountain ginseng root trunk; best value for money; sweet after taste; strong ginseng flavor	United States

(Continued)

TABLE 1 | Continued

Company	Company Headquarter	Country	Product Type	Product Classification	Positioning		Country of Origin
					Chinese	English	
Weiyuantang (位元堂)	Hong Kong	Hong Kong, China	Root slice, branch, whole root, powder	N/A	優質野生花旗參產自美國加拿大等地，質量與功效亦為上等。	Wild grown and imported from America, with superior quality and functions	United States
HK JEBN 楼上	Hong Kong	Hong Kong	Root slice, branches, whole root, powder	Age/ Size/ Shape	美國野山花旗蔘生長於罕無人煙的叢林之中，特別是美國東至東北的寒冷地區。多年以來美國原住民已懂採用當地花旗蔘，視為至寶。現在科學證實野山花旗蔘亦發現所含的活性成份－人蔘皂苷，從而肯定了野山花旗蔘的價值。野山花旗蔘每根外形也獨一無二，而每棵野山花旗蔘最少已生長有 5 年或以上，（美國農業部因保育理由，限制採蔘人不可掘出年份 5 年以下的野山蔘）。	Wild American ginseng grows in uninhabited forests, especially in the cold northeastern America. The Native Americans have known the applications of the local ginseng and treasured it since a long time ago. Nowadays the active ingredients of the wild ginseng called Saponins have been discovered and its value confirmed by science. Each ginseng root is unique by its appearance, and each wild ginseng root is at least five years old. (For conservational reasons the United States Department of Agriculture has forbidden the unearthing of wild ginseng roots below the age of five years).	United States
Home of Swallows 燕之家	香港	Hong Kong	Root trunk	N/A	美國野生花旗參於生長過程中，不施加任何化學材料，任其於完全自然的肥沃森林土質中自然生長，以保留它百分百純天然本質。	American wild ginseng with no chemical material during its growth, allowing it to grow naturally in completely natural fertile forest soil to retain its 100% pure quality.	United States
Tung Fong Hung 东方红	香港	Hong Kong	Root slice, trunk, whole root,	Size/ Shape	生長於美國的原始密林中，吸收大自然的天地精華，生長過程完全不受化學肥料、農藥或殺蟲劑的污染，產量稀少，極為珍貴。因天然根深入，故蘆頭細長而多節，有的由 1 吋到幾吋長，蔘鬚很長，有細珠粒，蔘身横紋密而深色；野生蔘以大粒、蘆頭蔘鬚完整為貴，近年科學研究指蘆頭的藥效比參身還要好。	From primitive dense forests in the United States, absorbing the essence of nature, the growing process is completely free from chemical fertilizers or pesticides. It is rare and precious. Because the root trunk is growing deep, it is slender and multi-sectional, long up to a few inches; It has a fine grainy skin, firm and dark color. Wild ginseng is expensive for its size and entirety of the roots. In recent years, scientific research has shown that trunk is more effective than other parts of ginseng body.	United States

(Continued)

TABLE 1 | Continued

Company	Company Headquarter	Country	Product Type	Product Classification	Positioning		Country of Origin
					Chinese	English	
ZTP 正中平	新加坡	Singapore	Root slice, trunk	Size/ Age	N.A.	N.A.	United States
Hockhua 福华	新加坡	Singapore	Root slice, trunk	Size/ Age	产地: 美国深山丛林 特点:产量极少，功效奇特。优点:福华所进口的野生花旗参都有世界野生动植物 保护协会(CITES)的证书。消费者大可放心选购。	All Wild American Ginseng imported by Hockhua are certified by CITES (Convention on International Trade in Endangered Species of Wild Fauna and Flora), an international body regulating the trading of wild and endangered Flora and Fauna.	United States
Wing Fung Hong Ltd 榮豐行	New York (on Amazon)	United States	Small Round	NA	半野生花旗参小泡	Half Wild American Wisconsin Ginseng; Free US Shipping; Helps Fatigue and Improves Energy; Fresh and New	United States
Dasao United States General Products Distributor Inc.	New York (on Amazon)	United States	Root trunk	NA	DaSao United States AAA Grade American Ginseng/ Half Wild Ginseng Gift Bag 美国威州花旗参/(西洋参)/半野生花旗参	High-Quality American Ginseng M/ L Long Root. 8oz per bag. 1lb is 2 bags - scientists have discovered that ginseng is beneficial in the following areas: Decreasing the harmful effects of stress. Increasing stamina. Improving memory. Fighting diseases. Decreasing high blood sugar levels.	United States (WI)
DABC EAGLE INC.	California (on Amazon)	United States	Root trunk	Shape (long vs pearl ginseng root)	美国威斯康辛州野生西洋参 100%威斯康辛州野生西洋参/花旗参，极为稀有，参龄大多十年二十年以上。参面横纹较显著，人参皂质含量最高。秋冬进补、年底走亲访友珍贵礼品首选哦！	American Wild Ginseng 15~20 Years, Wisconsin Whole Ginseng Root Hand-Selected. 100% Premium American Ginseng from Wisconsin, they are antioxidant rich food source, widely used as a dietary supplement and botanical element and Traditional Chinese Medicine (TCM). Helps you stay energized and healthy! our American Ginseng is non-GMO, vegan friendly, and gluten-free. No Caffeine, No Sugar, and No Preservatives. Great for Gift-Giving. Premium American Ginseng is renown for its aromatic taste, rich flavor, and traditional health benefits.	United States (WI)

(Continued)

TABLE 1 | Continued

Company	Company Headquarter	Country	Product Type	Product Classification	Positioning		Country of Origin
					Chinese	English	
China food co. LTD	Fujiang, China (on Amazon)	United States	Root trunk	Color (black or not)	西洋参天然野生精选		
TAK SHING HONG 德成行	California (on Google)	United States	Root truck, slice, power	Shape	德成行 美国半野生花旗参	Semi-Wild American Ginseng	United States
Green Gold Ginseng	Wisconsin (on Google)	United States	Root	Size/ Shape, semi wild or wild harvested	正野山参	Wild American Ginseng Small Roots	United States
Hsu's Ginseng Enterprises, Inc. 许氏人参	Wisconsin (on Google)	United States	Root, slice, powder	Size/ Shape transplanted, wild harvested	正野珍珠花旗参	Wild American Ginseng Pearl Roots	United States
Chinatown Online United States 中国城	New York (on Google)	United States	Root slice, powder	Size/ Shape semi wild or wild harvested	精选美国正野山参	Wild American Ginseng, Best-Quality American Ginseng	United States

Note that no vendor from Taiwan is listed here because none offered wild or semi-wild American ginseng online.

(SOSC) (International Fund for Animal Welfare (IFAW), 2014; Yu and Jia, 2015; Wong and Liu, 2019); in a survey of wildlife trade which included both physical and online trading platforms, for example, more than half of the approximately 33,000 items of wild plant and animal SOSC in trade were offered on Chinese websites (International Fund for Animal Welfare (IFAW), 2014).

The emergence and growth of e-commerce platforms provides expanding opportunities for United States-based forest farmers to connect directly with consumers in China and neighboring regions, thereby reducing the number of intermediaries involved in supply chains. An ability to connect directly with Asian consumers is an important next step in the development of the United States ginseng forest farming industry, as it will help provide opportunities to maintain or increase profitability while differentiating and branding semi-wild products (Arik et al., 2020). In our survey, we did find United States-based companies offering forest farmed ginseng using e-commerce platforms, but these were very limited (**Table 1**).

From a producer perspective, this lack of market penetration is primarily due to the complexity and costs associated with application for CITES export permits from the United States, along with language and communication barriers (Burkhart, pers. comm. with forest farmers; Robbins, 2003; Burkhart, 2011). However, it must also be noted that there are challenges on the importation side including tariffs, which can lead to smuggling (Hsu, 2000), and a reluctance to be transparent. For United States forest farmers to take advantage of e-commerce platforms, there needs to be non-intimidating mechanisms or pathways within the CITES export/import process to permit small quantities of semi-wild ginseng to be sold directly to consumers, perhaps as part of implementation of the new CITES "human assisted" production category. This is especially important since most United States forest farming operations are mostly small-scale, often producing on less than one hectare of forestlands (Persons, 1995, 2000; Davis and Persons, 2014; Burkhart et al., 2021).

While we found little content featuring sustainability and conservation messaging on ginseng vendor e-commerce platforms in our survey, research suggests that there is an emerging consumer awareness of these concepts in China (Jin and Zhao, 2008). Agricultural products which feature such messaging are often referred to as "green food" —a concept that was first proposed in 1989. In 1992, the country established a green food management agency (i.e., China Green Food Development Center) and announced the development of a green food industry (China Green Food Development Center (CGFDC), 1992). Some environmentally friendly packaging and labeling systems have also been used for promoting wild-cultivated plants in TCM (TRAFFIC, 2013). In 2020, livestreamed online trading has become a trend among young consumers who, perhaps surprisingly, also consume TCM products including ginseng (Liu, pers. observation). Younger Chinese consumers possess increasing awareness around sustainability, which may exert a significant influence on attitudes and consumer behavior (Huang et al., 2017; Sustainable Lifestyle Lab, 2019). Green marketing and certification could play a crucial role in making forest farmed ginseng appealing to consumers, especially as there is also widespread distrust of production and environmental claims (Wang et al., 2018). Authentication provided through certification could provide confidence and quality assurances to consumers seeking and willing to pay for forest farmed ginseng products. Similar branding (e.g., Wisconsin ginseng "seal") and messaging are already used within China for artificial shade produced ginseng originating from Wisconsin with good success (Ginseng Board of Wisconsin, 2021).

The convenience of e-commerce, however, also brings enforcement challenges as it will undoubtedly add difficulties in CITES enforcement when dealing with actual wild product (Bennett, 2011; Shirey et al., 2013; International Fund for Animal Welfare (IFAW), 2014; Yu and Jia, 2015; Hinsley, 2018; Wong and Liu, 2019). In our survey, we noted that e-commerce vendors located in Hong Kong China and Singapore displayed their CITES permits while those in Mainland China did not, demonstrating that enforcement of CITES on e-commerce should be monitored closely. To this end, Alibaba, Tencent, JD.com, and several other big e-commerce platforms in China joined in a "Wildlife Free E-commerce" campaign targeting online illegal sales of wild products in 2019. Unfortunately, illegal smuggling and ginseng trade continue (Ting, 2020) and the Covid-19 pandemic may have exacerbated the situation by restricting travel (Master and Nickel, 2020). Under the Covid-19 pandemic, new channels have developed in China for on-line trading of wild products such as the short video and live streaming APP Douyin (the Chinese version of TikTok). On these live streaming sales platforms, wild product advertisements sometimes include no key words or text, which makes monitoring and law enforcement even more challenging than traditional social media and the E-commerce platforms (Ebersole, 2020). Funding for research, collaboration, and monitoring of e-commerce trade will be needed to ensure proper enforcement of CITES regulations if forest farming is successful as a sustainable use strategy.

Product Certification

Forest farming of many indigenous eastern North American forest understory medicinal plants with significant commercial demand is increasingly acknowledged as a desirable future supply chain condition that could improve sustainability, quality, and livelihoods (Elevitch et al., 2018; Chittum et al., 2019). Increasingly, there is interest in exploring certification mechanisms for forest farmed non-timber forest products (NTFPs) in the eastern United States (Appalachian Beginning Forest Farmers Coalition, 2020), as an opportunity in such efforts. The idea of a ginseng certification program was proposed nearly two decades ago by Robbins (2003) but nothing emerged among international stakeholders. In 2014, a "Forest Grown Verification" (FGV) program was launched by Pennsylvania Certified Organic to provide a potential pathway for forest farmers to document ginseng and other forest "crops" in the eastern United States and provide consumer assurances regarding sustainability and source (Rubinkam, 2015; Leopold and Ormsby, 2016; Elevitch et al., 2018). The program is now administered by United Plant Savers (an NGO based in OH, United States) with forest farmer members enrolled throughout the eastern United States To date, however, forest farmers in this certification program have been selling primarily to United States consumers (United Plant Savers, 2020; Mountain Rose Herbs, 2019), because no direct export markets or sales to Chinese consumers have been possible as a result of CITES restrictions and lack of semi-wild product labeling opportunities within China and nearby regions.

Additional certification options for ginseng exist beyond the United States-based FGV program (Elevitch et al., 2018), perhaps most notably FairWild (2021), which could be used to in conjunction with FGV or as an alternative in international ginseng trade. FairWild is a "verification system that has specifically been designed to offer a meaningful and comprehensive guidance framework and certification option for all sustainably collected wild plant, fungi and lichen species worldwide (ibid)." However, broad enrollment in these programs will undoubtedly require further fine-tuning of standards and logistics using stakeholder input, in order to make certification accessible to the many low-income and poorly educated forest farmers in rural areas of the eastern United States Additionally there need to be incentives for forest farmers to want to join these programs as many are already profitable and see no need to complicate their farming businesses and divulge the wild-cultivated origins of their products, as discussed in Section "Regarding Research" (Burkhart, pers. comm. with forest farmers; Robbins, 2003).

CONCLUSION AND RECOMMENDATIONS

Our e-commerce survey results indicate that many Chinese medicine stores with a long tradition of selling ginseng within China do not offer wild or wild-cultivated ginseng, at least in visible e-commerce storefronts. Moreover, those that do sell wild or wild-cultivated ginseng lack any messages regarding any environmental benefits and sustainability associated with the *in situ* forest farmed ginseng. This *status quo* does not capture the increasing availability of forest farmed ginseng available from the United States, nor does it capture the emerging awareness of sustainability and demand for "green" products among Asian consumers. We suggest that wild-cultivated ginseng resulting from *in situ* -forest farming be prioritized and promoted as a sustainable use strategy within Asian countries, since it appeals to traditional TCM niche demand by consumers interested in wild traits and origins, and can also meet growing consumer desire for sustainable and green products.

Recent developments within the CITES regulatory trade framework to recognize wild-cultivated products through labeling as "human-assisted" could facilitate improved transparency during the process of importation and in retail shops and e-commerce markets. This pathway should also be explored to permit sales of small quantities of wild-cultivated ginseng from United States forest farmers directly to consumers, thereby incentivizing small-scale producers to be transparent.

Currently, small forest farmers find it easier to simply sell their product as wild. In efforts to promote forest farmed ginseng to consumers, the use and promotion of TCM quality assessment alongside emerging "green" product messaging will be key to encouraging Chinese consumers to choose forest farmed over wild ginseng.

However, it is likely that even with the new "human assisted" label in place, traders and consumers will continue to show a willingness to pay more for what is believed to be truly wild ginseng over human assisted products. In fact, "semi-wild" is an existing ginseng product category in online retail stores in the United States and Asia, with prices set somewhere between "wild" and "cultivated." There is a concern that this may lead to continued impetus to deceive within supply chains and reluctance for any significant cultural shift toward transparency. However, the possibility of alternative supply chains in which growers may relate to the end markets directly or with reduced steps has the potential to increase profitability along the product value chains and allow for new opportunities for fair pricing (Arik et al., 2020). The expansion of e-commerce platforms into China and neighboring regions can facilitate the creation of such alternative supply chains. Widespread implementation of environmental product labeling and certification can increase transparency regarding origins and documentation of *in situ* planting activities, particularly in the indigenous range of the species. Environmental product certifications issued in the United States will also likely help to address the widespread lack of trust in product origin, cultivation mode, and sustainability claims among Chinese consumers (Wang et al., 2018). While potential new sales venues and packaging trends in China and neighboring countries offers new opportunities, these also present new challenges in achieving CITES compliance while conserving remaining wild populations that will need to be concurrently considered.

We therefore offer the following recommendations for future research and collaboration intended to encourage broader recognition and demand for wild-cultivated ginseng, and help drive more transparent and rapid adoption of forest farming as a conservation strategy:

Regarding Research

1. **Map entire product value chains to increase transparency.** This should include a feasibility analysis and extent of alternative value chains to increase forest farmer profits.
2. **Conduct consumer preference and conjoin analysis studies.** These should examine awareness around ginseng conservation needs and surveys around sustainability concepts and willingness to pay for forest farmed products. This includes emerging value-added products such as extracts, teas, and processed supplements as these would encourage United States forest farmers to certify before exporting and generate new market penetration opportunities.
3. **Develop mechanism to conserve remaining wild ginseng stocks in the United States while providing germplasm and planting materials to forest farmers.** This should include efforts to select, retain, and breed for desired traits such as phytochemistry, disease resistance, and/or to maintain regionally adapted planting stock under forest conditions. Forest farmers should be encouraged and taught how to preserve "heirloom" stock and United States should encourage or partner in the development of ginseng nurseries to produce acceptable planting stock.

Regarding collaboration:

1. **Implement CITES "assisted production" category in international trade between treaty members, especially in United States exports to China, Hong Kong and Taiwan, and work to establish transparent pathways for sale of semi-wild ginseng.** Work with stakeholders (e.g., producers, sellers, buyers, traders, government agencies) to find acceptable pathways, including certification mechanisms, to document forest farmed ginseng in domestic supply chains and to reduce the complexity and costs associated with CITES permitting so that smaller quantities of ginseng may be legally and transparently sold by forest farmers who participate in these pathways. Promote regular dialogs and collaboration among all stake holders, including forest farmers in the United States, CITES authorities of major ginseng export and import countries, and emerging e-commerce platforms. Work to develop and/or recognize effective and non-costly "green" certification mechanisms.

Promote forest farmed ginseng as a green alternative to wild. A concerted effort should be made to educate Asian consumers about the plight of wild ginseng in the United States and the availability of wild-cultivated as an equal, and perhaps even superior (due to quality and phytochemistry assurances) substitution.

AUTHOR CONTRIBUTIONS

HL and EPB conceived and designed of the study. HL, EPB, and VC revised the manuscript. All authors compiled the data, drafted the manuscript, secured funding of the study including publication fees, gave final approval for publication and agreed to be held accountable for the work performed therein.

FUNDING

This research was partially funded by a grant from the FIU Tropics to HL, and grants by the Pennsylvania Department of Conservation Natural Resources research grants 12456, 14512, and 16558 to EPB.

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

frontiers in Ecology and Evolution

PERSPECTIVE
published: 30 March 2021
doi: 10.3389/fevo.2021.648550

Equity – the Bottleneck and the Opportunity

Jake Rice

Fisheries and Oceans Canada, Ottawa, ON, Canada

There is a widespread tendency for diverse uses of Nature, on scales from small and local to very large, to become unsustainable. Once unsustainable, bringing a use back to sustainability and keeping it sustainable then takes substantial effort and tools appropriate to the context of the use. This Perspective first asks why is the tendency for unsustainability so pervasive, when it is an outcome that no user group has adopted as an objective, and ways to keep uses sustainable are known. I argue and present evidence that the common factor underlying the pervasiveness of unsustainable uses of Nature is inequity in the distribution of the benefits created from those uses, with both the wealthy "winners" of the distributional inequities and those disadvantaged and in poverty driving uses toward increasing unsustainability in ways that depend on the nature of the inequities. Unless the inequity of distribution of benefits from uses of Nature is addressed as an issue in its own right, there are few or no pathways to medium or long-term sustainable use. However, if inequity is addressed broadly and effectively, many pathways are available and societies can select the pathways appropriate to their cultural and ecological contexts.

Keywords: inequity, sustainable use, scale, uses of Nature, transformational change, drivers of unsustainability

OPEN ACCESS

Edited by:
Yan Zeng,
Institute of Zoology, Chinese Academy of Sciences, China

Reviewed by:
Francois Bastardie,
Technical University of Denmark, Denmark
Ray Hilborn,
University of Washington, United States

Correspondence:
Jake Rice
jake.rice@dfo-mpo.gc.ca

Specialty section:
This article was submitted to Conservation and Restoration Ecology, a section of the journal Frontiers in Ecology and Evolution

Received: *31 December 2020*
Accepted: *03 March 2021*
Published: *30 March 2021*

Citation:
Rice J (2021) Equity – the Bottleneck and the Opportunity. Front. Ecol. Evol. 9:648550. doi: 10.3389/fevo.2021.648550

INTRODUCTION

The thesis of this Perspective is straightforward. It is that as inequity in the distribution of benefits from any use of Nature increases, the likelihood that the associated use can be made and kept sustainable both decrease correspondingly, and at an accelerating rate as the degree of inequity grows. After roles on many regional and national assessment teams of various sorts for four decades[1], I have had opportunities to examine the prominence of unsustainable uses of Nature from many different perspectives. Several patterns have emerged:

- Sustainable uses of Nature and its components are feasible, and they have been achieved on scales from small to very large (Hilborn, 2019; Hilborn et al., 2020).
- Being feasible does not mean sustainability of the uses are simple to achieve, and having been achieved does not mean the uses then have been easy to keep sustainable.

[1]E.g. co-chairing one of the IPBES Regional Assessments (Americas) and being co-Chapter Lead Author for the Sustainable Use of Wild Species Assessment, being an author on both IPCC Assessment Report V and the IPCC Special Report on the Ocean and Cryosphere, a core member of the Group of Experts for the World Ocean Assessment I (coordinator of Part VI on Biodiversity and Co-coordinator for Part IV on Fisheries), co-chapter lead for the Oceans and Coasts chapter of UNEP Global Environmental Assessment V.

- A wide range of measures have been promoted if not as "silver bullets" at least as silver-plated solutions for unsustainability across a wide range of types of uses and circumstances (e.g., allocation of secure property rights; development of networks of protected areas, devolution of management to local scale processes; consolidation of decision-making in a central agency with mature processes for MCS[2] (Young et al., 2018; Martin et al., 2020).
- Eventually these silver-plated solutions tarnish, as circumstances arise where the measures do not reduce existing unsustainability of uses or else they amplify unsustainability elsewhere, and/or the sustainability that they initially delivered begins to unravel, as pressures on the resource(s) or socio-economic processes compound faster than the governance processes can reign them in.

These assessments have found many causes that can contribute singly or in combination to the pervasiveness of unsustainability of uses of Nature, and for unsustainable practices to resurrect, even when those managing and participating in the use(s) think unsustainability has been overcome.

ROOTS OF UNSUSTAINABILITY

Candidate drivers toward the pervasiveness of unsustainability include:

- Uncertainties in the assessments and other knowledge sources used to inform decision-making, so advice cannot be accurate and precise enough to guide reliable decisions (Punt et al., 2012; Farcas and Rossberg, 2016).
- Non-stationarity of environmental conditions and/or population and ecosystem dynamics, so information from the past is an incomplete and only partially reliable guide to actions in the future, and increasingly unreliable as projections extend further into the future (Bastardie et al., 2017; Koons et al., 2017).
- Insufficient resources and/or legitimate authority for effective MCS, whether from the top down or from the bottom up, so compliance with management decisions is insufficient to deliver the intended outcomes (Quimby and Levine, 2018; Troumbis and Hatziantoniou, 2018; Giglio et al., 2019).
- Either insufficient risk aversion in decision-making, so outcomes are not robust to inherent variability in environmental, economic and social factors that influence the sustainability, or excessive risk aversion that necessarily incurs very high opportunity costs and perhaps incentivizes non-compliance when resources appear to be unused, while people are in need (Holm, 2019; Ono et al., 2019; Hansson, 2020).

Other drivers could be added to this list, and some of the ones listed may be decomposed into smaller, possibly more tractable, sub-groupings. However, a complete list of potential drivers to unsustainability isn't necessary, particularly when many of the factors presented as drivers toward unsustainability can be effective as drivers toward sustainability, if they are matched with policies and management tools effectively mixing incentives and deterrents. What matters is that:

- Substantial progress on each factor is possible when a proper diagnosis of the particular drivers underlying trends toward unsustainability is followed by implementation of appropriate measure(s) for the features of Nature being used or impacted, the manner of use, and the socio-economic context in which the use is occurring (Wright et al., 2020).
- Regardless of how much progress is made, unsustainability seems always "just around the corner" when either the factors previously responsible for unsustainable use re-emerge in ways that may diminish or negate the measures used to tame the factor or in places where the tools are not readily applied, or new circumstances are encountered to which the existing management regime is not robust (Cochrane, 2020).

This pervasiveness of unsustainability could be surprising, because resource users rarely have "degradation of the part(s) of Nature being used" as an objective. Multiple communities may have different goals for how and how much to use shared resources, but they are at least likely to share the objective that they do not want it degraded to the point where uses, particularly their own, are not possible (Bellangier et al., 2020; Gaebel et al., 2020). There may be economic strategies and accounting approaches where "cashing out" a resource and investing the profits is a rational strategy, but even in those cases, reaching that decision and keeping the economic strategy viable requires a vision of "sustainability" shared by all those affected by that choice (Clark, 1973; Defrancesco et al., 2014). Irrational choices also may be made by participants in harvesting, without the intent of causing unsustainable outcomes (Battista et al., 2018), or management may be ineffective is delivering the desired outcomes (Garcia et al., 2014) but those realities merely underscore the messages in this essay. People have to be working together to achieve sustainable outcomes, and willing cooperation requires all those working together to perceive that they are being treated equitably.

And that is where experience in diverse assessment and advisory processes has led me to ask a simple but sweeping question. Why is unsustainability in uses of Nature so pervasive, when it is the one outcome all users want to avoid and when solutions to the individual contributing factors are known and have been successful (at least temporarily) on diverse scales and types of uses?

A cynic might focus on the multiplicity of users of most parts of Nature, so blame can always be transferred when things go bad, and no group takes accountability for its share of the problem. There is support for such a cynic's view, both from small scales, and in more multi-user settings from the investments made in processes to build shared objectives for cooperative resource use (Costanza et al., 2017;

[2] MCS is Management, Control, and Surveillance.

Alexander et al., 2018; Gelcich et al., 2019; Bellangier et al., 2020). However, the integrity of small, self-governing communities with a common shared culture is a weak precedent for sustainability of a diverse but globalized world. Moreover, these and other references illustrate that cooperative objective-setting initiatives become increasing difficult, and produce consensus at progressively more abstract and less operational levels, as the intensity and number of resource users both increase. Similarly, some strategies seek sustainability by restricting access to resources sufficiently that macro-economic instruments can incentivize sustainable behaviors of those with access rights. These strategies narrowly improve sustainability of use of the resources, but often leave individuals or communities denied access facing reduced social and economic opportunity and potentially making important dimensions of sustainability worse, not better (e.g., Robards and Alessa, 2004; Van Dolah et al., 2020).

An optimist might say that failures to achieve or maintain sustainability in the past does not guarantee unsustainability will remain inescapable in the future. Knowledge keeps growing (particularly as a diversity of knowledge systems are used), capacity and tools to manage keep growing, and lessons from both successes (whether temporary or not) and new failures also keep growing (Cinner et al., 2019, 2020; Caswell et al., 2020; Hilborn et al., 2020). We all have to share some of this optimism, if we continue to be engaged in these assessment and related activities, work as experts in our areas of specialization, and read papers in volumes such as this one.

IS THERE A WAY OFF THE UNSUSTAINABILITY TREADMILL?

It is now common to say incremental change is not adequate to address the challenges of today's globalized world. "Transformational change" sounds great, is inclusive in scope and ambition (Abson et al., 2017; Horcea-Milcu et al., 2019), and vaguely enough delineated that people with diverse views, values and vulnerabilities can all endorse it, even while planning to do very different things under its umbrella (e.g., a Green or a Blue economy; devolution of decision-making paired with local empowerment and capacity-building). The list of transformational change components in the IPBES website[3] is enlightening:

1. Go carbon-neutral, and expect others and businesses to do the same
2. Work to make it easy, enjoyable, and inexpensive to go Earth-positive.
3. Make all subsidies and incentives work for – not against – the necessary transformations.
4. Make all decision-making precautionary, adaptive, inclusive and integrative across sectors and jurisdiction
5. Strengthen environmental laws and policies, and ensure their consistent enforcement – at home and abroad.

[3]https://ipbes.net/news/what-transformative-change-how-do-we-achieve-it

Every one of these things is worthwhile. Every one also has been tried many times, with track records of some progress, some setbacks, and outcomes that may eliminate an unsustainable practice for a while, but often end up mostly changing the nature of unsustainability, and/or where it is occurring. The very comprehensiveness of these "transformational changes" are part of their difficulty. The pathways by which each one of these components can be approached will look very different to the diverse perspectives (Heck et al., 2018; Horcea-Milcu et al., 2019; Rice et al., 2020). Making goals transformative rather than incremental does not in itself weaken the "blame game" among users sharing an over-used resource, nor make consensus easier to find when a broad conceptual goal has to be translated down to binding and restrictive limits on each Party (Jara-Guerrero et al., 2019).

Return to that core question "Why is unsustainability in uses of Nature so pervasive and nearly inescapable, when it is the one outcome all users want to avoid and when solutions to the individual contributing factors are known and have been successful on many different scales and types of uses?" After struggling with trying to find a viable answer through my long career of seeking sustainability, mostly within marine fisheries, I have concluded that there must be an underlying barrier that must be identified and dealt with effectively. Only then can we break this pattern and see real change – whether transformative or otherwise. Even though the evidence is incomplete, across all the cultural diversity of Humankind, that underlying and pervasive barrier is inequity in access to or the distribution of the wealth created by the benefits arising from our uses of Nature. I explain this perspective using primarily fisheries examples, but working within the global assessment frameworks has shown very comparable importance of addressing equity in uses of terrestrial resources as well, such as harvesting wild rice (Matson et al., 2019) and honey (Matias et al., 2018).

A few caveats on that statement. "Wealth" is not necessary measured in a currency exchanged commercially. It can be social capital or any factor that maintains or enhances one's place in one's society (Pascual et al., 2017; Ellis et al., 2019). By "inequity" I am not referring to a bland homogeneity of well-being, where every individual gets reward and constraints exactly equivalent to every other individual. Rather, cultural diversity is maintained only by respecting the diversity of values that different cultures may attach to the same parts of Nature; even within each society individual diversity ("taste") may differ in ways that can strengthen a community. I am using equity in the context of genuine social justice: equal access to and power within the processes that make decisions about how Nature's Contributions to People are accessed and distributed (Agyeman et al., 2016; Quimby and Levine, 2018).

Why is inequity in the access to and distribution of wealth created through uses of Nature a (possibly the) underlying cause of unsustainability uses of Nature? The reason is increasing inequity in the distribution of benefits necessarily increases pressures toward unsustainability from both the "winners" and "losers" in the inequity.

The few that accumulate an increasing proportion of the wealth sometimes come to make accumulating even more wealth be the goal of their operations. Individually that may be expressed as greed, and does not have to be universal. If even a minority of the "winners" in the distribution of wealth have the "Johnny Rocco Syndrome[4]" then it will drive the use to make creation of additional wealth for sake of having more wealth a priority (Soliman, 2014; Melnychuk et al., 2016). The successful minority can use this wealth as they wish. Uses may include redistributing some wealth "equitability" within their own value systems, but often includes using disproportionate wealth to have disproportionate influence over the decision-making processes. There are many commercial initiatives to adopt more socially responsible business practices (Cashore, 2002; Zucchella and Urban, 2014; Packer et al., 2019). Nevertheless, these, too, focus on using the wealth created through commerce responsibly, whereas intentionally limiting the amount of corporate wealth created is rarely considered "sound business practice." And the corporate world, like individuals, can use disproportionate wealth to influence decision-making processes in ways intended to minimally not threaten the means that they have used to accumulate their wealth (Osterblom et al., 2017).

Whether by individuals or corporations, gaining disproportionate wealth thus drives unsustainability both through potential for pursuing objectives of increasing wealth for its own sake, and through creating incentives to use wealth as power to influence the decision – making processes to not threaten their sources of wealth, and ensure any negative consequences of the increasingly concentrated wealth do not also fall disproportionately on those controlling the wealth. If this comes at the cost of families or whole communities displaced to urban ghettos or joining waves of migrants to the more affluent parts of the world, the unsustainability of these consequences may be easy to dissociate from the inequities behind decisions that actually cause it (Faist, 2018).

On the other end of the distribution spectrum are those receiving disproportionately little of the wealth created by uses of Nature. The concentration of wealth leaves an increasingly large proportion of the members of a community or society disadvantaged materially. This, in turn, leaves them both in greatest need of benefiting from further uses of Nature, and with the fewest options feasible for meeting their needs with sustainable choices (Leao et al., 2017). This is particularly the case if the paths to sustainability require greater costs or a slower rate of acquisition of benefits; neither of which is feasible for those in poverty. Moreover being marginalized economically within a community is likely to be accompanied by being disadvantaged in access to and exercise of power in decision-making (Vasseur et al., 2017; Trisos et al., 2019). These social and economic consequences of marginalization may become invisible if those most effected become migrants, but that just requires the boundaries in which evaluations of sustainability of outcomes to be redefined to continue to include all the livelihoods affected by the decisions.

So from both the few that become wealthy and the many that are left poor, inequity in the access to and distribution of wealth from uses of Nature is likely to result in pressure to increase the intensity of the uses or maintain the intensity of use when it is excessive. This is accompanied by both the hope by those controlling much of the wealth that they can be shielded from consequences of any resultant unsustainability of the uses, and the desperation of those disadvantaged, who knowingly or unknowingly accept the consequences of unsustainability as necessary if they are to alleviate their poverty. When efforts to rectify historical inequities are added to the challenge, the entire process can be stressed, as is happening with Canada's Reconciliation efforts with its First Nations Peoples.

[4]Named for the gangster in the movie Key Largo, who when asked "What DO you want" simply answered "More! I want MORE!"

DISCUSSION AND IMPLICATIONS

The possibility to diagnose the underlying cause of the pervasiveness and persistence of unsustainable uses of Nature should be encouraging, because a correct diagnosis can help target more effective efforts at solutions. Unfortunately inequity in the distribution of wealth and access to decision-making power is a problem that has been part of human civilization for recorded history. There is ample recognition across societies and nations that extreme inequity is unjust, and governance processes from local to global have adopted Principles and processes intended to address inequity (Agyeman et al., 2016; Burgass et al., 2020). Correspondingly progress in fighting poverty and marginalization is being made (Cochrane, 2020). Nevertheless progress is slow and unequal at all scales, with even negotiated modest sustainable development goals rarely achieved and progress usually far short of more aspirational goals (Racioppi et al., 2020; Huan et al., 2021).

Even if the solutions to inequity will require actions on Policy levels far broader than just approaches to uses of Nature, constructive efforts to try to improve equity have been tried in all uses of living resources. These effort can work, but even in working, may just push the drive to excessive and unsustainable use to a deeper level. I will illustrate this with fisheries, which I know well. Particularly after WWII, with the expansion of international fisheries, TACs were set for commercial fisheries to cap at sustainable levels the amount of "wealth" that could be taken. Although TACs did restrict harvest levels, the pervasiveness of unsustainability led to the "race for fish," making fisheries more wasteful and less profitable, thereby actually generating less "wealth," and quota over-runs were common unless there was extensive surveillance and enforcement. In turn efforts were made to address the race for fish by allocating secure property rights to the fish harvesters. Again there were initial successes in advancing sustainability. However, rapidly those participants who were initially more successful in harvesting their allocation, or had better access to outside capital, began to acquire more quota shares, or otherwise to gain a disproportionate share of the total catch (Melnychuk et al., 2016). This resulted in fewer participants in the fishery; consequently more people or communities marginalized and needing to find livelihoods elsewhere, with significant social costs and again a concentration of decision-making power in the successful few. Again Policy could and often did respond by limiting the amount that fishing opportunities could be concentrated, but it is far too early to conclude that these measures are finally enough to ensure full equity in the distribution of benefits from fishing (Asche et al., 2018; Caswell et al., 2020). There is some reason for pessimism, in that at a minimum there is inherently an inequity between those who do and don't qualify to even have access to a quota share, and the governance and MCS processes that have had to be created and maintained to support setting accurate quotas, controlling access, and ensuring full compliance are complex and costly, often with costs recovered in full or in part by "resource rent" collected from the legal users (Flaaten et al., 2017; Gunnlaugsson et al., 2018). This makes the overall systems vulnerable to stochastic events such as environmental changes that would diminish stock productivity, require lower harvest and generate less revenue to support the governance and MCS systems just when their challenges have increased, and to politicization, as wealth and corresponding power is increasingly centralized in the interests of those who may benefit disproportionately from undermining constraints on their ability to increase their control over the processes.

This is not solely a pathology of large-scale uses of Nature. it is well documented that cultures of small and relatively self-sufficient communities developed social and cultural norms that promote equity in access to and distribution of benefits from Uses of Nature. However, these cultural norms and customs have social overhead and costs to maintain, and vulnerabilities to externalities that challenged the well-being of the communities (Cinner et al., 2019; Pihlajamaki et al., 2020). They also tended to be exclusionary – or at least not fully equitably – in how the norms and customs were applied to members and non-members of the communities (Barnes et al., 2016). Even looking at the important successes these norms and customs may have in promoting sustainability at the community level, these successes are increasing challenged as globalization increasingly influences cultures and practices at every scale (Giron-Nava et al., 2019; Crona et al., 2020). For example in many places the portion of community-based catches and takes from hunting and fishing that enters trade has grown substantially, as the fish and game are targeted at urban food markets where families from rural areas have relocated seeking employment and opportunities. We are only beginning to understand how these changes are affecting sustainability of uses of Nature by these local communities, but I suspect many of the dynamics driving uses to unsustainability will be encountered, as "wealth" is increasingly influenced by market forces and product chains rather that community-scale well-being and social equity.

Overall Conclusion

Some voices are now calling for all human uses of wild species to be rethought, as society increases acknowledges animals, at least, are to some degree sentient and have some rights. The argument is that by treating Nature with greater Humanity, we will have a better foundation for interacting with Nature in ways that are sustainable. This may or may not be true, but it is a level of action far deeper than necessary to make the changes needed to promote sustainability. Equity is fundamental for People and cultures to be treating each other with Humanity. Simply fulfilling the many global commitments for People to treat each other with respect and justice will open up many possible pathways to use Nature sustainability. Failure to deal with inequity among people at every scale will ensure there remain few or no pathways that can attain and keep our uses of Nature sustainable.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

I have done all research, thinking and drafting of this manuscript, benefiting from four decades of collaborations with diverse colleagues globally.

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Conflict of Interest: The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

The reviewer RH declared a past co-authorship with the author to the handling editor.

frontiers in Ecology and Evolution

PERSPECTIVE
published: 20 April 2021
doi: 10.3389/fevo.2021.631556

Think Before You Act: Improving the Conservation Outcomes of CITES Listing Decisions

Rosie Cooney[1], Daniel W. S. Challender[2], Steven Broad[3], Dilys Roe[4,5] and Daniel J. D. Natusch[6]*

[1] Fenner School of Environment and Society, Australian National University, Acton, ACT, Australia, [2] Department of Zoology, University of Oxford, Oxford, United Kingdom, [3] TRAFFIC International, David Attenborough Building, Cambridge, United Kingdom, [4] International Institute for Environment and Development (IIED), London, United Kingdom, [5] Species Survival Commission/Commission on Environmental, Economic and Social Policy Sustainable Use and Livelihoods Specialist Group, International Union for the Conservation of Nature (IUCN), Gland, Switzerland, [6] Department of Biological Sciences, Macquarie University, Macquarie Park, NSW, Australia

OPEN ACCESS

Edited by:
Miguel Pinedo Vasquez, International Research Institute for Climate and Society (IRI), United States

Reviewed by:
Jared D. Margulies, University of Alabama, United States
Spartaco Gippoliti, Storia della Fauna, Italy

***Correspondence:**
Rosie Cooney
rosie.cooney@anu.edu.au

Specialty section:
This article was submitted to Conservation and Restoration Ecology, a section of the journal Frontiers in Ecology and Evolution

Received: *20 November 2020*
Accepted: *29 March 2021*
Published: *20 April 2021*

Citation:
Cooney R, Challender DWS, Broad S, Roe D and Natusch DJD (2021) Think Before You Act: Improving the Conservation Outcomes of CITES Listing Decisions. Front. Ecol. Evol. 9:631556. doi: 10.3389/fevo.2021.631556

The CITES treaty is the major international instrument designed to safeguard wild plants and animals from overexploitation by international trade. CITES is now approaching 50 years old, and we contend that it is showing its age. In stark contrast to most environmental policy arenas, CITES does not require, encourage, or even allow for, consideration of the impacts of its key decisions—those around listing species in the CITES Appendices. Decisions to list species in CITES are based on a simplistic set of biological and trade criteria that do not relate to the impact of the decision, and have little systematic evidentiary support. We explain the conservation failures that flow from this weakness and propose three key changes to the CITES listing process: (1) development of a formal mechanism for consideration by Parties of the likely consequences of species listing decisions; (2) broadening of the range of criteria used to make listing decisions; and (3) amplification of the input of local communities living alongside wildlife in the listing process. Embracing these changes will help to ensure CITES decisions more effectively respond to the needs of wildlife in today's highly complex and dynamic conservation context.

Keywords: CITES, conservation policy, international policy, sustainable use, wildlife conservation, listing criteria, appendices, Appendix II

INTRODUCTION

The Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) is almost 50 years old, and its age is starting to show. CITES has considerable strengths as the primary multilateral environmental agreement aimed to ensure that international trade in wild species does not cause conservation harm, including near universal accession (183 Parties) and an effective compliance mechanism (Sand, 2013). However, the trade that CITES was designed to regulate has evolved radically over the last 50 years, and CITES must also evolve to stay relevant.

At the heart of CITES are trade measures applied by Parties to species listed in the treaty's three appendices (Wijnstekers, 2018). For species listed in Appendix I, international trade is prohibited in all but exceptional circumstances. An Appendix II listing allows trade, subject to a range of conditions aimed principally to ensure legality and ecological sustainability (see Rose, 2014). Appendix III includes species of which individual countries are struggling to regulate domestic trade, and seek assistance from other countries to control trade (Wijnstekers, 2018). Decisions to amend the appendices (including addition or deletion of species, and transfer between Appendices), and other amendments (e.g., revision of quotas and annotations), are taken at biennial/triennial Conference of the Parties (CoP) meetings (adopted by at least a two-thirds majority vote), based on biological and trade criteria specific to each Appendix. Listing decisions fundamentally shape the conditions of international trade for the species concerned, because they determine the type and source of trade that is allowed and associated permits required.

However, the listing process is premised on the simplistic notion that increasing trade restrictions will improve the outcomes for species, without clear prior evidence to support this assumption. The listing mechanism was a reasonable response to conservation challenges in the early 1970s (when CITES was designed). However, the nature and scale of wildlife trade, the global conservation landscape, the scope of CITES regulation, and global trade dynamics more broadly, have since changed beyond recognition (Lloyds Register et al., 2013; Harfoot et al., 2018). Today, listing species in CITES Appendices often fails to result in the intended positive conservation outcomes. Here, we examine the fundamental logic of the CITES Appendix listing process, drawing on a number of examples. We propose changes to strengthen the CITES decision-making process to ensure listing decisions have the conservation benefits they intend.

THE PROBLEM

CITES Parties make decisions on Appendix listings and/or amendments without any formal consideration of the consequences of those decisions. The criteria for listing species[1] do not promote or mandate consideration of such consequences. Instead, the tests for including a species in the Appendices direct Parties to consider only whether a species is in trade, and actual or potential levels of threat it faces, not the likely conservation consequences of proposed listings. The assumption is that **if an internationally traded species faces a level of biological threat, its conservation will benefit from trade restriction**. Yet this assumption has no systematic evidential basis and, as we argue below, is frequently false.

In practice, CoP deliberations on species listings do range beyond the formal listing criteria. Parties and/or Observers regularly raise issues related to conservation impact, such as the challenges they will face in implementation, potential impacts on local livelihoods (and knock-on conservation consequences), and the "signals" that decisions could send to certain actors (e.g., poaching syndicates and other market actors). Nevertheless, such considerations are not part of the formal CITES listing process and there is no requirement for Parties to consider them. Indeed, it is a commonly made argument that Parties should *only* consider the listing criteria, that parties should *only* consider scientific (and specifically biological) information in their decisions, that they explicitly *not* consider impacts of listing decisions, and that considering such impacts would undermine the nature of CITES as a science-based treaty (Thorson and Wold, 2010; Challender and MacMillan, 2019). Such arguments have repeatedly (and successfully) been deployed in CITES CoPs and Standing Committee meetings to, for example, counter recommendations from the CITES and Livelihoods Working Group that decision-making consider the impacts of CITES interventions on the livelihoods of local users in order to understand their likely conservation consequences for species (CITES and DEA, 2016).

In other multilateral environmental decision-making arenas (as in national jurisdictions), the consequences of conservation actions are a key focus of debate. Imagine the United Nations Framework Convention on Climate Change (UNFCCC) adopting measures against climate change without any explicit consideration of how those decisions will actually affect the climate (or, more extreme, arguing that such consideration is unscientific). Detailed assessments of the climate trajectories likely to follow from potential Convention commitments are a crucial aspect of, and input to, negotiations. CITES presents a stark and unfortunate contrast. Below, we discuss the implications of this issue for Appendix I and II listings.

APPENDIX I: ONE SIZE DOES NOT FIT ALL

For Appendix I, the assumption that a ban on commercial trade will improve the conservation of a threatened species is intuitively sensible. In some cases, it is well-justified. We suggest that the case for Appendix I is generally uncomplicated when:

1) international trade is the key driver of threat,
2) the species faces threats across its range,
3) where international trade is not playing any positive role, and
4) where Parties at the same time implement a realistic, achievable strategy for long-term conservation of the species.

In the case of vicuña *Vicugna vicugna* (a small South American camelid), for example, the establishment of trade bans (by both CITES and the pre-existing Vicuña Convention) in a situation of rampant uncontrolled poaching, with no models of well-managed trade, helped drive poaching and illegal trade downward and enabled recovery of populations through focused protection efforts. After recovery, the ban was lifted and a successful community-based sustainable use program was developed (McAllister et al., 2009).

In other cases, evidence indicates Appendix I listing does not improve species conservation. This is likely when:

(1) *A species proposed for listing in Appendix I is threatened by drivers other than international trade*. In this case, imposing an international commercial trade ban may be irrelevant (or even counterproductive). For example, the polar bear *Ursus maritimus*

[1] Set out in Res. Conf. 9.24, Rev. CoP17.

has twice been put forward for uplisting from Appendix II to I, affecting trade from Canada (the largest range State, and the only range State without a national ban on trade; see CITES, 2016). However, polar bears are threatened by reduction in sea ice, not by trade; trade is a by-product of a cultural/subsistence harvest that would continue whether products were traded internationally or not (Wiig et al., 2015). Income to Inuit hunters, however, would be removed, potentially leading to less engagement in conservation and more conflict killing. Where international trade is not driving population decline, curtailing it is unlikely to help.

(2) *The conservation status of wide-ranging species varies considerably across their range, where they face many different contexts and forms of use and trade*. For example, there may be well-managed forms of use and trade in some countries while, at the same time, illegal and detrimental exploitation in others. At each CoP, proposals are submitted calling for Appendix I listings that are only justified in part of the species' range. For example, Saiga Antelope *Saiga tatarica* was proposed for Appendix I listing at CoP18. In one range country (Mongolia) the population is small and declining and likely meets Appendix I criteria, whereas in the main range country (Kazakhstan) the population is large and increasing with no evidence of meeting the Appendix I listing criteria. An Appendix I listing, under a "blanket" approach, would likely undermine successful working management models involving use and trade, and reduce conservation options for the global population (see Milner-Gulland, 2020). While CITES has evolved a "split-listing" approach (some populations in one Appendix, some in another) that has been successful for a number of species (e.g., vicuña, saltwater crocodile *Crocodylus porosus*) this is now discouraged (see CITES Res. Conf. 9.24, Rev. CoP17).

(3) *Unsustainable trade will persist despite its illegality*. If trade in a species is already illegal, then inclusion in Appendix I will often have little positive affect. It is possible that Appendix I listings may increase political will and resources dedicated to law enforcement (e.g., the tiger *Panthera tigris*; see GTRP, 2012). Alternatively, this measure could lead to scarcity-driven price increases and increasing poaching rates, and there are numerous examples of illegal trade in species thriving after inclusion in Appendix I (e.g., pangolins Manidae spp., African elephants *Loxodonta africana*, and orchids Orchidaceae spp. (Hinsley et al., 2018; Challender et al., 2020; Schlossberg et al., 2020). This situation is likely where:

- trade income (albeit illegal) is one of few livelihood options at the point of production, with no readily available or attractive alternatives (e.g., pangolins),
- powerful supply-side actors exist in trade and (corrupt) governments, and are invested in illegal trafficking activities (e.g., rhino horn trade from South Africa to Viet Nam; Hübschle, 2016)
- demand is longstanding and deeply entrenched, and not sensitive to price (Conrad, 2012; Challender et al., 2019),
- enforcement is difficult (e.g., due to remoteness, low capacity and resources, and/or low political priority; Challender and Waterman, 2017).

In such contexts, Appendix I listing can help species conservation only if accompanied by strong and well-funded management interventions e.g., shifting incentives for local users, building strong on-the-ground protection and enforcement and/or strengthening local governance structures. In reality, however, this is very rarely considered at the time of listing decisions (Challender et al., 2019). Listing species in Appendix I can also create incentives for captive production (Appendix I species are treated as if they are Appendix II if they are captive-bred, and can be traded for commercial purposes; Article VII, Para. 4). Shifts to *ex situ* production of wildlife can have unpredictable conservation impacts, such as laundering, depending on factors including comparative costs of production and consumer preferences (Natusch, 2018; Hinsley and 't Sas-Rolfes, 2020). These real-world complexities are largely ignored by the Parties to CITES, in favor of the simplistic assumption that trade prohibition will assist species conservation. In reality, the outcome is often continued illegal and unsustainable trade, with loss of any effective monitoring or management tools.

APPENDIX II: UNFULFILLED POTENTIAL?

Unlike Appendix I, CITES Appendix II listing offers the flexibility to tailor management options to the local content. It provides for international co-operation through a set of conditions and international trade permissions. The Convention text itself sets out a common-sense test for the listing of species in the Appendix; that is, a species should be included when regulation is required to ensure it does not meet the criteria for inclusion in Appendix I. This broad test would allow Parties to evaluate whether trade regulation will ensure a positive conservation outcome for a particular species, considering e.g., how traders and local communities will be affected, how they will likely respond, and how this response would then affect the conservation status of the species. However, the detailed listing criteria (Res. Conf. 9.24, Rev. CoP17) do not require information beyond trade and biological data to be considered by Parties in proposals. These criteria again express the untested assumption that trade regulation is a justified and appropriate conservation response for traded species facing a particular level of biological threat. But, as with Appendix I species, there are situations where this is not the case and, indeed, where listing provides little advantage yet comes at significant cost.

For example, giraffe *Giraffa camelopardalis* were listed in Appendix II at CoP18, despite the key threats to the species comprising habitat loss, civil unrest, illegal hunting for subsistence use of meat and hides, and ecological change (Muller et al., 2018). There is limited international trade in giraffe and there is no evidence that international trade poses a threat to any giraffe populations, or is likely to in the foreseeable future (IUCN and TRAFFIC, 2019; Dunn et al., 2021). Indeed, the countries that legally trade giraffe products have stable or increasing populations. It is difficult to see how CITES trade controls will improve the conservation status of giraffe, despite this listing being widely hailed as a "win" for conservation of the species (e.g., Wildlife Conservation Society [WCS], 2019).

Where international trade is, or could be, a significant driver of conservation threat, an Appendix II listing can provide a powerful set of tools for trade regulation and impact evaluation. Unfortunately, these measures are too often poorly implemented and enforced, and negative impacts of trade fail to be contained, frequently resulting in the case being made for an Appendix I listing (e.g., as with pangolins; Challender et al., 2020).

But why are Appendix II measures poorly implemented? The answer lies—in part—in the narrow context in which Appendix II listings are formulated and pursued. Critical stakeholders like local harvesters and traders are viewed as subjects of regulation rather than key stakeholders necessary for making conservation solutions work. CITES Appendix II listing decisions are made without any explicit attention to the costs of implementation, how they will be implemented in the relevant value chain, or how regulatory measures will provide positive incentives for compliance and adoption of good practice. This has created the perception that a species listed in Appendix II is in the waiting room for Appendix I, when in fact Appendix II is a form of certification that trade is legal and sustainable, and can actively prevent inclusion in Appendix I.

Engaging a broader suite of stakeholders in listing decisions, and expanding listing criteria to examine a greater range of factors influencing conservation outcomes, will ensure increased regulation required by governments is commensurate with local contexts, more manageable, and cost effective. Failing to do so risks range states banning legal trade rather than attempting to regulate it, potentially resulting in poorer outcomes for species and people. For example, the Philippines does not trade any Appendix II-listed seahorse species (Christie et al., 2011). This has not only curtailed a source of livelihood for harvesters and traders but has also negatively impacted conservation. The ban did not stop seahorse fishing; instead, it created a black market, and further narrowed the policy options available to manage trade at the local level. Evidence suggests increased prices for seahorses, new fishers entering the market, erosion of NGO and government agency legitimacy, and damaged trust and cooperation on coastal resource management (Christie et al., 2011). Similarly, ensuring that listing decisions accurately reflect the criteria mitigates the need to expend precious conservation resources on species such as the giraffe, where international trade clearly poses no conservation threat. Doing so allows those resources to be channeled more appropriately to species in genuine need of conservation action (Nossal et al., 2016; Khadiejah et al., 2019).

HOW SHOULD A REFORMED CITES MAKE DECISIONS ON AMENDING THE APPENDICES?

Wildlife trade takes place within complex social-ecological systems, as part of dynamic processes at multiple scales with intersecting social, economic, cultural, and ecological elements (Larrosa et al., 2016). Regulatory decisions are therefore interventions in these complex systems. Their impacts do not smoothly follow a simple cause-and-effect chain, based on a circumscribed set of parameters (Booth et al., 2021; and see Braverman, 2016). Understanding the likely conservation impacts of CITES decisions requires understanding how a regulatory change will affect the set of interacting dynamics that link this intervention to conservation of species on the ground.

The potential for positive conservation impact through introduction of trade measures cannot be assumed, or answered exclusively by biological science. Evidence-based analysis of a variety of socio-economic factors is equally, if not more, important to determining positive conservation outcomes. By failing to address such factors explicitly, CITES decisions are frequently made using very narrow criteria, and may be influenced by factors outside the scope of the treaty, such as animal rights and ethics (Challender and MacMillan, 2019). To reform CITES so that it is able to respond to the complex, rapidly changing dynamics of wildlife trade, we suggest that the following key principles need to be built into future CITES listing decisions:

(1) ***The likely conservation impacts of any important decision should be explicitly assessed and considered***. Parties should not make decisions based on accepted convention or simplistic criteria, but after carefully considering how they are likely—in practice—to affect species conservation. Species conservation should remain the clear focus of CITES—but the listing criteria and process to amend the Appendices need overhauling to ensure the Convention can achieve it. An explicit commitment to this principle would mean CITES is not used as a futile gesture of conservation concern in situations where it is poorly designed to address the threats a species may face. This consideration could take many forms. As part of proposals, Parties could set out expected impacts, theories of change and their underlying assumptions. For high-priority species, scenario planning exercises or a form of rapid participatory appraisal could be used in national or range State workshops.

(2) ***Decisions should be based on the best available information***. This includes all relevant scientific information—including from the social and economic sciences—that helps Parties understand how their decisions will affect conservation. This would make CITES a genuinely "science-based" forum. But the information included should go beyond science in order to address questions such as whether there is sufficient law enforcement capacity in a country to implement the decision, how the private sector will respond, how relevant landowners will respond, how rural community members will respond, and how consumer demand may change. Information approaching the standard of rigor required by science is rarely available on such questions; and yet their answers will typically determine the real-life conservation outcomes of a decision. Understanding them provides the best opportunity CITES Parties have to make decisions that actually foster long-term species conservation.

(3) ***The rural communities who live with wildlife should have a strong and formally supported voice***. Local people disproportionately bear the socio-economic costs of wildlife trade decisions. No other group faces such significant—even existential—impacts from wildlife decision-making, whether from wildlife trade, wildlife depletion, human-wildlife conflict, or field-level wildlife conservation and enforcement measures. Justice therefore demands they play a role in decision-making.

And pragmatically, effective decision-making requires the insights and information these groups bring, particularly on the nuanced and context-specific questions of how a trade intervention will translate to field-level species status (Cooney and Abensperg-Traun, 2013). Securing the support and buy-in of rural communities to conservation decisions is an important element in success, and enabling and supporting participation is critical to achieving this. CITES is a notable laggard in supporting the participation of Indigenous Peoples and local communities in its deliberations (Cooney et al., 2018; Sellheim, 2020). This exclusion is striking in the context of the vastly more extensive and influential network of animal protection NGOs that participate in and shape decisions at CITES meetings (Challender and MacMillan, 2019; and see Duffy, 2013), despite their tangential relevance to field-level conservation outcomes and responsibilities. A basic step toward a twenty-first century Convention is formal recognition and meaningful support for participation of rural representatives of Indigenous Peoples and local communities in CITES deliberations. We encourage Parties to include such groups in their delegations to CITES, where appropriate, and to move toward creation of formal mechanisms for their voices to be heard.

In conclusion, our main message is that Parties to CITES must think before they act if listing decisions are to meet their stated conservation objectives. Expanding the range of formal tools and information available for consideration of Appendix listings will help achieve this. Failure to do so risks CITES being stuck in a 1970s conception of conservation that ignores complexity, fails to achieve its objectives, and satisfies only a set of constituencies with little responsibility or impact on field-level conservation. The question is not if these modernizations will happen, but when and how. This is a matter of strategic vision that needs to be addressed with urgency and commitment if CITES is to avoid senescence, but rather mature into a potent and effective conservation regime well-equipped to address contemporary conservation challenges.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

AUTHOR CONTRIBUTIONS

RC drafted the initial version of the manuscript. DN carried out an extensive final re-draft. All authors extensively commented on the draft, re-wrote sections, and made important conceptual contributions that shaped the arguments within the manuscript.

ACKNOWLEDGMENTS

DC acknowledges support from The Oxford Martin Programme on Wildlife Trade.

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

frontiers in Ecology and Evolution

ORIGINAL RESEARCH
published: 21 April 2021
doi: 10.3389/fevo.2021.607660

China's Legalization of Domestic Rhino Horn Trade: Traditional Chinese Medicine Practitioner Perspectives and the Likelihood of Prescription

Hubert Cheung[1*†], *Lorraine Mazerolle*[2†], *Hugh P. Possingham*[1,3†] and *Duan Biggs*[4,5,6†]

[1] Centre for Biodiversity and Conservation Science, School of Biological Sciences, The University of Queensland, Brisbane, QLD, Australia, [2] ARC Centre of Excellence for Children and Families Over the Life Course, School of Social Science, University of Queensland, Brisbane, QLD, Australia, [3] The Nature Conservancy, South Brisbane, QLD, Australia, [4] Environmental Futures Research Institute, Griffith University, Nathan, QLD, Australia, [5] Department of Conservation Ecology and Entomology, Stellenbosch University, Matieland, South Africa, [6] Centre for Complex Systems in Transition, School of Public Leadership, Stellenbosch University, Stellenbosch, South Africa

OPEN ACCESS

Edited by:
Yan Zeng,
Chinese Academy of Sciences (CAS), China

Reviewed by:
Michael 't Sas-Rolfes,
University of Oxford, United Kingdom
Richard Patrick Reading,
Butterfly Pavilion, United States

***Correspondence:**
Hubert Cheung
h.cheung@uqconnect.edu.au

†ORCID:
Hubert Cheung
orcid.org/0000-0002-5918-9907
Lorraine Mazerolle
orcid.org/0000-0002-3691-8644
Hugh P. Possingham
orcid.org/0000-0001-7755-996X
Duan Biggs
orcid.org/0000-0003-3177-4677

Specialty section:
This article was submitted to Conservation and Restoration Ecology,
a section of the journal Frontiers in Ecology and Evolution

Received: 17 September 2020
Accepted: 12 January 2021
Published: 21 April 2021

Citation:
Cheung H, Mazerolle L, Possingham HP and Biggs D (2021) China's Legalization of Domestic Rhino Horn Trade: Traditional Chinese Medicine Practitioner Perspectives and the Likelihood of Prescription. Front. Ecol. Evol. 9:607660. doi: 10.3389/fevo.2021.607660

Despite the international ban on the trade of rhino horn that has been in place since 1977, persistent demand for horn in Asia has driven a spike in poaching over the past decade. This has embroiled the conservation community in a debate over the efficacy of banning trade relative to other solutions. Proposals for trade to be legalized and supplied through the dehorning of live rhinos or the production of synthetic horn are contentious. The need for empirical research into the potential impacts of legalization on demand was made more urgent in 2018 when China publicized its intentions to reopen its domestic trade and permit the use of rhino horn in medical treatment. In this study, we interviewed 84 Traditional Chinese Medicine (TCM) practitioners in the Chinese province of Guangdong. While 58 (69.05%, $n = 84$) of our interviewees were in favor of trade legalization, only 32 (38.10%, $n = 84$) thought it likely that trade legalization would cause them to increase their prescription of rhino horn over current levels. This is probably because clinical cases in which rhino horn is medically appropriate are uncommon. We also found that 33 (39.29%, $n = 84$) practitioners were open to using synthetic horn for patient treatment, which has implications for the viability of synthetic horn as a conservation tool. This research contributes empirical insight to advance the discourse on rhino horn trade policy.

Keywords: Chinese consumers, conservation policy, demand, medicinal use, poaching, rhino conservation, wildlife consumption, wildlife trade

INTRODUCTION

People and communities around the world consume wildlife products for diverse reasons (Thomas-Walters et al., 2020), making wildlife trade a tremendously lucrative industry. For many taxa, trade is legal and sustainable. However, the survival of thousands of species, including iconic wildlife-like rhinos and elephants, is threatened by unsustainable levels of illegal wildlife trade (IWT) ('t Sas-Rolfes et al., 2019; Tittensor et al., 2020). To protect species against over-exploitation, the

Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) came into effect in 1975 to regulate international trade in the taxa listed on its appendices. International trade for commercial purposes is prohibited for species listed on Appendix I (Smith et al., 2011; Harfoot et al., 2018), and CITES signatories are expected to implement these trade controls and enact domestic legislation as appropriate ('t Sas-Rolfes et al., 2019).

The current approach to rhino conservation is centered on international and domestic trade controls. All extant species have been listed on Appendix I since 1977 (with the sole exception being the South African white rhino population's inclusion in Appendix II, for which international trade of live animals and of hunting trophies is conditionally permitted). However, poaching has risen substantially since 2007, and Africa's rhinos are projected to go extinct within the next 20 years under such intense poaching pressure (Di Minin et al., 2015). Rhino are poached for their horns because each kilogram can fetch USD $30,000–60,000 on the black market (Eikelboom et al., 2020). The rise in poaching is attributed to growing wealth and demand in Asia, particularly China and Vietnam, where rhino horn is used in cultural, social and medicinal settings (Di Minin et al., 2015). Rhino horn is used as an ingredient in Traditional Chinese Medicine (TCM) pharmacotherapy (herbal decoctions for treating illness or promote health by restoring holistic balance), mainly to dispel heat, detoxify and cool the blood, and treat febrile diseases (Cheung et al., 2018a, 2020a). It is thought to impart potent "cold" properties, most appropriately used against heat that has been trapped deep within the body (But et al., 1990).

Trade Legalization Debate

Increased demand and poaching have raised skepticism over the effectiveness of trade bans (Conrad, 2012; Challender et al., 2019). Should high rates of poaching persist, tens of millions of dollars will be needed annually for rhino protection alone (Di Minin et al., 2015). Other conservation interventions have also been scrutinized. Increasingly militarized anti-poaching presents serious ethical concerns and risks alienating key stakeholders (Duffy et al., 2015). Recent research has also identified limitations to behavior change interventions aimed at lowering demand for animal-based TCM products in Asia (Moorhouse et al., 2020). These all point to the need for the conservation community to consider all available policy options.

Some conservationists have argued that permitting regulated trade of horn from the two African species of rhino can depress prices from their current black market levels and reduce financial incentives for illegal actors. Legal trade can also generate funds which can be invested in local community development and in strengthening security and protection for rhino (Biggs et al., 2013; Di Minin et al., 2015; Rubino and Pienaar, 2020). Rhino horn can supplied either through non-lethal, renewable harvest of horns from wild or farmed rhino (henceforth "harvested horn") (Lindsey and Taylor, 2011; Taylor et al., 2017) or through the mass production of bioengineered synthetics, which are being developed to be virtually indistinguishable from natural horn (henceforth "synthetic horn") (Chen, 2017; Mi et al., 2019).

However, other conservationists have raised concerns and pointed to uncertainties surrounding both supply and demand (Collins et al., 2013; Aguayo, 2014). In particular, how demand will respond to trade legalization is unknown. Legalization could lift stigma surrounding illicit consumption and expand demand at a time when the Chinese government is actively promoting TCM domestically and abroad (Haas and Ferreira, 2016; Eikelboom et al., 2020). The potential for poached horn to be laundered into legal stocks is a major concern, one which is exacerbated by persistent corruption along IWT routes (Smith et al., 2015; Wyatt et al., 2018; Eikelboom et al., 2020). There are also animal welfare concerns (Brown et al., 2019).

Views on the sustainable use of wildlife can be polarized (Hutton and Leader-Williams, 2003). As with the debate over the trade in ivory (Biggs et al., 2017), policymaking over legalizing the rhino horn trade has become similarly deadlocked. The proposals that several rhino range states have lodged for CITES to permit some international trade have all been rejected. These repeated rejections have led the Southern African Development Community to threaten outright withdrawal from the Convention, arguing that the restrictions imposed on their use of natural resources is unfair and driven by anti-sustainable use ideologies (Challender et al., 2015; CITES, 2019). Although international trade remains banned under CITES, some countries have moved unilaterally toward domestic legalization in recent years. In South Africa, home to the majority of the world's rhino, a 2015 high court decision lifted the national moratorium on domestic rhino horn trading (Collins et al., 2020). In 2018, China publicized its intentions to reopen its domestic rhino horn (and tiger bone) trade (People's Republic of China, 1993a, 2018b).

China's Revised Policy on Domestic Rhino Horn Trade

In 1993, China implemented several policies that shut down its domestic rhino horn trade. First, all CITES-listed taxa were added to the Directory on Special State Protection of Wildlife (People's Republic of China, 1993b), placing them under the scope of the Law on the Protection of Wildlife (People's Republic of China, 1989). The State Council further issued a circular to explicitly: (1) ban the import, export, sale, purchase, transport, carrying, and mailing of rhino horn; (2) abolish all rhino horn-related medicinal standards and prohibit further medicinal use; (3) promote the use of rhino horn substitutes; and (4) mandate that all horn stocks be registered (People's Republic of China, 1993a).

However, this was revoked by the State Council in 2018. In a new circular, the Chinese government outlined nuanced parameters within which a legal domestic trade is to be reopened; activities beyond these parameters are to remain illegal (People's Republic of China, 2018b). The use of rhino horn is to be limited to clinical application in TCM, medical research, preserving antique cultural artifacts, and as educational materials.

Under the conditions set out in the circular, only powdered rhino horn sourced from captive bred animals (excluding zoo animals) is to be permitted for medicinal use. Clinical access is to be restricted to "qualified" doctors in "eligible" hospitals for the treatment of severe, critical, or rare illnesses; the criteria to determine which doctors are "qualified" and which hospitals are "eligible" is to be determined by the National Administration of TCM. To prevent misuse and abuse, measures related to the quantity, structure, and labeling of rhino horn supplies are to be jointly established by the National Forestry and Grassland Administration, Ministry of Industry and Information Technology and National Administration of TCM (People's Republic of China, 2018b).

The circular immediately drew widespread criticism from international conservation and animal welfare organizations (Humane Society International, 2018; UNEP, 2018; WWF Global, 2018), prompting the State Council's Executive Deputy Secretary-General to clarify that the issuance of the detailed regulations needed for implementation would be postponed, though the statement indicated that the Chinese government remains committed to reopening trade sooner or later (People's Republic of China, 2018a). As such, empirical insight into how demand in China is likely to respond is urgently needed to inform conservation decision-making. As of the publication of this paper, the Chinese domestic ban on rhino horn trade and medicinal use continues to be in force, though various challenges continue to hinder enforcement efforts (Li, 2007; Wong, 2019). These include porous borders and insufficient information sharing with neighboring countries, as well as the relatively light threat of prosecution for and alleged involvement of officials in wildlife crimes (Stephens and Southerland, 2018).

Present Study

In this paper, we focus on the views and perceptions of TCM practitioners and the potential impact of trade legalization on their behavioral intentions with respect to the prescription of rhino horn. TCM practitioners occupy a unique intermediary position in the IWT chain (Phelps et al., 2016). In China, TCM is practiced alongside and integrated with biomedicine (Western medicine) at every level of the healthcare system (Chen and Qian, 2019). TCM practitioners can both prescribe and dispense medication to patients (Sun et al., 2008; Fang et al., 2013; Zhang et al., 2015), and so their use of medicinal ingredients like rhino horn affects both supply and demand—prescribing contributes to overall demand, dispensing provides retail supply.

Once domestic trade is reopened, the 2018 circular stipulates that "qualified" TCM practitioners will be granted access to rhino horn powder obtained from captive-bred animals for patient treatment (People's Republic of China, 2018b). However, the postponed issuance of regulatory details means that a number of critical questions are unanswerable at present (People's Republic of China, 2018a). The specifics surrounding access are unclear. What will qualify a practitioner for access to rhino horn? Which medical conditions or illnesses will warrant its use? The circular also makes no mention of synthetic horn. Whether its pharmaceutical use would be permitted or restricted is unknown, as is whether these products would even be considered rhino horn in legal terms (and thus be subject to the same regulations as natural horn).

Although the specifics of China's eventual reopening of trade remain unknown, empirical research will provide conservationists insight with which to evaluate the potential opportunities and risks associated with trade legalization in China and internationally. In this study, we conducted semi-structured interviews with TCM practitioners in China's Guangdong province. We focused on four questions:

1. What are the perspectives of TCM practitioners with regards to the present ban on the trade and medicinal use of rhino horn?
2. Do TCM practitioners support or oppose trade legalization for harvested rhino horn? For synthetic horn?
3. How likely are TCM practitioners to increase or decrease their prescriptions of rhino horn over present levels if harvested horn is legally available? If synthetic horn is legally available?
4. What demographic and professional characteristics predict changes to rhino horn prescription in terms of behavioral intentions if harvested horn is legally available? If synthetic horn is legally available?

METHODS

Study Area

Guangdong province is located on the southeastern coast of China. It is the largest Chinese province by population (108,490,000 in 2015) and is one of the wealthiest (household per capita disposable income ∼USD $4,170 and per capita GDP ∼USD $10,900 in 2015) (National Bureau of Statistics of China, 2016). In the provincial capital of Guangzhou, rates of wildlife consumption as food and for medicinal purposes is higher than other large cities in China-—31.2% of people in Guangzhou consume TCM or health products containing wildlife ingredients annually, compared with 1.5% and 2.8% in Beijing and Shanghai respectively (Zhang and Yin, 2014).

TCM practitioners most commonly prescribe rhino horn for dispelling heat, detoxifying the blood, and treating *wenbing* (Chinese in Traditional script/Simplified script/pinyin: 溫病/温病/*wēn bìng*; warm-heat infectious diseases) (Cheung et al., 2018a). These include such diseases as SARS and COVID-19, both of which are considered *wenyi* (溫病/温病/*wēn yì*; epidemics of *wenbing*) (Liu and Wang, 2020). *Wenbing* is most associated with acute infections and epidemics in southern China (Hanson, 2011).Taken together, these factors suggest that rhino horn is likely to be more affordable to and more widely used by Guangdong's residents of Guangdong than in other parts of the country, making it an appropriate focal point for our study.

Interview Methodology

We conducted semi-structured interviews face-to-face with 84 TCM practitioners in Guangdong province between 29th July and 14th November 2018 (excluding two interviewees who withdrew participatory consent; see **Supplementary Materials** for explanation). Semi-structured interviews are used extensively in environmental studies. A set of key questions is used to guide each interview (see **Supplementary Materials** for key questions), and interviewers follow up with additional questions and encourage elaboration to enhance data with nuance and context (Newing, 2011). Responses to questions regarding TCM practitioners' support of or opposition to trade legalization, and those regarding the likelihood that they would increase or decrease rates of prescription over current levels, were recorded using 5-point Likert scales. The research methodology we employed here built on a previous study in which we interviewed TCM practitioners in Hong Kong on the subject of rhino horn use (Cheung et al., 2018a). For the present study, we pilot tested our study instrument with 30 TCM practitioners in Hong Kong to improve the focus of our key questions, including refining our translated measures for connectedness-to-nature and formal deterrence (Cheung et al., 2020b).

We employed a broad definition of TCM practitioner for participant recruitment: any self-identified (licensed, qualified, or otherwise) physician who provides to members of the public TCM services (inpatient or outpatient; prescribes treatment). By using such broad criteria, we could recruit unlicensed individuals and herbalist shopkeepers who offer medical consultations and prescribe herbal decoctions in addition to physicians working in larger institutions (e.g., hospitals) (Li et al., 2017).

Our broad recruitment criteria meant that we were unable to sample randomly from the population, as the total population could not be determined as there was no official listing of all practitioners in the region. Instead, we recruited study participants using snowball sampling, an established method for studying sensitive topics (Heckathorn, 2011; Newing, 2011). We started with a core convenience group of 35 participants, who were recruited through personal contacts and acquaintances made through earlier work. A further 23 interviewees were approached initially through self-introduction. All interviewees were asked to refer fellow TCM practitioners to participate in our research; 26 interviews done through referrals. Studies of illegal tiger and ivory trading in China have used similar sampling methodologies that involved participant referrals (Wong, 2016, 2017). While such approaches to participant recruitment can make it easier to access populations that are difficult to study, they can incur methodological limitations and biases for study results.

The vast majority of interviews were conducted at the participant's primary workplace (e.g., hospital, clinic, and herbal medicine shop). The average duration of each interview was 45 min. We conducted 62 interviews before and 22 interviews after the State Council's circular to reopen domestic rhino horn trade was issued on 29th October 2018 (People's Republic of China, 2018b). Of the latter 22, only one interviewee had seen a news article on the subject and three others had seen related social media posts, none of whom were aware of any policy details. The remaining 18 had no knowledge of the circular. No interviewees had yet discussed the reopening of trade with colleagues. As such, any effects that the circular's release during our data collection period had on our results are most likely negligible. The demographic and professional characteristics of our sample are summarized in **Table 1**.

Data Analysis

We used descriptive statistics to examine perspectives on the current ban on rhino horn trade and medicinal use, as well as support or opposition to trade legalization, both for a legal trade supplied through the de-horning of live rhino and through the mass production of bioengineered synthetics. Descriptive statistics were also used to examine the perceived likelihood of increasing prescriptions of rhino horn over current levels if a legal trade is supplied through the de-horning of live rhino and through the mass production of bioengineered synthetics. We then conducted hierarchical multiple regressions for the perceived likelihood of increasing rhino horn prescriptions over current levels of use in different legal trade scenarios. Demographic and professional covariates were entered into the model in the first step, before the effects of two theoretical constructs (deterrence and connectedness to nature; see **Supplementary Materials** for a discussion of these constructs) and past prescription of rhino horn were included in step two. R (version 3.6.1) was used for these regressions.

Trade restrictions lie at the center of the current approach to rhino conservation. The success of both international and domestic trade controls hinges on how compliant stakeholders along the IWT market chain are (Arias, 2015; Phelps et al., 2016; Oyanedel et al., 2020). Sanctions imposed for regulatory violation are a formal deterrence measure (Grasmick and Bursik, 1990). Deterrence is an established concept in criminology, whereby effectiveness is dependent on three central pillars: certainty, severity and celerity. Deterrence (and regulatory compliance) can be increased by manipulating these three elements (Nagin, 2013). In essence, compliance with potential offenders must perceive that the risk of being apprehended is high, that the punishment is sufficiently severe, and that sanctions will be imposed without delay.

A major point of contention in the rhino horn trade policy debate is whether legalization would lead to increased demand. In the case of TCM practitioners, this would be through the increased prescription of rhino horn once legalized. Here, we measured the formal deterrence of legal sanctions on rhino horn prescription using a composite scale adapted from criminological research (Grasmick and Bursik, 1990; Allen et al., 2017). We included this construct in our hierarchical multiple regressions to investigate the effect of perceived deterrence on TCM practitioners' likelihood of increasing prescriptions of rhino horn if harvested horn and synthetic horn are legalized.

Although strong compliance and enforcement programs are necessary for regulatory measures to control environmental behaviors and deter violations, "regulation cannot by itself produce the behavioral changes needed to achieve sustainable environmental outcomes" (Paddock, 2012), and drivers of compliance that are values-based drivers are also needed (Challender and Macmillan, 2014). Normative motivations are driven by a person's moral duty and agreement with the importance of a given regulation. These are based on internalized values which lend legitimacy to regulations, and people with a stronger sense of duty to adhere to a certain rule can be expected to comply at greater rates (Burby and Paterson, 1993; Winter and May, 2001).

People with pro-environmental attitudes are more likely comply with environmental regulations (Paddock, 2012). The connectedness-to-nature scale (Mayer and Frantz, 2004) and other similar measures have been developed around the idea that reconnecting people to nature can foster positive ecological

TABLE 1 | Demographic characteristics of our sample of TCM practitioners.

Interviewee demographics—TCM practitioners					
Variable		***N***	**Variable**		**Result**
Sex (*n*)	Male	64	Age (years)	Mean	46.4
	Female	20		Median	45.5
TCM education (*n*)	No formal TCM training	11		Maximum	80
	Vocational training	8		Minimum	22
	Undergraduate degree	44	Experience (years)	Mean	21.7
	Graduate degree	21		Median	20
TCM specialization (*n*)	General/internal medicine	46		Maximum	55
	Orthopedics	10		Minimum	0
	Acupuncture	6	Primary workplace (*n*)	Public sector	51
	Cardiology	4		- WM hospital	20
				- TCM hospital	29
	Pediatrics	4		- Community health center	2
	Diabetes	3			
	Oncology	3		Private sector	33
	Neurology	2		- Private practice clinic	26
				- Herbal medicine shop	3
	Obstetrics and gynecology	2		- Home clinic	3
	Arthritis	1		- WM-style pharmacy	1
	Gastroenterology	1			
	Hepatology	1	Geographical administrative division in Guangdong province (*n*)	Qingyuan	28
	Neonatology	1		Shenzhen	19
	Pain medicine	1		Shaoguan	14
	Pulmonary medicine	1		Shantou	10
	Recovery and rehabilitation	1		Foshan	6
	Stroke	1		Guangzhou	4
	Urology	1		Zhuhai	3

behavior and reduce anti-ecological behavior (Tam, 2013). In this study, we administered a Chinese version of the connectedness-to-nature scale (Cheung et al., 2020b) to investigate its effect on the likelihood of TCM practitioners increasing prescriptions of rhino horn if harvested horn and synthetic horn are legalized.

Research Ethics

We complied with the Australian National Health and Medical Research Council's National Statement on Ethical Conduct in Human Research; institutional approval was granted by The University of Queensland (#2017002130).

RESULTS

We found that 40 (47.62%, all $n = 84$) interviewees were supportive of the existing ban on trade and medicinal use, while 28 (33.33%) interviewees were indifferent and accepting of this policy. Fifty-eight (69.05%) felt that the ban has had minimal or no negative impact on TCM's development. Two (2.38%) interviewees felt that the ban has had a major negative impact on TCM's development, while 20 (23.81%) others reported some negative impact. Three (3.57%) interviewees found the ban to be beneficial for TCM because it has encouraged innovation in the development of other treatments.

Fifty-eight (69.05%) interviewees were in favor of proposals to legalize trade in harvested rhino horn, with 13 opposed (15.48%) (**Figure 1A**). Thirty (35.71%) interviewees described the legalization of trade in harvested horn as a win-win situation: patients can receive the treatment they need, and rhinos do not have to be killed in order to for their horns to be obtained. Ten (11.90%) interviewees expressed views that mechanisms to regulate and certify supplies must be established and enforced to ensure the sustainability of such a trade. Eight (9.52%) interviewees expressed animal welfare concerns over dehorning.

However, even if harvested horn were to be legally traded, our interviewees were split between those who found it unlikely that they would increase their prescription of rhino horn over current levels if trade were legalized ($n = 45$, 53.57%) and those who predicted that they would increase their use of rhino horn ($n = 32$, 38.10%) (**Figure 1B**). When asked to elaborate, 39 (46.43%) interviewees explained that they would be unlikely to prescribe rhino horn even if trade were legalized because cases where it is suitable for patient treatment are infrequent or rare. Seven (8.33%) further stated that patients whose conditions severe enough to warrant treatment using rhino horn would have either been hospitalized for treatment using biomedicine or opted for it themselves. Four (4.76%) interviewees cited personal ethics as the reason they would never prescribe rhino horn, even if it

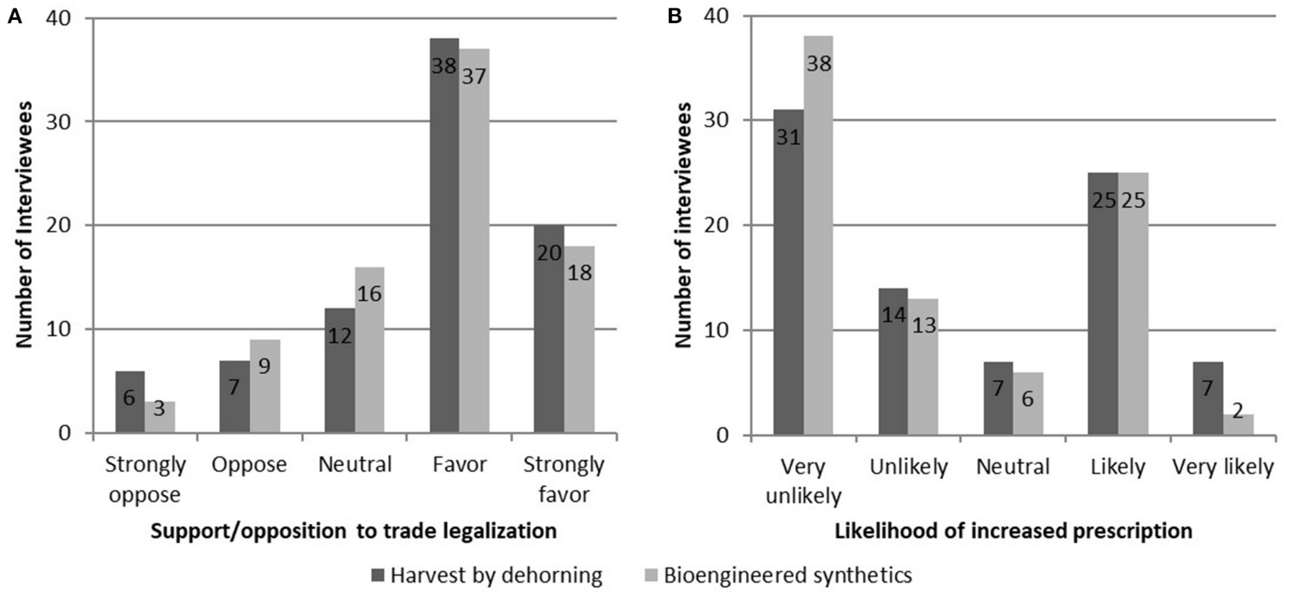

FIGURE 1 | TCM practitioners' **(A)** support for the legalization of trade in rhino horn supplied with harvested horn and synthetic horn; and **(B)** likelihood of increasing prescriptions of rhino horn from current levels if rhino horn were to be legally supplied with harvested horn and synthetic horn.

were legally available. A hierarchical multiple regression did not reveal any variables measured in our study (demographic factors, professional characteristics, connectedness to nature, feelings of shame, and deterrence) to have any statistically significant predictability with regards to the likelihood of increasing use over current levels if trade in harvested horn is legalized (**Table 2A**).

Fifty-three (63.10%) practitioners also supported the idea of a legal trade in synthetic horn; only 12 (2.38%) were opposed (**Figure 1A**). Fifty-one (60.71%) interviewees reported that they would be unlikely to increase prescriptions of rhino horn over current levels if synthetic horn were legalized (more than for harvested horn), with 27 (32.14%) predicting that they would be likely to do so (fewer than for harvested horn) (**Figure 1B**). Interviewees raised concerns over the pharmaceutical effectiveness and safety of consuming something synthetic, with 12 (14.29%) interviewees stating that under no circumstances would they ever consider prescribing synthetic or artificially manufactured medicinal ingredients to their patients. Eleven (13.10%) were of the opinion that a synthetic product simply cannot be made to be equivalent to "natural" rhino horn. Twelve (14.29%) interviewees stated that ample testing would be needed to assure them that synthetic products are safe and effective for treatment before they would consider using it, and 33 (39.29%) stated that they would only consider synthetic horn if it was shown to have equivalent or comparable clinical effectiveness to natural horn. A hierarchical multiple regression found that none of the variables we measured (demographic factors, professional characteristics, connectedness to nature, feelings of shame, and deterrence) were statistically significant with regards to likelihood of increasing rates of rhino horn prescription over current levels if trade in synthetic horn is legalized (**Table 2B**).

DISCUSSION

The increase in rhino poaching over the last decade and a half has called the efficacy of existing trade controls into question, and has stimulated a heated debate over policy alternatives like trade legalization (Biggs et al., 2013; Dang et al., 2020). The need for a better understanding of demand in China was made more urgent when the State Council issued its 2018 circular announcing that its domestic rhino horn trade is to be reopened (Cheung et al., 2018b). In this study, we conducted semi-structured interviews with 84 TCM practitioners in the southeastern Chinese province of Guangdong. We found that almost half of our interviewees were supportive of the current ban on the trade and medicinal use of rhino horn; however, we also found that the majority of TCM practitioners favor legalizing rhino horn if it were to be sourced through the dehorning of live rhinos and the production of synthetic horn (**Figure 1**). This apparent conflict in support among TCM practitioners for contrasting trade policies is likely the result of a general lack of awareness that rhino horn grows continuously throughout a rhino's lifespan and can be considered, at least theoretically, a renewable resource. The majority of our interviewees suggested that they are unlikely to increase their prescription of rhino horn over current levels even if its trade and medicinal use were to be legalized. This sentiment was more pronounced for synthetic horn than for harvested horn, largely due to concerns over pharmaceutical effectiveness and safety, as well as ethical opposition to the use of artificial medicinal ingredients. In contrast, supplying a legal trade with harvested horn was described by a third of our interviewees as

TABLE 2 | Hierarchical multiple regression for the effect of demographic factors, connectedness to nature, shame, and deterrence on TCM practitioners' likelihood of increasing prescriptions of rhino horn if (A) harvested horn is legalized, and (B) synthetic horn is legalized.

(A) Likelihood of increasing prescriptions if harvested horn is legalized								
Variable	**Model 1**				**Model 2**			
	B	***SE***	***β***	***p***	***B***	***SE***	***β***	***p***
Constant	2.605	1.669		0.123	1.964	2.338		0.404
Age	−0.010	0.033	−0.293	0.770	−0.012	0.034	−0.357	0.722
Gender (M/F)	−0.253	0.401	−0.631	0.530	−0.238	0.405	−0.587	0.559
Education	0.318	0.226	1.411	0.162	0.309	0.234	1.318	0.192
Experience	0.013	0.030	0.424	0.673	0.011	0.031	0.342	0.734
Workplace sector (public/private)	−0.346	0.385	−0.898	0.372	−0.358	0.390	−0.920	0.361
Connectedness to nature					0.017	0.475	0.037	0.971
Formal deterrence (legal sanctions)					0.175	0.228	0.767	0.445
Prescribed rhino horn in the past					0.398	0.394	1.011	0.315
R^2				0.065				0.082
Adjusted R^2				0.005				−0.016
ΔR^2								+0.017
ΔF				1.075				0.836
Df				5 (78)				8 (75)
p-value				0.381				0.574
(B) Likelihood of increasing prescriptions if synthetic horn is legalized								
Constant	1.974	1.601		0.221	0.374	2.214		0.866
Age	−0.002	0.032	−0.058	0.954	−0.008	0.032	−0.235	0.815
Gender (M/F)	0.056	0.385	0.147	0.884	0.072	0.384	0.188	0.852
Education	0.177	0.217	0.819	0.415	0.139	0.222	0.629	0.532
Experience	−0.002	0.029	−0.076	0.940	−0.002	0.029	−0.072	0.943
Workplace sector (public/private)	−0.099	0.369	−0.268	0.790	−0.103	0.369	−0.279	0.781
Connectedness to nature					0.170	0.450	0.378	0.707
Formal deterrence (legal sanctions)					0.320	0.216	1.479	0.143
Prescribed rhino horn in the past					0.398	0.373	1.067	0.290
R^2				0.031				0.073
Adjusted R^2				−0.031				−0.026
ΔR^2								+0.042
ΔF				0.496				0.736
Df				5 (78)				8 (75)
p-value				0.779				0.660

a win-win solution, whereby rhinos do not need to be killed for patients to receive the treatment they require.

Some conservationists and rhino range states see trade legalization as a potential way to reduce prices from their current black market levels, disincentivize poaching, and provide a renewable source of income to fund protection and enforcement (Biggs et al., 2013; Rubino and Pienaar, 2020). This remains controversial, and many other conservationists, range states, and international organizations have opposed such calls, concerned that legalization would increase demand and exacerbate poaching (Haas and Ferreira, 2016; WWF Global, 2018; Eikelboom et al., 2020). Although differences in entrenched values have led to a deadlock (Biggs et al., 2017; CITES, 2019), conservationists across the board agree on the need for policy to be informed with evidence and research (Gao et al., 2016; Haas and Ferreira, 2016; Wright et al., 2016; Chen, 2017; Hanley et al., 2018). Understanding how TCM practitioners and consumers—who are major stakeholders in the global marketplace for rhino horn—are likely to respond to trade legalization is important because any shifts in demand will directly affect the success of rhino conservation (Cheung et al., 2018a). The State Council's 2018 circular stipulated that rhino horn powder will be accessible to "qualified" doctors in "eligible" hospitals for limited use in TCM for patient treatment. Horn powder used for medicinal purposes will need to be obtained from captive bred animals (excluding zoo animals), though precisely how this would be sourced was not stated (People's Republic of China, 2018b). Although the implementation of the new policy has since been suspended, it amplified the urgency of gaining insight into the medicinal demand for rhino horn. Our study represents the first investigation of how TCM practitioners in China would potentially respond to domestic trade legalization.

Policy Implications

In its 2018 circular reopening its domestic rhino horn trade, the Chinese government indicated clearly that a legal trade will be subject to certain regulatory measures to be established by the relevant authorities (People's Republic of China, 2018b). This was reiterated in the clarification given by the State Council's Executive Deputy Secretary-General Ding Xuedong that implementation will be postponed, in which he maintained that "the circular should be implemented based on its detailed regulations for implementation"(People's Republic of China, 2018a). Our findings are particularly noteworthy in the context of the parameters outlined in the State Council's 2018 circular. In particular, the circular stipulates that medical access to rhino horn powder is to be restricted to "clinical use for the treatment of serious or critical conditions and rare illnesses that are otherwise difficult to cure" (床救治危急重症、疑 症/临床救治危急重症、疑难杂症/*lín chuáng jiù zhì wéi jí zhòng zhèng, yí nán zá zhèng*) (People's Republic of China, 2018b). Our findings appear to be consistent with this description, albeit on a coarse scale given that details of the specific conditions for which rhino horn can be accessed for medical use have yet to be established (or if they have been established, have yet to be announced) by the relevant government agencies as stipulated in the 2018 circular.

Around half of our interviewees stated that they are unlikely to prescribe rhino horn (whether harvested or synthetic) even if its use and trade were legalized. They described opportunities to use rhino horn as being rare, because patient cases in which its application is appropriate are uncommon. Previous exploratory research that focused on TCM practitioners in Hong Kong revealed similar trends and perspectives (Cheung et al., 2018a). The rarity of patient cases in which rhino horn is an appropriate (let alone necessary) treatment appears to be consistent with the parameters for medicinal use laid out in the 2018 circular. Our results indicate that conservationists should take into account the perceived rarity of clinical cases for which rhino horn is appropriate when assessing concerns that the removal of stigma associated with trade legalization will cause demand to increase, at least with regards to clinical use by TCM practitioners.

Our findings also provide insight into the potential viability of synthetic rhino horn as a conservation tool. These are being developed by several biotechnology firms (Mi et al., 2019) under the premise that: (a) "flooding the market with [synthetic horn] reduces the price, thereby (it is theorized), reducing the levels of poaching" (Crookes, 2017); and (b) "if synthetic horns that are biologically identical (bio-identical) to the real thing can be produced at a lower cost compared to the cost of supplying wild horns, the demand for wild horns would decrease as buyers shift consumption toward the synthetic products" (Chen, 2017). With rhino horn demand understood to be relatively price-inelastic in nature, recent economic modeling by Chen and 't Sas-Rolfes (2021) found that establishing a legal market for synthetic horn is likely to reduce poaching.

Concerns have been raised that introducing synthetic horn to the market may not reduce the supply of natural horn or disincentivize poaching if users are able to differentiate between them and perceive synthetic horn to be an inferior product (Chen, 2017). Indeed, our results show that many TCM practitioners would perceive synthetic rhino horn to be less desirable than natural horn. One in seven of our interviewees would never consider synthetic medicinal ingredients for patient treatment. On the other hand, it is encouraging that a substantial portion of TCM practitioners is open to the idea of using synthetic products for patient treatment and that perceptions of synthetic horn in relation to natural horn are not homogenous. We found that two in five TCM practitioners would consider using synthetic horn (if legally available and with the knowledge that it is a synthetic product) for patient treatment if its clinical effectiveness is shown to be equivalent or comparable to that of natural horn (*n.b.* we stress that evidence for the pharmaceutical efficacy of rhino horn in biomedical terms is limited and questionable at best). This has implications for the development of synthetic horn and its deployment as a conservation tool once domestic trade in China is reopened. If the pharmaceutical efficacy of synthetic horn can indeed be demonstrated, then a substantial portion of medicinal demand could be satisfied with synthetic products without great opposition from TCM practitioners.

Limitations and Future Research

In the present study, we were unable to identify any variables that could predict TCM practitioners' self-reported likelihood of increasing their rhino horn prescription rate if trade in harvested or synthetic horn were to be legalized (**Table 2**). Recognizing that the goodness-of-fit for the two relevant regressions were poor and noting the limitations of our sampling methods, we posit that a substantial amount of variance is attributable to the rarity of situations in which rhino horn is medically appropriate. Additional research may be able to provide further insight into other factors at play that can predict potential changes in rhino horn prescription rates which were not measured in the present study.

We stress the methodological limitations of our results. This study focused on self-identified TCM practitioners in Guangdong province. Our findings should not be interpreted as nationally representative because TCM practices and norms, socioeconomics, healthcare access vary across different regions of China (Ling et al., 2011; Li et al., 2018). Our study focused on perceptions and behavioral intentions, which may not reflect the actual behaviors that TCM practitioners will ultimately take upon the legalization of domestic trade (Ajzen, 1991; Sheeran and Webb, 2016). The broad inclusion criteria we employed for participant recruitment had both benefits and drawbacks. By reaching active practitioners who are not licensed or trained, we were able to gauge sentiments regarding the current trade ban and trade legalization from a wider group. However, this prevented us from sampling randomly from the total population of TCM practitioners.

The 2018 circular to reopen domestic trade was issued toward the end of our data collection period, and we were unable to adapt our study in response to the circular's issuance. Studies in the future should aim to provide more focused insight with regards to the stated parameters of China's trade legalization plans. For instance, future research involving TCM practitioners in China should concentrate specifically on individuals who work in hospitals. While the development status of the regulatory details necessary for the circular's implementation is unknown, the Chinese government's intention to reopen domestic trade sooner or later is unlikely to have wavered. It may be prudent for conservationists to engage with the relevant Chinese agencies tasked with establishing these regulatory details and implementation measures in order to be a part of that process to manage the risks to wildlife.

DATA AVAILABILITY STATEMENT

Due to the possible sensitivity of human subjects' data and in compliance with human research ethics approval granted by University of Queensland, survey data are only accessible to the authors. However, anonymized data may be accessible by request on an individual basis.

ETHICS STATEMENT

We complied with the Australian National Health and Medical Research Council's National Statement on Ethical Conduct in Human Research; institutional approval was granted by The University of Queensland (#2017002130). Written informed consent for participation was not required for this study in accordance with national legislation and institutional requirements.

AUTHOR CONTRIBUTIONS

HC conceived and designed the study, conducted the interviews, analyzed the results, and wrote the manuscript. LM, HP, and DB contributed to the design of the study, to the statistical analysis, and to the text of the manuscript. All authors approved the final manuscript for submission.

FUNDING

HC received scholarship and research funding from the Lee Shau Kee Foundation. DB is supported by an Australian Research Council Discovery Early Career Research Grant (DE 160101182).

ACKNOWLEDGMENTS

HC is very grateful to the Lee Shau Kee Foundation for their provision of scholarship and research funding for this project. DB is supported by an Australian Research Council Discovery Early Career Research Grant (DE 160101182). We are grateful to those who helped us over the course of this project, in particular LKY, XJK, and the individuals who connected us with stakeholders in the TCM community.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fevo.2021.607660/full#supplementary-material

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

frontiers in Ecology and Evolution

SYSTEMATIC REVIEW
published: 17 May 2021
doi: 10.3389/fevo.2021.630990

Mapping the Research Landscape on Poaching: A Decadal Systematic Review

Vukan M. Lavadinović[1]*, *Camila A. Islas*[2], *Murali Krishna Chatakonda*[3], *Nevena Marković*[4,5] and *Monicah Mbiba*[6]

[1] Faculty of Forestry, University of Belgrade, Belgrade, Serbia, [2] International Institute for Sustainability, Rio de Janeiro, Brazil, [3] Amity Institute of Forestry and Wildlife, Amity University, Noida, India, [4] The Institute of Heritage Sciences (INCIPIT), Spanish National Research Council (CSIC), Santiago de Compostela, Spain, [5] The University of the Basque Country (UPV-EHU), Leioa, Spain, [6] Sustainability Research Unit, Nelson Mandela University, George, South Africa

Poaching is a widespread activity that affects wildlife management goals and undermines conservation efforts worldwide. Despite its complexity, poaching is still commonly addressed by researchers as a one-dimensional phenomenon. To deepen the scientific understanding of poaching, we conducted a systematic literature review in the Web of Science and Scopus databases for the last 10 years, following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses methodology. We found that most studies were carried out in Africa, although 43% of all articles on poaching were published by researchers from the United States and the United Kingdom. The most studied species are elephants (22%), rhinos (19%), wolves (9%), and bears (6%). Although this study identified a wide range of motives and drivers behind poaching activities, more than half of the analyzed articles do not attempt to provide a deeper understanding of this phenomenon. Its understanding of poaching usually does not go beyond the environmental impact of illegal hunting. Our study's potential limitations may relate to the focus on exclusively English-language articles and, among them, only those discussing mammal, bird, and reptile species. Our findings indicate that global scientific knowledge on poaching in the last 10 years is biased. There is an imbalance between the developed countries that mostly produce knowledge on poaching (usually from Northern America and Europe) and the developing countries commonly an object of interest. This bias is potentially challenging, as the global scientific knowledge on poaching comes from limited experience based on charismatic species and selective case studies. To overcome this gap and develop a deeper understanding of poaching, the scientific community needs to overcome this bias and address illegal hunting wherever it affects the environment and undermines conservation efforts.

Keywords: poaching, wildlife, charismatic species, motives, drivers, Systematic review, PRISMA methodology

OPEN ACCESS

Edited by:
Amy Hinsley,
University of Oxford, United Kingdom

Reviewed by:
Michael 't Sas-Rolfes,
University of Oxford, United Kingdom
Daan Van Uhm,
Utrecht University, Netherlands

Correspondence:
Vukan M. Lavadinović
vukan.lavadinovic@sfb.bg.ac.rs

Specialty section:
This article was submitted to Conservation and Restoration Ecology, a section of the journal Frontiers in Ecology and Evolution

Received: *18 November 2020*
Accepted: *03 March 2021*
Published: *17 May 2021*

Citation:
Lavadinović VM, Islas CA, Chatakonda MK, Marković N and Mbiba M (2021) Mapping the Research Landscape on Poaching: A Decadal Systematic Review. Front. Ecol. Evol. 9:630990. doi: 10.3389/fevo.2021.630990

INTRODUCTION

Poaching is a global social, cultural, political, economic, and environmental challenge that affects wildlife populations, impedes the achievement of wildlife management goals, and undermines conservation efforts (Chiarello, 1999; Yiming et al., 2003; Lemieux and Clarke, 2009; Kaczensky et al., 2011; Archie and Chiyo, 2012). It is commonly referred to as illegal hunting, harvesting, killing, or taking of wildlife (Musgrave et al., 1993; Manel et al., 2002; Johannesen and Skonho, 2005; Liu et al., 2011; International Union for Conservation of Nature, 2020), which indicates that poaching is distinguished from hunting by its legal status. Gombay (2014) links the activity with the property rights and norms, whereas Rizzolo et al., 2017 suggest that poaching should include any non-authorized hunting of wild animals despite any ownership rights. Due to different perspectives on poaching, the definition is highly contested (United Nations Office on Drugs and Crime, 2016).

The role of hunting has changed over time, as well as the attitude toward it accordingly. Historically, in many foraging communities, hunting was a key livelihood activity that ensured survival. And yet, hunting became later a symbol of tyranny and moral indignation, especially during the Renaissance (Cartmill, 1993), the "Age of Exploration," big cat hunting during the period from 1898 until 1930 in Kenya and India (Storey, 1991), or European imperialism and colonialism (MacKenzie, 1988; Grove, 1995; van Uhm, 2016; Montgomery, 2020). On the other hand, hunting has also been used as a symbol of freedom, for instance, after the French Revolution with The August Decrees (The History Guide, 2004) or in Serbia after the Second Uprising against the Ottoman Empire (Lovački savez Srbije, 2004). Poaching at that time did not exist because ordinary people were allowed to hunt. Not only did hunting play a major role in the European imperial experience in Africa and Asia (MacKenzie, 1988), but also, generally, the history of wildlife and nature conservation has been strongly associated with European imperialism (MacKenzie, 1988; Grove, 1995). Such military and "biological expansion" of Europe (Crosby, 1986), denominated "ecological imperialism" (Crosby, 1986) or "green imperialism" was manifested in white aristocratic exploration, trade, expansion, power, and access to privileged exotic goods (MacKenzie, 1988; Grove, 1995) as well as hunting as a sport in the colonies (MacKenzie, 1988). The fusion of colonial history and conservation history is linked with the exclusion of local communities in the protection and certain restrictions on hunting or even the racial inequalities between Europeans and indigenous hunters (MacKenzie, 1988).

Poaching has deep social and cultural roots, which generates a complex understanding and manifestations of illegal hunting. It was considered as an act of rebellion against hunting privileges or imposed alien cultural values, a form of collective resistance, a violation of culturally determined human–nature interactions and coexistence, or an exercise of traditional rights (Bell et al., 2007). Nowadays, numerous anti-poaching movements are gaining momentum worldwide. According to Rizzolo et al. (2017), cultural factors can affect poaching because community norms impact how poaching is seen and whether the community responds with tolerance or sanctions. In certain socio-cultural and legal contexts where the community-based conservation model is present, the notions of 'poaching' and 'illegal hunting' should be distinguished from 'local hunting' which is seen as legitimate and as the contestation of the conservation discourse (Lubilo and Hebinck, 2019). Thus, understanding of poaching can change across temporal and spatial scales.

Hunting regulations vary significantly among different countries or regions, making it challenging to recognize poaching levels. Usually, poaching activities are considered illegal because they cause damage to the environment or are unethical or immoral. Hunting practices can also be labeled as poaching due to the diversity of regulations applied or cultural context. For example, trapping small carnivores is common in Hungary, roe deer-driven hunting with dogs is a widespread practice in some parts of Germany, but both these techniques are banned in Serbia, and as such, would be considered as illegal hunting. In contrast, in Brazil and India, hunting is forbidden, where only traditional communities and those suffering from hunger are allowed to hunt, with certain exceptions (Anonymous., 1972; Antunes et al., 2019; Bragagnolo et al., 2019). Thus, the perception of legal/illegal hunting, actors involved, and motives for poaching are diverse and complex, which results in illegal hunting occurring in different forms worldwide (Muth and Bowe, 1998; Suutarinen and Kojola, 2018; Montgomery, 2020). Nevertheless, the legal regulation of poaching has to do with imperialism, European socioeconomic interest and interference in species conservation and nature protection, the history of wildlife trade, and the social construction of the value of wildlife (van Uhm, 2018), and thus, the criminalization of wildlife trade which, once legal, became criminalized or "unregulated" (van Uhm, 2016) in the 20th century.

The illicit nature of poaching has made it hard to explore and challenging to monitor (Yiming et al., 2003; Lavadinović et al., 2012, 2015; Montgomery, 2020). Efforts to understand and curtail poaching often suffer from what has been called "disciplinary silo thinking" and fail to depict all components of poaching phenomena. Poaching is considered a one-dimensional problem many times (von Essen et al., 2014; Montgomery, 2020). Therefore, this study aims to provide a deeper knowledge of poaching and its limitations in the last 10 years (2011–2020). We conducted an assessment of the scientific literature to understand this phenomenon at the global level by collecting data on poachers, the geographic distribution of studies on poaching, wildlife species, and the reasons behind poaching. Our study is limited to mammals, birds, and reptiles because these wildlife species are hunted and poached across all continents and, as such, are suitable for comparison.

MATERIALS AND METHODS

To meet research goals, we conducted a systematic search of literature following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses framework (Moher et al., 2009). We searched for articles from SCOPUS and Web of Science databases on August 16, 2020. For Scopus, the following search string was used: TITLE-ABS-KEY (mammal OR wildlife OR bird OR game OR reptile OR bushmeat) AND (poaching OR "illegal hunting" OR "illegal killing" OR "wildlife crime" OR "wildlife trafficking") AND (causes OR reasons OR motivations OR perspectives) AND NOT (ocean OR sea OR timber OR fish OR coastal OR marine). In Web of Science, a modified search string with similar search terms was used as follows: ALL = ((mammal OR wildlife OR bird OR game OR reptile OR bushmeat) AND (poaching OR "illegal hunting" OR "illegal killing" OR "wildlife crime" OR "wildlife trafficking") AND (causes OR reasons OR motivations OR perspectives) NOT (ocean OR sea OR timber OR fish OR coastal OR marine). Only articles published between 2011 and 2020 were selected, which resulted in a total of 1,407 articles. Articles from Web of Science and Scopus were combined, and duplicates were removed, which resulted in a total of 1,082 articles to evaluate. First, we excluded all articles that were clearly unrelated to poaching or the illegal killing of wildlife by reading the titles. Second, we read the abstracts of the articles and discarded articles that were not relevant to our objectives. Lastly, we read the main texts for coding and extraction of information. We only considered articles on mammals, birds, and reptiles due to specific hunting practices and black-market demand. Finally, a total of 211 articles were selected for analysis, which corresponded to 19.5% of the total (n = 1,082). **Supplementary Figure 1** shows the flowchart for the identification, screening, and eligibility for the articles. For each article analyzed, several data were collected (**Supplementary Table 1**).

Data Analysis

The dataset was prepared in Microsoft Excel v.20. The data were sorted to prepare infographics for understanding the gaps on spatial and temporal scales. Statistical analysis was done using SPSS v.27 for conducting descriptive statistics, chi-square test, and correlation. Data visualization was done using free access Free Web Creator Visme web page (visme.co). To display the location of studies *versus* the origin of authors/institutions, proportional symbol maps were built in Tableau Desktop v.2020.3, which allows encoding the values per location, with size and/or color. Continent classification was used according to World Population Review (2020). For performing correlations between the variables, initially, the data on species, drivers, motives, and continents were converted into nominal data, and the numerical assigned to these variables were defined in the variable view of the datasheet. Pearson's correlation test was performed to check the significance and strength of correlation between the variables. A chi-square test was performed to see if there was any variation in the articles published between the years.

RESULTS

In total, 211 scientific articles published from January 2011 to August 2020 were analyzed. We found a significant variation among articles published between years (χ^2 = 46.109; df = 9; $p < 0.05$), showing an increasing trend over the years. Approximately 30% of the articles focused on problems of poaching and wildlife management, whereas 20% analyzed poaching as part of wildlife trafficking. The other articles covered various topics related to poaching; among the most common are human–wildlife conflict and poaching as a threat to conservation efforts. Thus, it can be said that approximately 50% of articles attempted to provide a deeper understanding of poaching, whereas the other half was focused on its negative impact on wildlife.

Our analysis shows that poaching is a challenge that is an object of interest for a variety of scientific fields and disciplines (**Supplementary Figure 2**), such as environmental sciences, biodiversity conservation, ecology, genetics, remote sensing, wildlife management, hunting, economics, sociology, anthropology, political sciences, human dimensions in wildlife management, and law. All identified scientific disciplines were classified according to The Organization for Economic Co-operation and Development categories (OECD, 2007). Although the natural sciences' articles are the most common, social studies also have valuable contributions to knowledge production on the topic. We noticed a high number of articles that combine different scientific disciplines. It is also important to note that even inside fields, research on poaching is increasingly becoming interdisciplinary, especially regarding the methods used. As such, poaching seems to be a complex issue explored by different scientific disciplines.

In our sample, 79% of the studies were conducted in one of the 56 countries identified in this research. The other 11% of the analyzed articles have research locations in more than one country, of which the most numerous are regional studies, followed by global studies. Global studies were twice the number of regional studies. The remaining 10% of the articles from the sample did not have a study in any country in particular. The next step was to analyze only articles with study locations in one country or regional studies within the same continent (n = 183). In this way, we identified Africa as the most studied continent among the selected articles, as almost half of the performed research were located there (49%) (**Supplementary Figure 3**). The continents that follow are Asia (21%), Europe (17%), South America (7%), and North and Central America (5%). Australia and Oceania are represented with only one article, which studied poaching in Samoa.

The findings show that the selected articles involve 42% of all South American countries, 33% of African, 29% of Asian, 28% of European, and 17% of all North American countries. Accordingly, the analyzed studies are unevenly distributed per continent, as one-third of European studies origin from Scandinavia (**Supplementary Figure 3**); two-thirds of South American studies are from Brazil; around two-thirds of Asian studies are located in China or south-eastern Asia; half of the studies in North and Central America are from the United States (US). In Africa, half of the studies are located in the south, which means that around one-quarter of all selected articles analyzed in this research have their studies in one of the following countries: The Republic of South Africa, Namibia, Botswana, Zambia, Zimbabwe, Mozambique, or Madagascar. In the selected articles, the most popular countries for conducting studies on poaching are the Republic of South Africa (8% of all selected articles), Tanzania (7%), Zimbabwe, and China (6% each). These results indicate the uneven distribution of studies on poaching among continents and countries.

To find out which countries are the most productive on the topic, we analyzed the country of each first authors' institution. We found that European countries were the most productive, with 77 articles published, followed by North and Central America, with 59 articles, and Africa, with 36 publications, Asia has 22 articles, Australia and Oceania 10, whereas the least productive continent is South America, which published only seven articles (**Supplementary Figure 4**). The most productive country is the US, which published 26% of all analyzed articles, followed by the United Kingdom (17%) and the Republic of South Africa (7%). In fourth place is Australia, which published 4% of analyzed articles, despite not having any study located on its territory. Other European and North American countries are in similar situations, which suggests a misbalance between the scope of studies produced by developed countries and the number of studies located in their territories.

To identify this mismatch, we developed a coefficient of productivity (C_P) for continents, which we calculated by dividing the number of published articles by the number of studies located on that continent (**Supplementary Table 2**). Australia and Oceania (C_P = 10) showed the highest C_P value, which suggests that for each research conducted on this continent, its scientists published 10 more articles on poaching. Australia and Oceania are followed by North and Central America (C_P = 6.6) and Europe (C_P = 2.4). These continents produced more articles on poaching than the number of studies conducted on its territory. In contrast, Asia, South America, and Africa published fewer articles than the studies they hosted.

Most analyzed articles involve research on particular wildlife species (57%). However, a considerable part (43%) either do not consider specific groups or species, as they address poaching as a broad activity or only briefly mentioned them. Within the first group of articles, we ran an analysis to identify which species are the most explored among researchers. Data show that elephants (22%), rhinos (19%), wolves (9%), and bears (6%) are targeted by more than half of all selected articles, which makes these species the most researched ones (**Supplementary Figure 5**). Among big cats' species, the most studied are tigers (5%) and lions (3%), whereas, for bird species, vultures were targeted by 5% of the selected articles and raptors by 3%. In the category "other species," the most dominant groups are apes, which gather half of this category.

A considerable part of the analyzed articles (43%) do not mention any motives for poaching, but those that do show its diversity. For better visualization, identified motives have been grouped and presented in **Supplementary Figure 6**. Income category gathers all motives that aim to improve poachers' household incomes or gain personal profit in various ways, such as offering bushmeat or parts of the animals in the black market, in some cases even capturing live animals to be sold like pets. These motives are the most discussed in the selected articles, which deal with this aspect of poaching. In second place is the category multiple motives, which are combined on a different basis from other categories, and which overlap. This category suggests that poaching is a complex human activity that is performed for more than one reason. Conflict with wild animals and subsidence are also identified as the commonly discussed topics in the selected articles. Poachers who hunt wild animals for the trophy (category trophy) and various acts of rebellion or opposition against authorities (category political) gather the same number of articles. We find it interesting that several articles identified male affirmation and thrill as reasons for poaching. They are considered inside the category others.

More than half of the articles (55.4%) do not discuss any drivers of poaching activities at all. Among those which do (44.6%), we identified in total 35 different drivers, which are mentioned various times. We grouped drivers into five categories to make them easier for comparison, although this approach potentially limits their diversity. The social–economic drivers are the most discussed (n = 68), followed by political (n = 19), social–cultural (n = 15), and ecological ones (n = 8). The remaining drivers (n = 12) have been gathered in the category others (**Supplementary Figure 7**). Among the socioeconomic drivers, the most common is the personal search for an increase in income (40%), the black-market demand for wild animals and their parts (example: illegal trade, organized crime, and corporations) (26%), poverty (15%), and providing food security (7%). In the category of social–cultural drivers, the most numerous are culture/traditions in general (47%), demand for ingredients for medicine (13%), and tradition and traditional rights (13%). From the political drivers, the most mentioned are fragile state security, wars and terrorism (37%), the lack of specific programs and enforcement for poaching (21%), and corruption (21%). Category ecological drivers consist of species availability (50%) and seasons (25%, e.g., people usually poach more in the dry season). In the category of others, the most numerous driver is accessibility (42%).

In the interest of providing deeper knowledge on poaching, we tested correlations between different variables from the analyzed articles. Only two analyses provided statistically significant and positive correlations between species and motives (r = 0.14; $p < 0.05$) and between drivers and motives (r = 0.25; $p < 0.01$). However, both correlations are weak, so we did not go into further analysis.

DISCUSSION

There are a few caveats that we recommend readers consider in the interpretation of our results. This study covers only journal articles, although there are likely other literature sources that provide valuable knowledge on poaching. For the systematic review, we used Web of Science and Scopus databases exclusively, despite the possibility that they will not provide us insight into all available and relevant literature on poaching. Although we focused only on English-language publications, we acknowledge the existence of relevant literature in other languages. Because this study is limited to birds, mammals, and reptile species, there are likely studies on other species that we did not consider. Moreover, it should be underlined that the literature search was conducted in August 2020; hence, any literature on poaching published after our data search was not considered.

Being a complex issue, poaching has been of interest to many different scientific disciplines. Although natural sciences are better represented, social sciences and humanities, likewise articles that combine several scientific disciplines, have gained space in recent years. These results suggest that understanding poaching requires the involvement of a broad spectrum of scientific disciplines, which has to contribute from different aspects to understand this problem.

Our findings reveal an uneven spatial distribution of studies on poaching for both their origin and study location. Researchers showed particular interest in Sub-Saharan Africa, Southeast Asia, and China, which could be explained by significant poaching and trafficking activities in these regions (Lemieux and Clarke, 2009; Liu et al., 2011; Gao and Clark, 2014; Zhou et al., 2018; Coleman et al., 2019; Lunstrum and Giva, 2020). This finding contrasts with the report of the United Nations Office on Drugs and Crime (2020), which demonstrates that every country in the world plays a role in combating wildlife crime. Martin et al. (2012) find that geographical biases are common in ecological studies in general. Thus, it is likely that regions identified in our study are for researchers more attractive than the others.

We noticed in our findings another bias regarding the origin of the published articles. The most productive continents are Northern America and Europe, whereas the most productive countries are the US, United Kingdom, The Republic of South Africa, and Australia. Researchers from these countries published more articles on poaching than the rest of the world in the last decade. The productivity found for these countries is in accordance with other authors' findings within different research topics (Falagas et al., 2006; Soteriades et al., 2006; Ribeiro et al., 2019). Despite having the most productive researchers, both North America and Europe have fewer studies on their territories than other continents. This is even more evident among the most productive countries. For all these Anglo-Saxon countries, except R. The Republic of South Africa, it is common to have researchers who published more articles on poaching in other parts of the world than in their own countries. Boshoff (2009) found in his research strong dependence of African researchers on their European colleagues, which he describes as neo-colonial science. Malhado et al. (2014), in their study, found that "scientific imperialism" is still present in the case of Amazonia. Many researchers agree that colonial legacy plays an important role in developing countries in many aspects, including wildlife conservation (Mkumbukwa, 2008; Bluwstein, 2018; Infante-Amate and Krausman, 2019). Greater researchers' interests in poaching in former colonies than in their own homeland could be compared with Britain's role in nature conservation during the late Victorian period when the country imposed its control in other parts of the world (MacKenzie, 1990). Malhado et al. (2014) consider that foreign influence in Amazonia is decreasing, but it still plays an important role, despite local researchers' capacities being sufficient to deal with their countries' conservation challenges. We believe that international cooperation is essential to combat poaching efficiently and wildlife trafficking, as long it does not neglect other regions nor diminish the sovereignty of the countries or tries to impose a "one model fits all" approach. Still, our findings indicate that in practice, these relationships are built in a "one-way" direction because the leading countries do not have studies on their territory performed by foreign researchers if they are not affiliated with national institutions.

Our findings demonstrate the imbalance between the publishing of "Northern" countries and the number of studies conducted in "Southern" ones. Commonly, it is considered that the "North" has adequate knowledge to resolve challenges that the "South" faces. However, Sollund and Runhovde (2020) offer the example of Norway, which failed to confront the illegal wildlife trade. The same authors raise concern that the northern countries have expectations regarding conservation in southern countries that they themselves neglect. Goyes et al. (2019) exemplify why global dialogs are crucial in combating international wildlife trafficking, as it is not possible to understand challenges in one region of the world without understanding what happens in the others. According to the same author, it is not productive nor efficient to use northern theories and narratives to understand southern problems to help marginalized southern communities. This northern domination of research relevant to poaching and limited research led and published by southern researchers in southern countries relates to the "North–South divide" or its variations the "North–South gap" and "North–South cleavage" (Eckl and Weber, 2007). The global North–South divide in research has become an established discourse in scholarly writing and has been highlighted in various scientific disciplines and fields, such as climate change (Blicharska et al., 2017), health research (Walsh et al., 2016; Kok et al., 2017), conservation studies, and sustainable development (Jeffery et al., 2008). Having said that, we should acknowledge that the outcomes related to this North–South dichotomy in research on poaching will be similar or equivalent in the case of any other research topic. Building on the framework of postcolonial theory (Hammer, 2005), we argue that the research interest on poaching of the north in the south is grounded in the interconnection between European exploration, imperial experience, power, trade, and wildlife conservation. Poaching thus must be regarded within the historical and imperialist context of European colonialism and postcolonial discourse on nature conservation (Singh and van Houtum, 2002).

Black markets have various demands for animal species, which can increase poaching pressure on wildlife and undermine management plans or conservation efforts (Ribeiro et al., 2019; Scheffers et al., 2019; Morcatty et al., 2020). The report of the United Nations Office on Drugs and Crime confirms that nearly 6,000 species are targeted for poaching and illegal trade, whereas no single species was responsible for more than 5% of seized incidents in the last 20 years (United Nations Office on Drugs and Crime, 2020). Thus, we expected that the scientific community would have an interest in a wide range of species affected by poaching. However, our findings show a strong bias toward charismatic species. Half of the analyzed articles on poaching target only three wildlife species, such as elephants, rhinos, and wolves, of which two are found in Africa. Nevertheless, we believe that concern for these species' survival is not the only reason behind their popularity in the scientific community. It is in accordance with Redpath et al. (2017), who found out that large carnivores in Europe and North America are the most intensively monitored and studied large mammals in the world. It is likely because researchers are more attached to iconic species and tend to study them more (Fleming and Bateman, 2016; Fink et al., 2020). These species identified in our study are considered to be charismatic and, as such, are used to attract public attention, receive more research interest, and policy coverage (Courchamp et al., 2018; Sibarani et al., 2019; Thompson and Rog, 2019). Lundberg et al. (2020) consider charismatic species to be an effective fundraising tool, which likely attracts researchers to study them.

It should also be taken into consideration that there are research priorities among scientists. Ellison and Degrassi (2017) suggest that some species, such as flagship ones, are considered to be more valuable than others in conservation efforts and, as such, attract more attention. Despite not necessarily agreeing with this statement, we acknowledge it could be considered a criterion for a selection. On the other hand, the main reason that makes these species to be considered flag species and attract interest and empathy among scientists, ENGOs, policymakers, and the public is the same one that makes them remain severely endangered (Courchamp et al., 2018). Besides charismatic species, researchers' interest is focused on human–wildlife conflict/human–wildlife coexistence, which we found to be specially related to wolves and birds of prey. Our findings are in accordance with Lavadinović et al. (2017), who found that wolf poaching is an especially popular topic among Scandinavian researchers. In our sample, Scandinavian authors produced one-third of all European articles on poaching. Human–wildlife conflict exacerbates hostility toward wildlife and has become a major threat to species conservation (Anand and Radhakrishna, 2017). However, it is difficult to estimate its scope, as retaliatory killing is widespread among common farmers worldwide (Konig et al., 2020).

Approximately half of the studies did not provide any insights into poachers' motives to hunt illegally. We noticed that many articles often do not go beyond general suggestions, which is not sufficient for a deeper understanding of poaching. Motives behind poaching identified in this study, such as income, subsistence, or trophy, among others, are in accordance with findings of Muth and Bowe (1998). However, the categorization of motives in our study is different, as we grouped them according to the sample size. Muth and Bowe (1998), for example, identified thrill killing as a separate motive for poaching, whereas in our study, it is placed in group others. Our results demonstrate that in analyzed articles, financial gain and human–wildlife coexistence were the most discussed reasons for poaching. Another finding is that motives for poaching commonly overlap. It is in accordance with Montgomery (2020), who identified between poachers' motives "innumerable subcategories." Drivers of poaching were also poorly studied in analyzed articles, as more than half of studies did not consider them. Findings indicate that social–economic drivers were the most prevalent ones for poaching in the reviewed studies, which is similar to Lynch et al. (2017). We noticed that in our findings, drivers for poaching commonly overlap, indicating the challenge to understand deeper the reasons behind poaching. Our findings support Montgomery (2020), who advocates for the recognition of the complexity of poaching as a vital step to align conservation practice and social justice effectively. As such, a deeper analysis is still needed to deconstruct the poaching phenomenon (von Essen et al., 2014). Correspondingly, we believe qualitative studies, particularly anthropological and sociological ones, might offer further insights into the biological, economic, and socio-political motives for poaching. Further to the debate surrounding poaching motives, the absence of a universally accepted definition of poaching (United Nations Office on Drugs and Crime, 2016) makes it challenging to understand this complex issue better. Hence, previously quoted authors indicate not only how deep roots and diverse character poaching has but also how its forms and meanings are multi-layered (Bell et al., 2007). In the same way, Bell et al. (2007) ground poaching in the collective identity, Brymer (1991) rethinks poaching and hunting as a "deviant subculture," whereas Eliason (1999, 2003) looks at poaching from the philosophical perspective intending to identify "wildlife law violators" and deeper roots of such behavior.

The majority of analyzed studies from our sample consider poaching as an environmental threat (Chiarello, 1999; Yiming et al., 2003; Lemieux and Clarke, 2009; Kaczensky et al., 2011; Archie and Chiyo, 2012). However, poaching has a more complex and far-reaching influence because it is, along with illegal wildlife trade, a part of wildlife crime (United Nations Office on Drugs and Crime, 2020), environmental or green crime (Hall et al., 2016; van Uhm, 2018). As such, poaching affects climate change and biodiversity (United Nations Office on Drugs and Crime, 2020). According to the same source, wildlife crime also impacts national security, social–economic development, and public health. Profits from wildlife crime support the rise of organized crime, spread corruption, obstruct justice, and often involve government officials in various scope and at various levels (Hauenstein et al., 2019; Titeca, 2019; United Nations Office on Drugs and Crime, 2020). Moreover, a wildlife crime has a negative influence on fragile governments, which can participate in wildlife crime activities and businesses. In such a manner, illicit activities are camouflaged under legitimate companies, making the control of wildlife crime even more challenging (van Uhm and Nijman, 2020). Scientists also associate poaching with armed conflicts and terrorism (Beyers et al., 2011; Rotshuizen and Smith, 2013; Haenlein et al., 2016). Thus, poaching's negative consequences go beyond environmental challenges and, in various forms, impose threats to society and stability worldwide (Lavorgna, 2014). The complexity of wildlife crime and its severe negative impacts on both nature and society raise the need for adequate measures to curb poaching. Among analyzed studies, we noticed that implementation of more intensive wildlife monitoring and game protection is discussed. It also includes better trained and equipped gamekeepers to combat poaching. Green militarization is a commonly addressed issue in studies on poaching in the last decade. Militarized conservation has increased worldwide in the past decade, although it is still understudied (Duffy, 2014; Lunstrum, 2014). Thus, researchers highlight the importance of engaging critically with the militarization of conservation, as it frequently produces unforeseen consequences (Lunstrum, 2014; Duffy et al., 2019). Duffy et al. (2019) identified five major themes emerging as critiques to militarized conservation, which include understanding the ways that local communities experience militarized conservation; how the militarization of conservation can contribute to violence; where conservation operates in the context of armed conflict; and how it fits in with and reflects wider political–economic dynamics. Massé et al. (2018) propose closer interaction between military studies and the political–ecological work on green militarization to provide more adequate solutions in combating wildlife crimes.

FINAL CONSIDERATIONS

Our findings suggest that knowledge on poaching motivations and drivers in the last decade is spatially biased. Studies are mostly led by researchers affiliated with institutions from developed countries, although most of such studies are usually conducted in Sub-Saharan Africa or few other popular regions. Scientists like to study charismatic species such as elephants, rhinos, wolves, or few others. However, there are many other parts of the world with high biodiversity and many more poached species or are killed for illegal trade, but not many studies have been conducted in the last decade. In other words, knowledge on poaching in the last decade is based on selective studies, narrow findings, and limited information. Nevertheless, it still shapes actions on illegal activities or biodiversity protection on a global scale. To better understand these threats, it is necessary to study them everywhere they occur and affect biodiversity or undermine conservation efforts. If it is not a case, like it is in our study, obtained knowledge is not sufficient to support action in many regions of the world.

Findings from this study confirm that poaching is a complex issue that occurs in different forms and various reasons. As such, it has a severe impact on the environment. Although poaching is explored in many scientific disciplines or applied fields, it is usually considered as a threat to conservation efforts, and most studies do not go beyond the evaluation of its negative impacts. Thus, it seems that the analyzed scientific knowledge is not sufficient to develop efficient measures against poaching. Only a limited number of studies from our sample tend to provide a deeper understanding of poaching by analyzing underlying motives and drivers. Considering spatial limitations, there is a concern that available knowledge on poaching is not applicable in other parts of the world. Besides, poaching seems to be a complex social–environmental problem, which integrates innumerable dimensions. It is increasingly important for researchers, NGOs, and policymakers to have an understanding of the social–ecological systems they study, to be deeply involved in generating information and decision-making for combating poaching and illegal trade in their countries. These issues should not be delegated to other nations, but they need to include them when they can contribute. There is a greater need for research to overcome geographical biases and geopolitical relationships to provide the knowledge necessary to combat poaching and wildlife trafficking at the global and local levels.

DATA AVAILABILITY STATEMENT

The data supporting the findings of this study are available from the corresponding author on request.

AUTHOR CONTRIBUTIONS

VL and CI analyzed part of the data and contributed to all sections of the manuscript. MC designed the method, analyzed part of the data, ran statistical tests, contributed to discussion, and prepared the references. NM prepared figures, contributed to introduction, discussion and the final version of the manuscript, and critically revised the manuscript. MM ran the literature review, prepared the section "Materials and Methods," and did the proofreading. All authors contributed to the article and approved the submitted version.

ACKNOWLEDGMENTS

We want to express our gratitude to the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) for bringing authors together and supporting our research interests. Moreover, we thank their institutional affiliations. NM is grateful to the Institute of Heritage Sciences INCIPIT CSIC, her supervisors César Parcero-Oubiña and Cristina Sánchez-Carretero, the MSCA-ITN Project "Critical Heritage Studies and the Future of Europe—CHEurope," and the University of the Basque Country (UPV-EHU).

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fevo.2021.630990/full#supplementary-material

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

frontiers in Ecology and Evolution

POLICY BRIEF
published: 14 June 2021
doi: 10.3389/fevo.2021.675400

China's Conservation Strategy Must Reconcile Its Contemporary Wildlife Use and Trade Practices

Yunbo Jiao[1]† and Tien Ming Lee[2]*†*

[1] School of Law, Sun Yat-sen University, Guangzhou, China, [2] Schools of Life Sciences and Ecology, and State Key Laboratory of Biological Control, Sun Yat-sen University, Guangzhou, China

China's supply-side conservation efforts in the past decades have led to two bewildering juxtapositions: a rapidly expanding farming industry vs. overexploitation, which remains one of the main threats to Chinese vertebrates. COVID-19 was also the second large-scale zoonotic disease outbreak since the 2002 SARS. Here, we reflect on China's supply-side conservation strategy by examining its policies, laws, and practices concerning wildlife protection and utilization, and identify the unintended consequences that likely have undermined this strategy and made it ineffective in protecting threatened wildlife and preventing zoonotic diseases. We call for China to overhaul its conservation strategy to limit and phase out risky and unsustainable utilization, while improving legislation and enforcement to establish full chain-of-custody regulation over existing utilization.

Keywords: supply-side conservation, wildlife farming, wildlife trade, species conservation, COVID-19

OPEN ACCESS

Edited by:
Franco Andreone, Museo Regionale di Scienze Naturali, Italy

Reviewed by:
Amaël Borzée, Nanjing Forestry University, China
Zhaomin Zhou, China West Normal University, China

Correspondence:
Yunbo Jiao
jiaoyunbo@mail.sysu.edu.cn
Tien Ming Lee
leetm@mail.sysu.edu.cn

†ORCID:
Yunbo Jiao
orcid.org/0000-0001-6473-6357
Tien Ming Lee
orcid.org/0000-0003-2698-9358

Specialty section:
This article was submitted to Conservation and Restoration Ecology, a section of the journal Frontiers in Ecology and Evolution

Received: *03 March 2021*
Accepted: *06 May 2021*
Published: *14 June 2021*

Citation:
Jiao YB and Lee TM (2021) China's Conservation Strategy Must Reconcile Its Contemporary Wildlife Use and Trade Practices. Front. Ecol. Evol. 9:675400. doi: 10.3389/fevo.2021.675400

INTRODUCTION

As China fought to bring the coronavirus disease (COVID-19) pandemic under control since the beginning of 2020, this was already the second large-scale zoonotic disease outbreak in China within just two decades [the first being the severe acute respiratory syndrome (SARS) coronavirus outbreak in late 2002[1]]. Similar to the SARS coronavirus, the international scientific community confirmed that the COVID-19 coronavirus also originated in wildlife (Calisher et al., 2020), though its host species are still undetermined (Zhou and Shi, 2021). Nonetheless, to reduce the risk of animal-to-human transmission, the Chinese government promptly imposed a temporary ban in January 2020 on the transport and sale of wildlife in markets, restaurants, and online (Zhou et al., 2020), and a complete ban in the following month on the consumption of most terrestrial wild animal species as food (including both wild and captive sources) (Koh et al., 2021). But how did we get here?

While acknowledging that the direct and indirect factors contributing to biodiversity loss and outbreak of zoonotic disease are complex and multifaceted, here we focus on explaining why China's conservation strategy must either reconcile its contemporary wildlife use and trade practices or run the continued risk of being rendered ineffective in protecting threatened species and preventing future zoonotic pandemics. We reflect on China's conservation strategy by reviewing its policies, laws, and practices concerning wildlife protection and utilization, identify the unintended consequences that may have undermined this strategy, and make recommendations to overcome

[1]World Health Organization. SARS (Severe Acute Respiratory Syndrome). Available online at: https://www.who.int/ith/diseases/sars/en/ (accessed March 2, 2021).

them. Consequently, the insights and takeaways from China's lesson may prove valuable for many other countries worldwide.

CHINA'S LEGAL FRAMEWORK FOR WILDLIFE PROTECTION AND UTILIZATION

China has a complex mix of laws, regulations, and policy directives for the protection and management of wildlife species as well as their habitats. Currently, there are over 50 wildlife-related national legal documents in effect (MEE, 2014). Among them, the Wildlife Protection Law (*WPL*; revised in 2016) – by setting out the wildlife ownership, scope of protection, protection and management mechanisms, and the administrative liability and penalties for violation – serves as the backbone of China's wildlife legal framework.

The wild fauna species protected by the *WPL* include those listed in: (1) the List of Wildlife under Special State Protection (SSP), which is further differentiated between the first-class SSP (Class-I SSP) and second-class SSP (Class-II SSP); and (2) the List of Terrestrial Species of Important Ecological, Scientific or Social Values. The List of SSP wildlife was firstly promulgated in January 1989 (NFGA and MARA, 1989) and remained largely unchanged until February 2021 when an updated List was released with substantial revisions, including enlisting of 517 new species (the SSP species now totaled at 980) and uplisting of 65 species from Class-II to Class-I SSP (NFGA and MARA, 2021). In 1993, in fulfilling its obligation under the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), CITES Appendix-I and Appendix-II non-native species were granted the Class-I SSP and Class-II SSP, respectively (NFGA (National Forestry and Grassland Administration), 1993).

In Chinese wildlife legal parlance, the term utilization (*利用 Liyong*) is referred broadly to activities associated with the exploitation and trade of wildlife, including living organisms, their body parts, and products. The *WPL* 2016 prohibits hunting/catching, killing, sale, purchase, and end-use of SSP species and their products (Article 21, 27, 30). However, the Law gives exemptions to the utilization of SSP species for a specified range of purposes and sets up various regulatory schemes (**Table 1**), with a view to ensuring that such exempted uses and trades are under "adequate regulation and stringent supervision" (Article 4) and not detrimental to the survival of wild populations. In contrast, the utilization of non-protected species is less regulated by the current legislation (i.e., their hunting and farming do not mandate relevant permits) (Xiao et al., 2021).

The *WPL* 2016 supports the utilization of protected species for species conservation, public education, scientific research and other non-commercial purposes (**Table 1**), but restricts the commercial utilization to captive-bred specimens of the SSP species for which (1) there exist well-established breeding techniques; (2) there is a relatively large stock of captive populations; (3) restocking can be met by individuals in captivity; and (4) such utilization is conducive to reducing exploitation pressure on wild stocks (Xinhua News, 2017). The Law authorizes the National Forestry and Grassland Administration (NFGA) and the Ministry of Agriculture and Rural Affairs (MARA) to draw up and promulgate, within their respective remit and based on scientific evaluation, a utilization list of terrestrial/aquatic species that meet the above terms (Article 28). Once included in the utilization list, the Law allows for the revocation of the SSP status from the farmed populations of such SSP species, albeit their wild counterparts remaining as SSP protected and may still be threatened by trade to a varying extent. During 2017–2019, the NFGA and the MARA released three successive utilization lists, which contain a total of 30 SSP and CITES-listed species [e.g., sika deer (*Cervus nippon*) and Indian bullfrog (*Hoplobatrachus tigerinus*)] for full commercial farming and trade (NFGA, 2017a; MARA, 2017, 2019).

CHINA'S WILDLIFE FARMING AND TRADING PRACTICES

China's wildlife farming began in the 1950s (Ma, 1992) and expanded in the 1980s (Li, 2007). In the early 2000s, in response to the decimation of the wild populations of many medicinally and economically important species (e.g., bear, musk deer), a series of regulations and policies were introduced to tighten the restriction on commercial harvesting of wild animals and support the development of domestic farming industry, so as to promote the strategic transition in the use of wildlife from relying on wild to captive-bred sources.

The most notable was the 2003 *Circular on the List of 54 Terrestrial Animal Species...* (hereafter the "54-species List") issued by the NFGA (2003), which had, for the first time, expressly legalized the commercial farming and trade of some 54 fauna species for which there was claimed to have in place well-established breeding techniques. Following this, China put in place a set of preferential policies (e.g., tax deduction, low-interest loans, and secured market entry) to guide and incentivize new investments [especially from manufacturers of traditional Chinese medicine (TCM) and light industrial goods] in breeding these 54 species (NFGA, 2004). As a result, local farming operations mushroomed after 2000 (e.g., Yunnan province; Yang and Li, 2009).

By 2016, the number of registered commercial farms reached 7,958, with an annual production value of USD 7.9 billion (NFGA, 2017b). Between 2005 and 2019, the NFGA had granted a total of 4,194 "Permits for Captive Breeding SSP-I Species" to 3,054 entities, of which 2,718 were commercial farms (including 1,538 deer farms) (NFGA, 2019).

Across China, there are at least 80 species of wild animals being farmed for different commercial purposes (MARA, 2020; NFGA, 2020). Use as food has increasingly become the main boost for the farming operations in several provinces [e.g., Zhejiang (Zhu et al., 2008) and Yunnan (Xiao et al., 2018)] in terms of both the magnitude of farms involved and stock in captivity.

In order to track the sale and purchase of wildlife products from protected species and attest their legality, China instituted,

TABLE 1 | Permissible forms of utilization of species under special state protection (SPP), as stipulated in China's *Wildlife Protection Law* 2016.

Forms of utilization	Source of specimens	Purposes	Regulatory measures	Legal provisions
Hunting, catching, or killing of SSP species	Wild & captive	Scientific research, population control, epidemic monitoring, or other special, non-commercial purposes	Special hunting and catching permit	Art. 21
Captive breeding of SSP species	Mainly captive, wild as exception	Species conservation; other purposes (incl. commercial)	Business registration; captive-breeding license	Art. 25
Sale, purchase, transport, carrying, and post of SSP species and products thereof; use of SSP species as raw materials for making other products (excl. medicines)	Mainly captive, wild as exception	Scientific research, captive breeding, public exhibition and performance, heritage preservation, or other special, non-commercial purposes	Business registration; prior approval; special marking; quarantine certificate	Art. 27, 33
Export of SSP species; import and export of CITES-listed species	Wild & captive	Commercial and non-commercial purposes	Import, export, or re-export permit; quarantine certificate	Art. 35
Manufacturing, sale, and clinic use of medicines containing ingredients of SSP species	Mainly captive, wild as exception	Medicinal use	Stock management and quotas control; prior approval; special marking; pharmaceutical regulations; limited to government-designated manufacturers, pharmacies, and hospitals	Art. 29
All forms of utilization	Farmed specimens of the species on the "List of Species under Special State Protection for Captive Breeding"	Commercial purposes (e.g., food, healthcare products, leather and fur products, medicines, ornaments, pets, etc.)	Captive-breeding license; special marking	Art. 28

since May 2003, a pilot scheme called "Special Marking for Wildlife Trade and Utilization" (NFGA and MARA, 2003). Such markings have been given to business entities and the animals they raise or the wildlife products they produce and sell; wildlife affixed with a special marking can be transported and sold legally. In the *WPL* 2016, the special marking scheme was elevated to be one of the fundamental management mechanisms for wildlife farming and trade. So far, only a small proportion (1,300 by 2015; Wang, 2016) of wildlife farming and trading businesses is covered by the special marking scheme (**Table 2**). The species legalized for commercial farming and trade include not only those on the 54-species List for which there are relatively abundant, exploitable farmed specimens, but also the state-protected and CITES-listed species – e.g., leopard, saiga antelope (*Saiga tatarica*), and rare snake species – for which captive breeding is not viable at the commercial level (Xiao et al., 2018; Challender et al., 2019a) and their supply is reliant on stockpiles and wild extraction from within China and abroad (NFGA et al., 2007).

UNINTENDED CONSEQUENCES OF A CONSERVATION STRATEGY

From the above review, it is evident that China has attuned its national conservation strategy towards the supply side since the early 2000s for a solution to balancing the competing needs for species conservation and meeting an increasing demand for wildlife products. On the one hand, this "conservation through commercial farming and utilization" strategy, which is also known as supply-side conservation (Phelps et al., 2013), supports the development of a wildlife farming industry and promotes related commercial trade and use of their farmed specimens. Through the provision of captive products, wildlife farming is expected to attain the simultaneous achievement of meeting the social–cultural demand for wildlife products and alleviating the poaching and hunting pressure on wild populations (Jiang et al., 2007; Wang et al., 2019). On the other hand, China's wildlife legislation sets in place a complex licensing system built around the permits for hunting, captive breeding, import and export, and special marking scheme with an aim to regulate the legal trade and to prevent the illegal trade.

However, this strategy did not work well for Chinese-protected species. Some of the intensely farmed and exploited species – e.g., forest musk deer (*Moschus berezovskii*) (Wang and Harris, 2015) and Sika deer (Harris, 2015) – have fragmented ranges or are experiencing a continuing decline in their wild populations, despite their increasing farmed stocks. However, updated assessments of the status of wild populations of many other farmed species are evidently lacking. Nevertheless, overexploitation for food and TCM remains one of the major recent causes of the endangerment of most of the imperiled Chinese vertebrates (MEE and CAS, 2015). Here, we highlight three specific unintended consequences that we believe have undermined China's supply-side conservation strategy, making it ineffective in protecting threatened species and preventing zoonotic disease outbreaks.

First, while advancing wildlife farming and trade in the name of protection, this strategy did not consider the preconditions underlying supply-side approach (Tensen, 2016) against China's contexts, such as the consumer preference for wild over captive (Gratwicke et al., 2008; Dutton et al., 2011), and dependency on wild for restocking for many species (e.g., frogs, snakes) (Xiao et al., 2018). This has resulted in the failure of farmed specimens to substitute for wild-sourced ones and unabated exploitation of wild populations, as well as an increased demand (especially for wild meat and health tonics; Zhang and Yin, 2014) due to the presence of the legal market.

Second, the existing special marking scheme that was devised to help wildlife regulators and enforcers tackle the laundering of wild animals was not effective. This is due to the following: (1) High policing burden. The existence of large numbers of small, scattered, and often unregistered household farms makes regulation and enforcement extremely challenging. A nationwide law enforcement campaign against illegal wildlife trade launched between January and February 2020 revealed that the total number of Chinese wildlife breeding sites could be over 16,000 (Xinhua News, 2020), which is double the number of the registered commercial farms (close to 8000) noted previously. (2) Limited application on live animals. So far, only 18 species have been requested to apply the marking scheme to their live specimens (**Table 2**). (3) Lack of forensic tools. Critically, forensic tools, particularly those that can be conducted *in situ*, are needed in determining specimen identity, provenance, or legal status. However, the shortage of wildlife forensics laboratories and their limited testing capacity (currently restricted to only species identification) impair wildlife authorities' ability to detect illegal trade, including the abuse and forgery of the markings (Shao and Jiang, 2017).

Third, the legal gaps, the jurisdictional overlaps among multiple wildlife regulators, and the lax enforcement led to the absence of wildlife quarantine and market supervision. Despite the *WPL* 2016 stipulating that wildlife in sale must come with a quarantine certificate (Article 27), the animal health supervision station under the MARA focuses their work mainly on poultry and livestock, and rarely conducts quarantine on wild and farmed animals before butchering, transport, and sale due to the lack of protocols, pathogen data, and vaccinations (Liu et al., 2015). As for market supervision, while both the NFGA and the State Administration for Market Regulation are mandated to establish enduring working mechanisms for inspecting wildlife sold within and outside of local marketplaces, their enforcement efforts

TABLE 2 | Entities and wildlife products covered by the special marking scheme during 2003–2017[#].

Type of wildlife products	Marked entities^	Marked wildlife products^	Marked species
Food and healthcare products	98	170, incl. wine products (e.g., bone-strengthening wine, bear-bile wine, three-snake wine, three-genital wine, gecko wine), dried and frozen meat products	Bear, red deer, sika deer, wild boar, ostrich, Siamese crocodile, Nile crocodile; Indian bullfrog
Fur and skin products	65	Raw furs and skins; leather and fur products	Leopard, tiger, Arctic fox, red fox, mink, raccoon dog, ostrich, brown caiman, Siamese crocodile
Animal specimens	18	–	Undisclosed*
Arts and crafts	5	Arts and crafts made of deer antlers and skins, ostrich skins	Sika deer; ostrich
Live animals	6*	Live organisms	Bear, elephant, giant panda, Hylobates, leopard, lion, Mongolian kulan, orangutan, Przewalski's horse, red panda, takin, tiger, golden snub-nosed monkey, leaf monkey, crab-eating marque, rhesus macaque, crane, stork, swan, Chinese alligator, brown caiman, Siamese crocodile
Manufacturers and retail outlets of Erhu containing python skins	309	Erhu made from python skins	Python
Traditional Chinese medicine (TCM)	Undisclosed*	TCM containing ingredients of bear bile, elephant skins, leopard bones, musk, pangolin scales, saiga horns or parts of state-protected or CITES-listed snake species	Bear, elephant, leopard, musk deer, saiga antelope, pangolin; gecko, rare snake species
Number of government-designated hospitals for clinic use of TCM containing endangered species^		- TCM containing musk or bear bile: 66 - TCM containing Saiga horns: 492 - TCM containing pangolin scales: 711 - TCM containing parts of state-protected or CITES-listed snake species: 702	

[#] *Data were collated from the Notices issued during 2003–2017 by the National Forestry and Grassland Administration (NFGA) and its precursor, the former State Forestry Administration, which included: 2003 (No. 2, No. 3); 2004 (No. 1, No. 6); 2005 (No. 3, No. 5); 2007 (No. 8); 2008 (No. 15); 2009 (No. 5, No. 6); 2011 (No. 1; No. 4); 2012 (No. 1); 2013 (No. 5, No. 6); 2014 (No. 1); 2015 (No. 8, No. 9); 2016 (No. 13); 2017 (No. 8).*

^ *Overlaps exist among the government-designated hospitals for clinic use of TCM containing protected species. Overlaps also exist among the marked entities as a company may produce two or more types of wildlife products. Information from personal contacts suggests that some of these products (e.g., bear-bile wine) are currently taken off the marked wildlife list.*

* *The following information was not disclosed to the public: (1) the marked manufacturers and pharmacies of TCM containing bear bile (NFGA, 2005: No. 3), leopard bone (NFGA, 2005: No. 6), Saiga horn, pangolin scales, or parts of state-protected or CITES-listed snake species (NFGA et al., 2007: No. 8); (2) the marked entities that produce and sell products made from parts of rare snake species, or tiger or leopard skins (NFGA et al., 2007: No. 8); and (3) the marked entities that captive breed some 18 endangered or high-value species excluding crab-eating marque, rhesus macaque, brown caiman, and Siamese crocodile (NFGA, 2005: No. 5).*

appear ineffective in preventing the illegal trade in part due to overlapped supervisory remit, overburdened workload, and a lack of expertise, trained personnel, and resources (Li, 2018; Liu and Zhang, 2020).

In short, the rapid expansion of wildlife farming and trade for commercial ends, coupled with the inability of China's regulatory system to effectively distinguish wild-sourced and captive-bred wildlife, has created a loophole where farming facilities are laundering wild animals and local markets selling illegal wildlife. With the poorly enforced animal quarantine and market supervision, the intermingling of wild, captive, and domestic animals presents an ideal opportunity for the exchange of pathogens among diverse species and the spillover from wild hosts to humans.

RECOMMENDATIONS

As such, we call for an overhaul of China's conservation strategy to limit and phase out risky and unsustainable wildlife farming and trade, while improving legislation and enforcement to establish solid, full chain-of-custody regulation over the existing utilization from harvesting and farming to end-use. We make the following four inter-related suggestions.

Ban on Risky Use of Wildlife

Given China's ingrained cultural beliefs and large numbers of household-based farms, an outright ban on wildlife trade may lead to the perpetuation of black markets and substantial loss of livelihoods (Challender et al., 2019b; Roe and Lee, 2021). Hence, we suggest a reassessment of current permissible farming and trading practices based on their potential public health risk and conservation, cultural and economic benefits, and banning all forms of high health-risk use of wildlife that involves close human–animal contact yet lacking appropriate quarantine inspection (e.g., exotic pets). For cultural and TCM use, we suggest improving the sustainability and traceability of supply chains through initiatives including (1) seeking substitutes (Luo et al., 2013) (e.g., water buffalo horn is a widely known substitute for rhino; Hinsley et al., 2020); (2) developing certification schemes underpinned by the special marking for farming operations and farmed products (e.g., as an extension of the existing China Forest Certification; Wang et al., 2017), as well as sustainability standards for wild extraction (e.g., FairWild Standard for the harvest of wild medicinal and aromatic plants; Hinsley et al., 2020); and (3) engaging stakeholders (e.g., wildlife farming/trading businesses and local communities) in standard setting and encouraging public reporting of non-compliance behavior (Tröster and Hiete, 2018). On the consumer end, we suggest reducing or redirecting demand through initiatives including (4) education and awareness-raising campaigns to dispel myths about wildlife's curative or tonic effects (e.g., the alleged use of pangolin scales in stimulating breast milk secretion; Hua et al., 2015); and (5) social marketing campaigns (Greenfield and Verissimo, 2019) to encourage abandonment of unsustainable traditional customs, or to redirect demand onto non-threatened substitutes with similar cultural credibility (e.g., directing demand for animal-derived TCM onto herbal substitutes; Moorhouse et al., 2020).

Expanding the *WPL*'s Protection Scope

We propose the following: (1) while retaining the key state protection for rare or endangered species through the SSP listing, the *WPL*'s protection scope should be augmented to offer universal protection to all wild species (Chang et al., 2015; Liu, 2020; Lü and Chen, 2020); (2) conducting regular national wildlife surveys to enable a better and timely understanding of the current status of and the evolving threats to species and habitats; and (3) adjusting the SSP list regularly to reflect the latest changes in population status and threats and offer the appropriate level of protection (Zhou, 2015; Gong et al., 2020).

Clarifying Jurisdictional Boundaries and Strengthening Surveillance System

(1) We propose accelerating the updating and amendment of relevant supporting regulations, measures, standards, and technical manuals for the *WPL* (including developing wildlife quarantine protocols with reference to those currently available for poultry and livestock), such that the jurisdiction for various wildlife authorities along the chain of custody is clear and well-defined. (2) We recommend incorporating the One Health approach (WHO (World Health Organization), 2017) into building an integrated inter-agency and inter-sector national surveillance system for infectious zoonoses that is supported by a network of accredited veterinary and public health diagnostic laboratories, a better reporting system from both formal (e.g., medical care facilities) and informal (the public) channels, and a shared national pathogen database for both wild and farmed animals (Gebreyes et al., 2014; Guo, 2020).

Combating Wildlife Laundering and Illegal Trade

We suggest the following: (1) registering all farming facilities, closing out those having no valid permits or not meeting the legal requirements on breeding operations (e.g., founder stock), and promoting the consolidation of small family-based farms into satellite farms affiliated to a few large-scale farms in order to facilitate management and enforcement (e.g., python farming in Hainan Province; Natusch and Lyons, 2014); (2) registering and applying special marking to farmed animals, and establishing individual-based archives (e.g., genealogy) to enable traceability; (3) placing the burden of proof on farmers and traders to provide evidence for the provenance of the animals they raise or sell; (4) strengthening both paperwork oversight and on-the-ground inspection of farms and trading sites, and cracking down on illegal purchase and resale of poached animals under the guise of captive breeding or special markings; and (5) investing and leveraging modern and advanced forensic techniques such as high-resolution x-ray fluorescence (Brandis et al., 2018), and isotopic and elemental markers (Natusch et al., 2017) to reinforce the utility of the special marking.

CONCLUSION

Making supply-side conservation work is critical at the global scale because of its potential to be both a conservation tool and a solution for sustainable use of wild species for a significant number of countries where the use of wildlife by local communities is often an imperative rather than a choice (Roe, 2008). The current setback in China serves as an important warning for the world of the potential negative impact of commercial farming and trade as a supply-side conservation approach when implemented improperly. Nevertheless, if China can take advantage of this opportunity to remedy its conservation strategy, it could become a role model for the rest of the supply-side conservation world. In this sense, the upcoming new amendment of the Wildlife Protection Law (The NPC, 2020) is a fundamental window for China to overhaul its conservation strategy to better serve the triple goals of conserving biological diversity and ecological integrity, facilitating the establishment and strengthening of conditions for promoting sustainable and equitable use of wildlife, and preventing the emergence and spread of zoonotic diseases in China and around the world.

AUTHOR CONTRIBUTIONS

YJ did the data collection and analysis. Both authors did the study design, writing, and manuscript revisions, and approved the final manuscript.

FUNDING

This work was supported by research grants from Sun Yat-sen University (20wkpy08) to YJ and from the National Natural Science Foundation of China (grants 41180944 and 41180953), the Guangdong Provincial Research Fund (grant 42150016), and the European Commission (grant ENV/2018/403-527) to TL.

ACKNOWLEDGMENTS

We thank Rick Ruan for comments on an earlier version of the manuscript, and two reviewers for their constructive feedback.

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

frontiers in Ecology and Evolution

BRIEF RESEARCH REPORT
published: 25 June 2021
doi: 10.3389/fevo.2021.631795

Orchid Obscurity: Understanding Domestic Trade in Wild-Harvested Orchids in Viet Nam

Leigh-Anne Bullough[1]*, Nga Nguyễn[2], Rebecca Drury[3] and Amy Hinsley[4]

[1] Independent Researcher, Swansea, United Kingdom, [2] Independent Researcher, Ha Noi, Vietnam, [3] Fauna and Flora International, Cambridge, United Kingdom, [4] Wildlife Conservation Research Unit, Department of Zoology, Oxford University, Oxford, United Kingdom

OPEN ACCESS

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***Correspondence:**
Leigh-Anne Bullough
leigh.anne.bullough@gmail.com

Specialty section:
This article was submitted to
Conservation and Restoration
Ecology,
a section of the journal
Frontiers in Ecology and Evolution

Received: 20 November 2020
Accepted: 27 April 2021
Published: 25 June 2021

Citation:
Bullough L-A, Nguyễn N, Drury R
and Hinsley A (2021) Orchid
Obscurity: Understanding Domestic
Trade in Wild-Harvested Orchids
in Viet Nam.
Front. Ecol. Evol. 9:631795.
doi: 10.3389/fevo.2021.631795

Unsustainable and illegal wildlife trade is a well-known conservation issue, but there are still large gaps in our understanding of how trade chains operate for the majority of over-exploited wildlife products. In particular, the large-scale global plant trade is under-reported and under-researched, and this is even more pronounced when the trade takes place within a country's borders. A clear example is the trade in orchids, all species of which are listed by the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). Although countries such as Viet Nam are known hotspots for the large-scale collection of wild orchids for the international horticultural trade, little is known about how plants move from the wild to the end-consumer, what role is played by domestic markets and the sustainability of this trade. We use a mixed-methods approach to determine the structure of trade chains for orchids in key trading areas of Northern Viet Nam, and use a thematic framework to identify five groups of actors trading wild-harvested orchids. Trade occurs both domestically and internationally, underpinned by demand for rare, wild plants. An important first step to address the illegal and unsustainable plant trade is to recognise it as a major and growing conservation issue, and develop diverse approaches that consider the complexity of the supply chains involved. It is imperative that the scale and process of domestic trade is understood, and its impact on long term conservation of these species assessed to make more informed decisions about effective interventions that take into account the full supply chain.

Keywords: non-timber forest products, sustainable use, Orchidaceae, plant trade, biodiversity loss, over harvesting

INTRODUCTION

Unsustainable commercial wildlife trade is a rapidly expanding (Rosen and Smith, 2010), leading threat to biodiversity (Phelps and Webb, 2015). Whilst global efforts to address this practice are increasing, disproportionate amounts of attention are focused on a few charismatic animal species (Balding and Williams, 2016). Therefore, there are prevalent data gaps for the vast number of species over-exploited for commercial trade, particularly groups such as plants, fungi and invertebrates (Margulies et al., 2019). International trade in many species is monitored by the Convention on the International Trade of Endangered Species of Wild Fauna and Flora (CITES), however even trade in these species can be overlooked when it takes place on a domestic scale, with data often coming only from enforcement seizures or media reports that are difficult to collate (Pistoni and Toledo, 2010; Siriwat and Nijman, 2018). Unchecked, unrecorded domestic markets can directly drive species declines (e.g., in elephants following international trade bans: Milliken, 2002), or channel wildlife products into larger international trade networks (e.g., seahorses in Viet Nam: Giles et al., 2006). Addressing these knowledge gaps is essential to improve interventions aimed at reducing illegal wildlife trade, which are often poorly targeted and based upon broad assumptions rather than specific knowledge of trade processes, likely limiting their potential success (Phelps et al., 2016).

One under-researched yet extensively traded group is orchids, which are traded globally for horticulture, medicine, food and other purposes (Hinsley et al., 2018). Only a small proportion of orchid species have been assessed by the IUCN Red List but still reveal alarming trends—84 out of 85 tropical Asian slipper orchids (*Paphiopedilum)* are threatened with extinction, and trade is listed as a threat for every species (IUCN, 2020). However, for most orchid species, little is known about trade networks, harvesting sustainability, drivers of trade, or potential significance of international trade. This is of major concern because their population sizes, restricted ranges, and natural sensitivity to a variety of threats, such as habitat and climate change, make orchids highly vulnerable to the added pressure of overharvesting (Koopowitz, 2001). Further, whilst legal trade is widespread and contributes to livelihoods in low-income countries its sustainability is undermined if illegal trade goes unchecked (Hinsley and Roberts, 2018).

Recognising the trade threat, every one of the ∼29,000 species of the family Orchidaceae is included in the CITES Appendices (making up over 70% of all listed species: UNEP-WCMC, 2018), thus all international trade in these species and their derivatives is legally limited or prohibited, apart from in exceptional circumstances. Orchid trade is also prohibited to varying degrees under national legislation in numerous source countries including Viet Nam, where all wild orchid species are protected under Government decree No.32/2006/ND-CP, with *Paphiopedilum* species afforded the highest level of protection, banning all exploitation and commercial use.

Despite increasing awareness of the threats, effective interventions to reduce illegal orchid trade are hampered by a lack of data on supply chains and processes, and drivers of behaviour of actors within the supply chain (Hinsley and Roberts, 2018). Studies into domestic and regional trade are increasingly taking place (e.g., Gale et al., 2019; Ticktin et al., 2020), but trade in most orchid species is still relatively unknown. In Southeast Asia, a hotspot of orchid trade, studies have been conducted to understand the complexities of regional markets in Thailand, Myanmar and Lao People's Democratic Republic (Thomas, 2006; Phelps and Webb, 2015; Phelps et al., 2016). However, very little evidence exists concerning the nuances of trade in Viet Nam, despite its numerous orchid species (Teoh, 2005) and evidence of wild-collection for the international illegal trade leading to serious species declines (e.g., Averyanov et al., 2014). We attempt to address this knowledge gap by investigating the collection and trade of wild-harvested orchids in Viet Nam. Specifically, we aim to (a) gather data on the extent of wild-orchid use and trade in our study areas; (b) identify the main actors involved in the wild orchid trade and how they interact; (c) identify some of the key drivers of trade. We then use these data on the structure and characteristics of the wild orchid trade to draw conclusions on the potential conservation implications of the trade.

METHODS

We used a mixed-methods approach including key informant interviews (n = 24) and structured surveys (n = 123) conducted between May and June 2018 in three sites in Northern Viet Nam. These were selected following consultation with local experts at Fauna and Flora International (FFI) Viet Nam (pers. comm. Kempinski, 2018, personal communication). Selection was based on three criteria: presence of karst limestone habitat, due to their importance for several orchid species; evidence (often anecdotal) of orchid trading in these areas; and good relationships with the local Forest Protection Department (FPD) to facilitate the work. The sites comprised one urban site in Ha Noi (Dong La district), one rural site in Ha Nam province (Ba Sao), and one rural-urban-fringe area in Cao Bang province (Cao bang city).

Key Informant Interviews

We used semi-structured key-informant interviews to explore informants' perspectives of, and involvement in, the orchid trade. This method is useful when investigating complex and potentially sensitive behaviours in a previously little-researched context (Young et al., 2018). We devised the initial interview guide from relevant orchid-trade literature (Phelps and Webb, 2015; Hinsley et al., 2018), which was translated into Vietnamese by a native speaker.

We selected initial key informants recommended by the local FPD in each field site, with further participants found through snowball sampling (Newing, 2010). The criteria for inclusion were: involvement in or specialist knowledge of the orchid trade, being over the age of 18, and residence in one of our study sites. We discontinued interviews in each field site when we reached saturation (Guest et al., 2006), or were unable to identify new informants. With permission from informants, all interviews were audio-recorded and, after completion, transcribed and translated into English. To minimise bias and ensure nuance was captured during translation, transcriptions were compared to the original audio recordings with a native Vietnamese speaker. We updated the interview guide to triangulate respondents' answers and to draw more robust conclusions. No informant refused to be interviewed.

Surveys

We used surveys to gain a broader understanding of participants' attributes and behaviours in a wider context, to glean information about the scale of trade, and to understand demand for orchids. We asked about participants' use, harvest, trade and purchase of orchids, the frequency of these behaviours, and the purpose (e.g., personal or commercial use).

We translated the survey into Vietnamese, and back-translated it to English to check for accuracy.

We surveyed residential areas within each site, sampling residents in close geographical proximity to the processes of trading. In Ha Nam and Cao Bang, we sampled within 5 km of the forested areas reported by the local FPD to be a wild orchid source. In Ha Noi, residents of the Dong La district were sampled within a 5 km radius of specialist shops or farms selling mainly orchid species. We sampled every other house and (though this was not requested specifically) typically spoke to the head of the household, unless they were not present. If there was no answer, or participation was refused, the next house was sampled, before returning to the original sampling pattern.

We piloted the survey to ensure questions were culturally appropriate, understood as intended, and to test the clarity of concepts and language used. Following the pilot, no changes were required. A native Vietnamese interviewer read the survey aloud to participants in Vietnamese and data were recorded using Open Data Kit v.1.15.1 (Open Data Kit, 2018). The data were stored using Ona (Ona, 2018). After completion, survey responses were translated into English.

Ethics

We obtained free prior informed consent from all participants, who were aware that participation was non-obligatory, and under assurance of anonymity and confidentiality. We ensured anonymity by excluding identifying information. The study was approved by the ethical procedure of the Department of Life Sciences, Imperial College London.

Data Analysis

We used the Framework Method to systematically review the interview data to draw explanatory conclusions from identified themes, in an unambiguous and rigorous way (Ritchie and Spencer, 2002). We familiarised ourselves with each transcript, noting recurrent subject-matters. Then we identified a thematic framework, based on these subject-matters, or "themes." We used this framework to code the data using QSR International's NVivo 12 qualitative data analysis software (NVivo, 2018). Once coded, we identified a subset of themes based on our interpretation of their relevance to the research question. To increase the validity of our interpretation, we asked six people with no prior knowledge of the research topic (age range: 25–70), to apply our thematic framework to a subset of the interview data (n = 4 interviews each), ensuring every interview was assessed by a second person. This review identified no new themes, though definitions of terms were discussed and clarified. The lead author analysed the data, and defined their observational standpoint using the framework outlined by Clark (2002) to account for any potential bias in interpretation.

We calculated descriptive statistics from the survey data, summarising the number of people who used, harvested, bought and sold any plants, specifically orchids. We applied chi-squared tests and Fisher's exact tests in the "Mass" package in R (R Core Team, 2020) to determine the association between different behaviours (collecting, buying, trading, and using orchids) and key demographic variables (province of residence, gender, and age). In answering how many orchids were collected from the mountain or forest, several respondents used kilograms rather than number of plants. To provide a minimum estimate of plants collected, we use Gale et al.'s (2019) database of orchid stems per kilogram for different orchid taxa, using the minimum (3.1 stems per kg) and median (62.3 stems per kg) estimate of all genera recorded in Viet Nam (identified using[1]) to estimate potential volumes of plants.

RESULTS

We conducted 24 semi-structured interviews (13 interviews with singular respondents, and 11 with pairs of respondents. Each pair consisted of the same "category" of informant (see **Table 1**) living/working in the same establishment). In total, we interviewed 35 respondents across three field sites, covering four main types of key informant. We surveyed 123 households, with two refusing to participate (Ha Nam: n = 40; Cao Bang: n = 50; Ha Noi: n = 33).

Survey Results

Of the 123 survey participants, 52% identified as female, and 47% male. Fifty three per cent were between 18 and 44 years old, and 46% were 45 years and older. In the 12 months before the survey, 61.8% of participants (n = 76) used wild plants (food: n = 54; decoration: n = 41; medicine: n = 15; trading: n = 11; building: n = 1; shade: n = 8; other: n = 7). Most reported buying plants from a market, shop or the internet (n = 46), with fewer sourcing plants directly from the wild themselves (n = 26) or via somebody else (n = 8). Fifteen reported "other" sources, including wild plants transplanted onto their own land some time ago (n = 4), as a gift (n = 3), and buying from people in ethnic minority groups (n = 1).

Half of participants who used wild plants in the 12 months before the survey had used orchids within this same timeframe (n = 38, 30% of the sample). Nineteen% (n = 23) reported buying orchids, 11% (n = 13) selling them, and 14% (n = 17) collecting wild orchids. People bought orchids for growing at home (n = 9), re-selling (n = 8), and decorating their house (n = 6). Traders also bought from diverse sources (from people in minority groups: n = 6; other provinces: n = 4; door-to-door sellers: n = 3; orchids farms: n = 2).

The chi-squared and Fisher's exact tests showed no evidence of significant association between any behaviours and gender or age, although slightly more men reported collecting orchids than women, and slightly more under 35-year-olds reported selling orchids than would be expected by chance (**Table 2**). There was a significant association between location and all behaviours, with more Ha Nam participants reporting that they had bought, used, and collected orchids than would be expected by chance, and more Cao Bang respondents reporting selling orchids than expected. Ha Noi respondents reported less participation in all behaviours than would be expected.

[1] https://wcsp.science.kew.org

TABLE 1 | Participant quotes from interview data providing evidence for concepts identified through the thematic framework analysis.

a) Drivers of trade—Rarity	b) Process of trading—Buyer preferences	c) Drivers of trade—Conservation through Trading	d) Future of trading—Over-exploitation of orchids
1. "Foxtail orchids that have all white flowers, its rare and expensive, so many people want them. People would fight each other to buy one like that. Everyone would love to own it. But it's hard, not just anyone is able to own it" **R16 Cao Bang**	2. "In my farm, I believe that people are more into orchids from the forest. Orchids from the forest are sellable. People love wild orchids because of the wild beauty and fragrant smell. . .they are just gorgeous" **R17 Cao Bang**	3. "I myself try to keep and preserve many species. . .I have many expensive orchids, I bought them no matter how expensive they are, thousands of dollars, to preserve the species. I have paid a lot of money to buy rare and endangered species" **R16 Cao Bang**	4. "There are large numbers of people who exploited the orchids in the forest. Back in the day, they took part of the orchids and still left some stems so they could keep on growing. But nowadays, people over exploit, they take out everything from the forest. Therefore, the number of orchids in the wild reduces and becomes rarer" **R6 Ha Nam**
5. "They are not special when they (orchids) are surrounded by many of them, they become hot when they are in places where there is only a few of them" **R9 Ha Nam**	6. "People always prefer natural orchids with origin from the forest. Orchids from the lab are unnatural, people don't like them" **R6 Ha Nam**	7. "They (the government) need to develop and preserve orchids at once. Or it will be dangerous someday. There will be no more orchids. If the forest runs out of orchids, we need to preserve and breed them in farms" **R17 Cao Bang**	8. "Orchids nowadays is running out, people already took everything from the wild. In the past. . .we sold so many wild orchids from the forest, there were a couple of dozens of species of wild orchids being displayed in the shop. But now. . .we have none" **R9 Ha Nam**

Five people reported how many plants they collect in a single trip (1–2 plants: n = 3; 3–4, and 25–30: n = 1 each), and six reported the weight of plants collected (2–3 kg: n = 2: 7–8, 10, 15, and 20 kg: n = 1 each). Using our minimum conversion estimate, this is between 6 and 62 stems per trip, and with the median conversion estimate at 125–1,246 stems per trip.

Main Themes From Interviews

We identified four main themes from the interview data: drivers of trade, sources of orchids, the process of trading and the future of trading (**Table 1**). Drivers of trade included demand for rare plants and a desire to conserve them. Sources of orchids included wild or artificially propagated plants, as well as the places or people they were bought from. The process of trading included discussions of how orchids moved through the supply chain, who they are traded between and how the trade is facilitated. The final theme concerned data related to how respondents perceive the functioning of future trading. These themes were analysed to produce key concepts regarding orchid trade in Viet Nam, and present a fuller picture of trading in Northern Vietnam.

Actors in the Supply Chain

We used data from the "process of trading" and "source of orchids" themes to identify five groups of actors that participate in the orchid trade (**Table 3**): (1) personal harvesters, (2) commercial harvesters, (3) intermediary wholesale vendor, (4) commercial vendor, and (5) orchid hobbyist. These groups are distinct but not mutually exclusive, with some respondents belonging to more than one group, or change groups in certain circumstances. For example, Respondent 5 is an orchid hobbyist but stated "*I will see if there are orchids in the mountain, I will go get them if I see them with my binoculars*" and so would also be a personal harvester in that circumstance.

Opportunistic harvest by orchid hobbyists is small scale. Most hobbyists obtain their orchids from commercial vendors or trade amongst themselves, as Respondent 5 said *"In the community (of hobbyists) we only buy from farms, we don't go to the forest to get orchids."*

Supply Chain Process

The orchid trade chain in our study sites constitutes a complex web of interactions of the five groups identified (**Figure 1**). Wild orchids can enter the trade chain via personal or commercial harvesters, or via opportunistic harvest by orchid hobbyists. Interviewees reported that once the orchids have entered the chain, the pathways through personal and commercial gardens can be cyclical, with the monetary value of the orchids increasing each time they pass through an actor. As Respondent 6 remarks *"he (commercial trader) sells to me for 10 million VND, I resell with a higher price."*

The movement of orchids from harvesters, through commercial vendors and hobbyists is made more efficient by intermediaries, locally termed "wholesale traders." These intermediaries travel to rural areas to buy wild orchids on behalf of commercial vendors, who order certain species or amounts of orchids (**Table 3**). The inclusion of these actors means that commercial traders or orchid hobbyists do not need to travel to source areas. Wholesale traders therefore serve to increase the volume of orchids available, whilst decreasing the time it takes buyers to access them by removing barriers, such as finding appropriate harvesters. Wholesale traders have become more widespread and numerous in more recent years, enabling those further down the supply chain to access large volumes of wild orchids more easily. Orchid hobbyists also engage in small scale trading amongst the orchid community, who interact regularly to trade or exchange knowledge. This inter-community trading ranges from local sales or swaps to national trading at orchid shows. Trading between members is regular, based on a shared passion rather than driven by profit and is facilitated by social media. Respondent 18 said,

TABLE 2 | The relationship between reporting one of four orchid-related behaviours (collecting, buying, using, or trading) and province, gender and age, determined using X^2 or Fischer's exact tests with standardised residual values.

Level		Behaviour											
		Collecting orchids			Buying orchids			Using orchid			Selling orchids		
		Not collected	Collected	X^2 or Fischer's exact *p*-value	Not bought	Bought	X^2 or Fischer's exact *p*-value	Not used	Used	X^2 or Fischer's exact *p*-value	Not sold	Sold	X^2 or Fischer's exact *p*-value
Location	Cao Bang	0	0	Fischer's exact $p < 0.00$	0.4	−0.8	Fischer's exact $p < 0.00$	0.6	−0.9	Fischer's exact $p < 0.00$	−0.7	2	Fischer's exact $p < 0.00$
	Ha Nam	−0.8	1.9		−1.1	2.4		−2	3.0		0.4	−1.1	
	Ha Noi	0.8	−2.1		0.8	−1.6		1.5	−2.2		0.5	−1.3	
Gender	Male	−0.4	1.1	$X^2 = 2.02$, $df = 1$, $p = 0.15$	−0.2	0.3	$X^2 = 0.08$, $df = 1$, $p = 0.77$	−0.4	0.5	$X^2 = 0.54$, $df = 1$, $p = 0.46$	−0.2	0.2	$X^2 = 0.21$, $df = 1$, $p = 0.64$
	Female	0.5	−1.1		0.2	−0.3		0.5	−0.6		0.5	−0.5	
Age category	<35	−0.1	0.2	Fischer's exact $p = 0.95$	0	−0.1	$X^2 = 0.71$, $df = 2$, $p = 0.70$	−0.4	0.5	$X^2 = 0.77$, $df = 2$, $p = 0.68$	−0.5	1.3	Fischer's exact $p = 0.29$
	35–54	0	0.1		−0.2	0.5		0	0		0.1	−0.4	
	>55	−0.1	−0.3		0.3	−0.6		0.3	−0.5		−0.3	−0.9	

Positive residual values (green) indicate that this group reported this answer more than would be expected by chance, and negative values (red) indicating that this answer was reported less than would be expected. Lighter red and green shading denotes some difference to expected, while darker shading shows a large difference, and grey shading showing that the value is within the expected range. See SM for full results.

TABLE 3 | Descriptions of the roles and demographics of different actors in the supply chain.

Actor	Role	Demographic description	Respondent quotes about actor groups
Personal harvester	People who harvest wild orchids from the forest to grow at home	Usually local and/or people of ethnic minority who live close to forested areas in highland provinces. Occasionally includes those who would ordinarily purchase orchids, but opportunistically harvest orchids from the forest	"I got them in the forest while I went to the forest to raise my goats. I saw the orchids fell down from old big trees, I took them home to grow" **R14, Cao Bang**
Commercial harvesters	People who harvest wild orchids from the forest to sell to other people	Usually local and/or people of ethnic minority who live close to the forest in highland provinces. Occasionally people from outside the local area will travel to a forested area specifically to harvest orchids	"We buy from local people. There are people who will collect (wild) orchids... we buy from them" **R9, Ha Nam**
Intermediary wholesale traders	People who order certain orchid species from harvesters and buy them with the purpose of selling them onto other people	Usually people who live in the district containing the forested area, but not necessarily living in close proximity to the forest. They have the means to travel to other areas to sell orchids	"They buy from wholesale people, they will deliver just by one phone call... when there weren't wholesale people, I had to go directly to forest...order minority and local people...to get orchids for me...but nowadays, there are wholesales people living in these provinces, so people don't need to travel" **R23, Ha Noi**
Commercial vendors	People who buy orchids to grow them and sell them onto other people	Usually people with large commercial orchid farms that have the capability to buy and sell kilograms of orchids at a time. Situated in both highland and lowland provinces	"We get orchids from the local orchid farms. They breed and grow orchids at their farms and sell to people...their orchids are originally from the forest but (have been) tamed (grown) for years" **R3, Ha Nam**
Orchid hobbyist	People who buy orchids to grow them in their garden	Usually people with small personal orchid gardens, more often situated in lowland provinces	"I love them so much I don't sell them, I just keep them in my garden" **R18, Cao Bang**

"I do sell...but not for money—just to keep the relationship with other people in the community...I sell on the internet, mainly Facebook."

Commercial vendors, conversely, sell their orchids for profit as a business. Businesses vary in size, from home-based nurseries to others that spread over an acre or more. Vendors sold in different

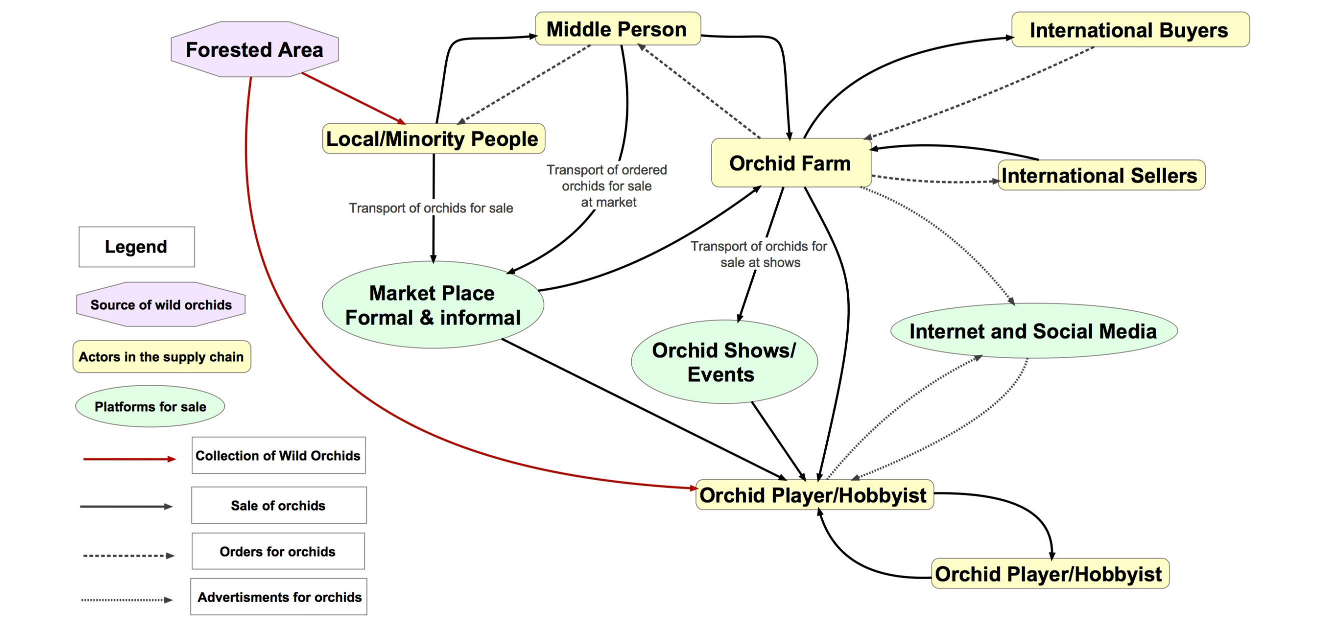

FIGURE 1 | Conceptualisation of the supply chain of orchids including the flow of goods, orders for those goods and advertisements for those goods.

locations to varying degrees. We identified three main locations of trade from the data: markets; orchid shows; and the internet and social media. Locations of trade are places where people either physically trade orchids, or advertise and agree sales. The internet and social media are an important platform for trade between commercial vendors and orchid hobbyists. It is used to advertise orchid species, agree on trade deals or induce face-to-face sales. Many respondents remarked that this platform plays an increasingly important role, simplifying and streamlining trade:—*"Orchid farmers are using (the) internet a lot…(it is) the most effective platform for us to sell" (*Respondent 22).

We found no evidence of export of orchid species directly by interviewees, although respondents did report in-person trading with international buyers, who transport orchids across international borders. As Respondent 20 states: *"foreigners come here* (Vietnam) *and buy, they bring them* (orchids) *back to their countries by themselves."* It was commonly cited that language barriers made exporting internationally difficult, and thus was not typically engaged in. Most respondents were aware that it is illegal to trade certain orchid species internationall, as Respondent 23 summarises: *"slipper orchids, according to international law, are not allowed to be traded internationally—they can't be exported."*

Drivers of Trade

Our interviewees reported that orchid trade is driven by the demand for beautiful, rare, wild-harvested plants. Strong preferences for wild plants were reported by 54.2% (n = 19) of interviewees, for example, Respondent 22 stated they preferred wild orchids *"because it's the natural beauty, the orchid is unique."*

Rarity was also reported as an important factor, adding a desirability to collect orchids because they are "special"—*"special beautiful orchids are the rare ones…hard to find" (Respondent 3).* Respondents also reported that rare orchids could be sold for higher prices, making it economically viable to invest in finding remaining specimens: *"they will be expensive if we have a hard time finding them in nature"* (Respondent 9).

We found that a common theme underpinning the drivers of trade is an authentic passion for orchids, as reported by 70.8% of interviewees (n = 25). The depth of this passion is described by Respondent 7 who stated *"orchids and plants in general have souls…the more you know them, the more you realize."* This is linked with a desire to conserve orchids, and recognition that wild orchids are becoming rarer. Some respondents even linked their rarity to over-exploitation—Respondent 7 states *"you should collect orchids to preserve the culture as well as the biodiversity,"* whilst Respondent 6 recognises *"there are a large number of people who exploited the orchids in the forest.the number of orchids in the wild reduces, becomes rarer."*

DISCUSSION

We show that wild-harvest and domestic trade in orchids takes place across our study sites, and is increasingly organised and efficient. Large-scale harvesting and trade of wild orchids in other areas has been shown to drive over-exploitation and lead to population declines (Hinsley et al., 2018), suggesting that the trade in Northern Viet Nam could be of conservation concern. This study is a vital first step in increasing the potential for effective, evidence-based conservation initiatives for traded orchid species, which has been highlighted as a priority (TRAFFIC, 2008; Hinsley et al., 2018). Our work demonstrates the need for further research into these trade chains, including to quantify the level of wild collection, establish sustainable harvest levels for wild orchids, determine the contribution of wild orchid trade to livelihoods, and to investigate the role of cultivation in reducing wild orchid trade. It also reinforces the need for plant trade to be taken more seriously as a major, growing threat to biodiversity (Phelps and Webb, 2015; Williams et al., 2018; Margulies et al., 2019).

While our surveys found differences in orchid-related behaviours in different locations, our interviews showed that wild orchids are collected and traded in all of our study sites. The surveys were designed to investigate orchid trading in the broader community, and show that different locations likely play different roles in the supply chain. For example, more selling was found in the forested area of Cao Bang, while more buying and using orchids was found in Ha Nam. However, by triangulating data with our interviews, we show that, even in Ha Noi, where all orchid behaviours were less likely than would be expected amongst the wider community, trading does continue to occur at some level, with specialist vendors and hobbyists still present. Conceptualising this supply chain using Phelps et al. (2016), it is likely that the wild orchid trade in Viet Nam is a "redundant channel network"—where there are few barriers to participation in trade and low enforcement. Our results characterise the actors of this trade, and provide evidence toward understanding the network structure—both of which are key to implementing targeted interventions of this potentially unsustainable illegal trade (Phelps et al., 2016).

Our findings highlight the possibility that international trade chains are linked with domestic trade, and these linkages warrant further investigation. In contrast to the work of Phelps and Webb (2015) in Thailand, we did not find evidence for large scale international export of orchids, with most respondents reporting trading domestically. While this may be a result of social desirability biases amongst respondents concealing their involvement in illegal behaviour (Newing, 2010), most expressed a willingness to trade with international customers if the opportunity arose. Practical reasons cited for lack of international trade, such as language barriers, act as obstacles for some traders, but are likely not the case for all. A market for wild orchids clearly exists, and further study may reveal that commercial vendors or other intermediaries, possessing the relevant language skills, are tapping into this niche which will have implications for CITES enforcement. We found that commercial traders were willing to trade with international buyers despite knowledge that it was illegal to export these plants. This may be a strategy to avoid being caught themselves, but also supports earlier findings that awareness of CITES rules does not prevent trade actors from breaking them (Hinsley et al., 2017). Viet Nam is rated in the highest category for its national legislation that underpins CITES implementation[2]. However, CITES enforcement could be undermined if commercial vendors trade with international commercial greenhouses, laundering illegal wild plants as legally cultivated in international markets could undermine CITES rules in the country (Phelps and Webb, 2015). Without a better understanding of domestic wildlife trade chains, and formal monitoring of the domestic trade, species extinction due to over-harvesting remains possible even if international trade is monitored and regulated through CITES.

We show that there are five key types of actors in the wild orchid supply chain in Northern Viet Nam, and that movement of orchids between them has become faster and easier in recent years. Only through understanding the complexity of actors' interactions can we design specific, targeted interventions to increase the sustainability of this trade (Mendelson et al., 2003). For the orchid trade in our study locations, a key focus should be new intermediary actors, who move more wild orchids from forested areas to a variety of consumers more quickly and efficiently than in previous years. Accessing orchids has become faster and easier, a trend that will likely continue as standards of living improve, access to forests is increased due to fragmentation and development, and online platforms are increasingly widely utilised. The negative impact of this rapidity from source population to trade has been documented in the case of wild *Paphiopedilum canhii* plants, approximately 99.5% of which were harvested within 6 months of being described (Averyanov et al., 2014). The combination of more efficient supply-chains and the high demand for rarity in the domestic trade could lead to rapid over-harvesting being replicated, even for yet undiscovered species (Vermeulen et al., 2014). This, combined with the complexity of the trade chain, the fluidity of the actors and the difficulty in enforcing legislation (Thomas, 2006) presents a significant challenge. Further understanding the interactions between commercial vendors and intermediary traders will allow an understanding of how high-volume, high-value species are moved from the wild to customers.

We provide evidence that the key drivers of wild orchid trade in Northern Viet Nam are likely to be the demand for rare, wild plants, combined with the ease of accessing these wild plants. We show preferences for wild-sourced orchids that reflect previous findings amongst both orchid consumers and traders (Hinsley et al., 2015; Williams et al., 2018). Preferences for wild plants likely links to consumer perception that rarity is desirable, which can drive harvest and precipitate species extinction (Courchamp et al., 2006). We note that preferences for wild products do not always translate directly into purchases due to barriers such as availability, legality and price—especially when legal alternatives exist (Hinsley and 't Sas-Rolfes, 2020). However, we show that in Northern Viet Nam, there are both preferences for wild orchids and the ability to collect or buy them easily, suggesting that fewer barriers between preferences and purchase exist in this market. This closely aligns with findings in China, where wild orchids were openly available and often cheaper than cultivated alternatives, meaning that even consumers without preferences for wild plants were likely to purchase them (Gale et al., 2019). While wildlife farming has been proposed as one approach to reducing wild harvest of traded species, certain conditions must be met for this to be successful (Phelps et al., 2016). However, our study echoes that of Gale et al. (2019) and Phelps et al. (2016) in demonstrating that introducing cultivated orchids into

[2]https://cites.org/eng/legislation/National_Legislation_Project

the supply chain may not be enough to prevent wild orchid trade, due to consumer preferences and ease of wild-harvesting. In addition, we show that the orchid trade clearly contributes to livelihoods in rural areas, such as Cao Bang. While cultivation can bring economic benefits, it may shift income from trade away from those who currently harvest in favour of wealthier landowners, and could lead to increased harvesting, as rural harvesters attempt to compensate for these losses (Williams et al., 2014). While further work is needed to investigate consumer preferences and market dynamics more broadly, it is likely that better enforcement of trade regulations, coupled with protection of orchids in their wild habitats, may provide some barriers to the harvesting of wild orchids.

Our results demonstrate that there is will amongst stakeholders in the orchid supply chain to conserve orchids, and that involvement of these stakeholders could be key to developing strategies for sustainable trade. We found high levels of concern for wild orchids amongst our respondents, with several explicitly stating that over-exploitation was leading to species loss. However, the level of concern regarding orchid conservation, coupled with the intense passion within the orchid community, support calls for greater engagement of orchid growers in tackling illegal trade (Williams et al., 2018). Our study suggests that conservation concern from orchid trade actors is currently misdirected into demand for wild orchids. Each actor who expressed a desire to conserve orchids felt that the orchids would be "safer" in their collection than in the wild, a phenomenon observed in other studies of the orchid trade (Mackenzie and Yates, 2016; Hinsley et al., 2017). Parallels are seen in trade chains of other species, such as amongst some exotic animal collectors, who justify their participation in illegal trade because they see owning these species as a valid conservation approach (Beetz, 2005; Slater, 2014).

It is clear that wild-collection and commercial trade of orchids is occurring in northern Viet Nam. Mirroring recommendations made by Phelps and Webb (2015), we call for greater recognition of domestic trade as a key threat to species and highlight the need for greater action at both national and international levels. Ultimately, bold, multi-dimensional strategies that go beyond enforcement must be adopted to address unsustainable trade (Challender and MacMillan, 2014; Phelps et al., 2014). Opportunity exists in Northern Viet Nam to work with commercial traders and hobbyists to develop more diverse approaches to addressing illegal trade. While stronger enforcement of existing regulations and *in situ* protection of wild orchids may help reduce commercial trade-driven over-exploitation in Viet Nam, this should be accompanied by more comprehensive and multi-stakeholder interventions underpinned by improved understanding of orchid trade networks—including interactions between legal, illegal, domestic and international trade, consumer motivations and market dynamics.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Imperial College London. Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

AUTHOR CONTRIBUTIONS

L-AB and NN collected all the data. L-AB, NN, and AH analysed the data. L-AB wrote the manuscript with input from AH, RD, and NN. All authors contributed to the design of the survey and interview guide.

FUNDING

Funding for the in-country data collection of this study was provided by the Royal Horticultural Society Coke Trust Bursary Fund 2018. AH was supported by the Oxford Martin Programme on Wildlife Trade and the Kadas Fellowship at Worcester College, Oxford.

ACKNOWLEDGMENTS

Josh Kempinski and the wider Fauna and Flora International team in Vietnam provided logistical support.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fevo.2021.631795/full#supplementary-material

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

frontiers in Ecology and Evolution

PERSPECTIVE
published: 09 August 2021
doi: 10.3389/fevo.2021.637228

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A Perspective on the Role of Eco-Certification in Eliminating Illegal, Unreported and Unregulated Fishing

Catherine S. Longo[1], Leah Buckley[1], Stephanie D. Good[2], Taylor M. Gorham[3], Lauren Koerner[1], Samantha Lees[1], Shen Yan Liow[4], Oluyemisi Oloruntuyi[1], David Schley[1], Jake Rice[5†] and Rohan J. C. Currey[1†]*

[1] Department of Science and Standards, Marine Stewardship Council, London, United Kingdom, [2] Centre for Ecology and Conservation, University of Exeter, Penryn, United Kingdom, [3] Department of Biology, Dalhousie University, Halifax, NS, Canada, [4] Department of Science and Standards, Marine Stewardship Council, Singapore, Singapore, [5] Science Branch, Fisheries and Oceans Canada, Ottawa, ON, Canada

OPEN ACCESS

Edited by:
Tien Ming Lee, Sun Yat-sen University, China

Reviewed by:
David Agnew, Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR), Australia
Andrew M. Song, University of Technology Sydney, Australia

***Correspondence:**
Catherine S. Longo
katie.longo@msc.org

† These authors share senior authorship

Specialty section:
This article was submitted to Conservation and Restoration Ecology, a section of the journal Frontiers in Ecology and Evolution

***Received:** 03 December 2020*
***Accepted:** 09 July 2021*
***Published:** 09 August 2021*

Citation:
Longo CS, Buckley L, Good SD, Gorham TM, Koerner L, Lees S, Liow SY, Oloruntuyi O, Schley D, Rice J and Currey RJC (2021) A Perspective on the Role of Eco-Certification in Eliminating Illegal, Unreported and Unregulated Fishing. Front. Ecol. Evol. 9:637228. doi: 10.3389/fevo.2021.637228

Illegal, unreported and unregulated (IUU) fishing activities threaten marine biodiversity, livelihoods, food security, and human rights across the globe. Often occurring in waters that are difficult to control, and across multi-sector, transboundary, value chains that are hard to regulate, such a complex and heterogeneous problem requires multiple strategies beyond sovereign nations' legislation alone. Here we explore the mechanisms through which eco-certification, by fostering private-public and cross-jurisdiction cooperation, can incentivize fishers to adopt best practices in harvesting and ecosystem impacts mitigation, increase the transparency of fishery operations and accountability to suppliers. The Marine Stewardship Council (MSC) sets globally recognized standards for fisheries sustainability and supply chain assurance, based on the FAO Code of Conduct for Responsible Fisheries. Building on the MSC experience of over 400 certified fisheries representing 18% of global wild marine catch, we analyze examples and available information on the changes achieved by the seafood industry through engagement with the program, with particular focus on the elimination or reduction of illegal, unreported or unregulated fishing practices. We propose here that different, interlinked mechanisms come into play: the Standards provide best practice guidelines for improved catch documentation, monitoring, control and surveillance (MCS), and strengthening regulations. These lead to change either through (1) direct improvements required for fisheries to achieve the certificate (e.g., in Fishery Improvement Projects) or, (2) once certified, to maintain the certificate, or (3) as an emergent effect of the engagement process itself, requiring stakeholder cooperation and transparent information-sharing leading to a greater culture of compliance, and (4), as an effect of strengthening chain of custody documentation and standardizing it across jurisdictions. We also discuss limitations, such as the capacity for fisheries in low-income regions to embark on the management and social reform required, and evolving challenges in seafood sustainability, such as ethical concerns for forced and child labor and shark finning. While not the single silver bullet against such a complex problem, we argue that certification is an important tool in addressing IUU fishing.

Keywords: MSC, monitoring control and surveillance, IUU, market incentives, value chains, fishery improvement projects

INTRODUCTION

The global decline in biodiversity is well documented (IPBES, 2019), with growing international calls for stronger conservation and its more sustainable use (WWF, 2018; IUCN, 2019; Secretariat of the Convention on Biological Diversity [SCBD], 2020). Commercial fisheries have consistently been identified as a main driver of declines in marine biodiversity (IPBES, 2019), with illegal, unreported and unregulated (IUU) fishing being a persistent factor in unsustainable fisheries (Cabral et al., 2018). IUU fishing is also associated with organized crime, including slave and child labor, widespread fraud and corruption (Mackay et al., 2020).

Rather than opting for a purely conservation-oriented approach[1], the strategy laid out for example through the UN Sustainable Development Goals (SDGs) places the problem in the context of the needs for global food security, livelihoods and societal well-being, setting targets for improving the sustainability of fishing (e.g., SDG14[2]), rather than abandoning the practice (UN World Food and Agriculture Organization [FAO], 2020a).

Substantial guidance and policy frameworks are available to promote fisheries sustainability (FAO Code of Conduct for Responsible Fisheries; UN World Food and Agriculture Organization [FAO], 2001), yet the growing global demand for seafood continues to incentivize practices that evade resource management regulations or exploit their absence. IUU practices are found in all types and sizes of fisheries, occurring both on the high seas and in areas within national jurisdiction (Macfadyen et al., 2016).

Illegal, unreported and unregulated fisheries emerge where there are gaps or 'gray areas,' in jurisdictional competencies, and where Monitoring, Control and Surveillance (MCS) systems are weak. These provide opportunities to circumvent regulations, for example through use of 'flags of convenience,' i.e., vessels switching registration to countries that are not signatories of international agreements, or transshipments of illegal catches to transport them outside of national jurisdiction and/or avoid local landing regulations (UN World Food and Agriculture Organization [FAO], 2016a).

While these vulnerabilities in the regulatory framework provide the opportunity, economic incentives or lack of alternative revenues often drive IUU fishing (Macfadyen et al., 2016). Market exclusion of seafood sourced from IUU fisheries can remove this incentive, provided catch from legal and well managed sources can be effectively distinguished, and the supply chain does not allow substitution or mislabeling of IUU catch.

The 2001 International Plan of Action to Prevent, Deter and Eliminate Illegal, Unreported and Unregulated Fishing (IPOA-IUU) summarizes the range of necessary strategies as: "The key to success in reducing and eventually eliminating IUU fishing is the adoption, application and enforcement of strong flag, coastal, port and market state regulation" (UN World Food and Agriculture Organization [FAO], 2001). As part of the market-related solutions, the Port State Measures Agreement (PSMA), is the first legally binding measure of its kind, intended to stop IUU catch from being landed and encourages States to work with commercial enterprises to penalize trading of IUU catch (UN World Food and Agriculture Organization [FAO], 2016a).

Though these strategies have been articulated with a focus on State regulatory responsibilities, successful reform requires the participation and buy-in of the actors involved in fishing and trading seafood (e.g., UN World Food and Agriculture Organization [FAO] (2020a) mentions "enforce deterrent sanctions. This includes [. . .] from the first point of sale through the whole trade chain, so that consumers and value chains also are motivated to accept only legally caught fish products"), and their coordination beyond single jurisdictions (e.g., UN World Food and Agriculture Organization [FAO] (2020b) states "This RPOA-IUU aims to combat IUU fishing in the WECAFC area of competence through effective regional cooperation among the WECAFC Member States"). Here is where private, multi-stakeholder initiatives such as eco-labeling have a role to play. Eco-certification is an increasingly widely applied tool for incentivizing best practice adoption in fishing and seafood industries, using the label recognition to give improved market access to sustainable fisheries (Certification and Ratings Collaboration [CRC], 2018). Seafood certification and ecolabelling programs such as the Marine Stewardship Council (MSC), one of the most established, are founded on the assumptions, or 'theory of change,' that adding value to sustainably harvested seafood, through a robust certification process and assured chain of custody (CoC), induces self-reinforcing positive interactions between consumers, market actors, and industry (Arton et al., 2020). This positive feedback loop is assumed to incentivize more fisheries to make improvements that align with best sustainable practices (Komives et al., 2019; Arton et al., 2020; van Putten et al., 2020).

Here we argue that programs like MSC provide an effective set of mechanisms of achieving the goals set out in the IPOA-IUU by offering a pathway to guide and incentivize improvement toward well documented, well managed harvest practices, helping strengthen private/public sector cooperation,

[1]www.end-of-fishing.org

[2]https://sdgs.un.org/goals/goal14

and bridging jurisdictional gaps across transboundary fishing resources and supply chains. While studies on the MSC or other eco-certification schemes are typically viewed in the context of fisheries that operate legally within well-monitored and managed frameworks, here our focus is the potential contributions that the presence of best practice guidelines provided by the MSC Fisheries and Chain of Custody (CoC) Standards and the market and reputational recognition offered by eco-certification, can make to addressing illegal, unreported and unregulated (IUU) fishing.

This overview is intended to capture 20 years of MSC's experience of working with multiple stakeholders, reflecting practitioner knowledge not easily documented in academic literature, in order to identify strengths and weaknesses in contributing to eliminating IUUs. We also discuss limitations of this type of tool, and remaining knowledge gaps. We conclude by discussing ongoing and imminent challenges facing not only the MSC program, but all seafood and marine sustainability initiatives.

DIRECT AND INDIRECT EFFECTS OF THE MSC PROGRAM

The MSC program plays a direct part in addressing Illegal, Unregulated and/or Unreported practices by providing best practice guidelines, based on the FAO Code of Conduct for Responsible Fisheries (Agnew, 2019), laid out in the Performance Indicators (PI) under each of the three Fisheries Standard Principles (P). These Principles address how fisheries are managed, how catches are reported and monitored for target (P1), bycatch and incidentally encountered species, as well as other ecosystem impacts (P2), and effectiveness of governance structures, decision-making mechanisms and enforcement (P3) (**Table 1**). Fisheries strive to comply with such requirements either in order to meet improvement targets and potentially become certified, or, once certified, in order to retain their certificate.

In addition to these explicitly set targets, IUU practices may be reduced as an indirect result of better coordination, cooperation and culture of compliance engendered by some of the Fishery and Chain of Custody (CoC) requirements, and by the public and transparent process of the audit itself (**Table 1**). In addition, strict limitations on the scope of fisheries eligible for certification e.g., excluding anyone convicted for shark finning or slave labor (section 7.4, Marine Stewardship Council [MSC], 2020a), can indirectly put pressure on uncooperative 'bad actors' because harvester groups will have an incentive to exclude them from the certificate, and from ensuing economic benefits (**Table 1**).

Fisheries in Improvement Toward Sustainability

One of the common challenges preventing fisheries from getting certified is failure to meet the Fisheries Standard requirements due, for example, to absence of enforcement and inability to deter illegal practices in the fishery (Stratoudakis et al., 2015b). Though many fisheries around the world are still far from meeting MSC sustainability requirements, the benefits of certification can motivate less well-managed fisheries to embark on a pathway to sustainability. The Fisheries Standard itself is often used as a tool to perform a gap analysis in fisheries that do not yet meet the standard, to prioritize improvements, whether with MSC certification as an end goal or not, using MSC's pre-assessment process and employing a suite of improvement tools (Marine Stewardship Council [MSC], 2019a). The greatest improvements in certified fisheries have been found to occur in the years leading up to entering the program (Martin et al., 2012), including improved governance and data collection (Bellchambers et al., 2016; Travaille et al., 2019). This provides an important mechanism to improving global fisheries sustainability and reducing IUU fishing, considering a quarter of the world's (reported) fisheries' catch is either certified or stated they are working toward MSC certification through improvements projects (Certification and Ratings Collaboration [CRC], 2018). A fishery improvement project (FIP) sets out formal plans for how the fishery will work, with the support of business, NGOs and other stakeholders, to attain a consistently high level of performance.

Some fisheries have used a combination of the MSC gap analysis, market demand for certified seafood and the FIP process to undertake actions to address IUU related issues such as through implementing measures to monitor and track IUU levels in the Barents Sea cod fishery (Steering Committee of the State of Knowledge Assessment of Standards and Certification [SCSKASC], 2012; SFP, 2012); assessing IUU levels and facilitating engagement with compliance authorities on plans to address illegal fishing in the Bahamas lobster fishery (Sullivan-Sealey, 2011; Travaille, 2020) and installing Vessel Monitoring Systems (VMS) and developing observer expertise on vessels in the Guyana seabob fishery (iNewsGuyana, 2015). Implementation of these activities led to improvements and ultimately to certification. In addition to formalized FIPs, progress may also be delivered through informal collaborations with government and stakeholders (Conservation Alliance for Seafood Solutions [CASS], 2019; Travaille et al., 2019), as in the case of the Suriname seabob fishery (ISEAL, 2017).

There are likely to be more examples of fisheries that started their improvement journey from a state of serious failures in regulation, documentation and compliance. But these are less likely to voluntarily publish their performance, for example, in self-reporting web platforms such as FisheryProgress[3] (but see also Cannon et al., 2018).

Even the simple quantification of illegal catch, regionally as well as globally, has been fraught with methodological challenges and debate to overcome the gaps and anecdotal nature of the evidence (Gavin et al., 2010; Hilborn et al., 2019 in response to Pramod et al., 2019; Donlan et al., 2020 and references therein). Thus, in the following section, we rely on the records of fisheries in the MSC program to discuss where eco-certification offers behavioral incentives and mechanisms that deliver positive change – we argue that these same incentives and mechanisms

[3] fisheryprogress.org

TABLE 1 | Conceptual overview summarizing the different mechanisms, direct and indirect, through which the MSC program can incentivize practices that prevent, deter, and eliminate IUU fishing, detailing the program components, the actors involved, the activity within the program, and the types of outcomes observed.

[1]	**Direct effects**			**Indirect effects**							
Stage	**Pre-certification (FIPs) or during certification**			**Pre-certification (FIPs) or during certification**				**Audit**	**During certification**		
Actors	Fishers			Fishers/ Managers		Fishers/Supply chain	Supply chain actors	Fishers/ Managers	Fishers	CoC/Fishery certificate holders	
MSC components[2]	***Fisheries standard***			***Fisheries standard***		***CoC standard***		***Fishery public reports***	***Fishery/CoC certification scope***		
	P1	*P2*	*P3*	*P1, P3*	*P3*	*P3*	*P2,3,4,5*	*Audit and public comment stages*	*no shark finning*	*no IUU fishing*[3]	*no forced or child labor*[4]
Illegal	Accounting of illegal catch in target species assessments/ control rules*	Improved estimates of illegal retained[5]/ incidental/ bycatch spp*	MCS system detects illegal activities*	Clear evidence for decision-making* creates trust and compliance	Inclusive decision-making* creates trust and compliance	Illegal catch excluded from supply chain at sea	Illegal catch excluded from supply chain	Transparent and inclusive mechanism to raise issues about illegal catch	Market exclusion of illegal (or unethical) operators	Market exclusion of IUU blacklisted operators	Market exclusion of illegal (or unethical) operators
Unreported	Improved catch estimate of target species*	Improved catch estimates of retained[4]/ incidental/ bycatch spp*	Improved MCS generates new data*	Coordinated monitoring and enforcement efforts, across jurisdictions, improve likelihood of detection		Unreported catch excluded from supply chain at sea	Unreported catch excluded from supply chain	Open information sharing from managers, fishers, NGOs, etc.			
Unregulated	Improved target stock management	improved management of retained[4]/ incidental/ bycatch spp	Jurisdictions develop full regulatory frameworks	Transparent dispute- resolution and cooperative management* of transboundary/ RFMO stocks removes loopholes		Interoperative chain of custody documentation helps close loopholes across catch documentation jurisdictions		Information exchange leads to reciprocal trust and accountability			

The reference to specific components of the Fisheries Standard is further elaborated in ***Supplementary Table 1****.*

[1]*Acronyms and symbols: MCS, Monitoring Control and Surveillance; CoC, Chain of Custody; P, Principle; *, relevant conditions found in condition analysis (see* ***Supplementary Table 1****).*

[2]*Referring to requirements, scope and audit guidelines laid out for Fisheries Standard v. 2.1, Chain of Custody (CoC) Standard v.5.0, Fishery Certification Process v. 2.2.*

[3]*In addition to excluding shark finning fisheries from certification, requirements on finning are also present under Principle 1 for shark fisheries applying for certification.*

[4]*Since 2019 this includes additional requirements for cases needing on-site third-party labor audits, specified in "MSC Third-Party Labour Audit Requirements" v.1.0.*

[5]*'Retained' species are landed by the fishery but not the 'target' populations assessed (or pre-assessed) under Principle 1 for carrying the MSC ecolabel.*

are likely to be at play also in fisheries at the start of the improvement journey.

Fisheries Improving Once Certified

As stated in guidance for auditors, "In relation to IUU, the MSC intention is that UoAs [Unit of Assessment] be harvested legally and that IUU is non-existent, or where IUU does exist it is at a minimum level such that management measures, including assessments and harvest control rules and the estimation of IUU impacts on harvested species and the ecosystem, are capable of maintaining affected populations at sustainable levels" (Marine Stewardship Council [MSC], 2018). Certified fisheries must comply with all national and international law, and IUU fishing should be clearly considered in assessments and included in documentation of unobserved mortality (Marine Stewardship Council [MSC], 2018). To be certified, the MSC Fisheries Standard instructs that ecosystems and fish stocks must not be suffering detrimental impacts from IUU fishing, even if it is caused by others (Marine Stewardship Council [MSC], 2018). Further, vessels listed on IUU blacklists are not permitted to be used for catching or transporting fish (Marine Stewardship Council [MSC], 2019b), aligning with the IPOA-IUU strategies (UN World Food and Agriculture Organization [FAO], 2001).

As a result, a group of fishers would not pass the certification audit if operating illegally, or if they were catching a population with no management of sustainable harvest. The MSC program does allow 'conditional' certification of fisheries that, for a limited number of Performance Indicators (PIs) under each of the three Principles, meet minimum sustainability requirements (i.e., 60 score) but not yet best practice (i.e., 80 score). Such fisheries retain their certificate if they address the 'conditions' through time-bound explicit milestones in an action plan, monitored during surveillance audits. These certified entities represent a sample of best performing actors, that, if they did have any issues in their past, are now taking the last steps in a set of incremental changes to arrive at best practice. Though these are not fisheries riddled with multiple and egregious IUU behaviors, the certificate reports documenting progress on such 'conditions' provide explicit and systematic reporting of changes on well-defined issues. This can be indicative of the range of activities less performant fisheries, lacking a similarly standardized and detailed record, undertake in making strides toward legal, well-regulated and well-documented management.

An analysis of the text describing conditions' rationale, action plans or milestones (**Supplementary Table 1**), shows how all three Fisheries Standard Principles can be associated with improved practices or mitigation of illegal, unregulated and unreported fishing (**Table 1**, fields under 'Fisheries Standard Requirements'). The analysis highlighted many examples of fisheries with recent conditions across four themes: reporting of 'Illegal catch estimates' for the population considered under the certificate, 'Reporting' of legally required information for other species captured, inclusive and/or 'Transparent decision-making,' and effective Monitoring Control and Surveillance ('MCS') systems (**Supplementary Tables 2, 3**).

Principle 1 requires, among other things, that information is available on illegal catch estimates of the stock being evaluated for certification, even if these are due to other harvesters. Fisheries have attracted conditions to address this issue across different Principle 1 PIs, because correct estimates of removals feed into the status assessment of the population (PI 1.2.4), can be determined through monitoring (PI 1.2.3) and are part of the key sources of uncertainty to consider when evaluating if harvest control rules are robust (PI 1.2.2) (**Supplementary Table 1**). For example, the Lake Peipus perch and pike-perch certificate requires that the fishery "Design a scientifically valid approach to determine the sources and amounts of pikeperch mortality associated with recreational and IUU fishing" as one of its action plan Milestones for a condition on PI 1.2.4. The harvester group that holds the certificate are not responsible for those fishing activities, but those removals must be accounted for to have a correct assessment. Similar improvements were requested of the Bratsk Reservoir perch fishery, with an explicit outcome being managers' transparent documentation and justification for how IUU catches are estimated. The action plans often explicitly require producer associations to work collaboratively with institutions (e.g., "meet with fishery managers to review data, discuss uncertainties, and consider modifications to the stock assessment methods." States the Lake Peipus 3rd Surveillance Milestone for condition on PI 1.2.4), in some cases across jurisdictional powers (e.g., Estonian and European monitoring of Lake Peipus), adding a new layer of transparency to the institutions' own activities.

All the other species that are caught by the fishery but are not being assessed to potentially carry the ecolabel are evaluated under Principle 2, whether targeted, retained or discarded bycatch, or incidental catches and interactions with Endangered Threatened and Protected species (ETPs) (**Table 1**). It is often the case that species with low or no commercial value are inconsistently monitored, resulting in patchy knowledge of fishing impacts and populations status. Yet, this information is often required by law and vital to managing and conserving these species (Lewison et al., 2004; Agnew et al., 2009). It is no surprise that a high proportion of conditions raised for Principle 2 requirements are around improved monitoring and reporting of such species (Marine Stewardship Council [MSC], 2016, 2020b). MSC requires that information is provided regardless of whether it is legally mandated by local management regulations. Even when filtering only for those cases mandated by law, so as to meet the commonly understood definition of 'unreported' catch, there are a broad range of examples of improved reporting of intentional or incidental catches, from sharks, to finfish to marine mammals (**Supplementary Tables 1, 2**). In the Australian Eastern Tuna and Billfish Fishery the concern was actually about the status of the Argentine squid stock used as bait in the fishery. In this case the fishery committed to either ascertain that the presence of IUU squid fishing isn't threatening its sustainable harvest, or, if this cannot be confirmed, to seek a different source of bait. In other cases, the condition requires establishing a new monitoring program to ensure a sustained source of information, such as the Cornish hake or Poole Harbor clam and cockle fisheries (**Supplementary Table 1**).

If a fishery needs to demonstrate there are no "Unreported" or "Unregulated" activities, and there is effective enforcement of regulations, this will often result in conditions on strengthening MCS systems under Principle 3 (**Table 1**), specifically for PI 3.2.3 (**Supplementary Table 1**). The Western Asturias Octopus Traps Fishery of Artisanal Cofradias, for example, was first certified on condition that it would address reported non-compliance in the number of octopus traps used by some fishermen. Since then, the Asturias administration has implemented that gear are marked as a pre-condition to obtain the octopus fishing license and now 100% of vessels are marked and found compliant. The condition also required that by the Third Surveillance Milestone "Evidences that enforcement capacity has been improved shall be provided." Since then, satellite tracking has been installed on all the vessels included in the certificate and the government committed to purchasing a new addition to the patrol fleet. The latest public draft report marks the condition as having been met (González et al., 2021).

In addition to these direct improvements, conditions can also drive improvements indirectly (ISEAL, 2017). This can happen when, for example, the effort to fulfill them results in increased cooperation across stakeholders, or transboundary institutions, or increased transparency and inclusivity of the governance process, thus increasing institutions' accountability, social license, and fishery participants' culture of compliance.

Indirect Effects: Building a Culture of Compliance and Stakeholder Cooperation

Giving all the parties involved in the fishery the ability to be engaged and consulted in operational decisions can be effective in reducing IUU fishing by creating a culture of compliance, as it builds legitimacy and establishes normative behaviors (Jagers et al., 2012; Pomeroy et al., 2016). Principle 3 requirements of the Fisheries Standard are designed so that a robust regulatory system goes hand in hand with an inclusive and transparent process.

For example, the PNG Fishing Industry Associations purse seine Skipjack and Yellowfin Tuna Fishery was asked to "undertake improvement in prescribing a process for multi-stakeholder efforts in the tuna technical advisory consultative committee setup and their full participation in regards to any program or activity that aims to improve the management and development of the tuna fisheries," to close a condition on PI 3.1.2 (consultation roles and responsibilities). On the other hand, conditions on PI 3.2.2 (decision-making processes) require a clear and documented process for taking decisions, thus creating accountability for governing institutions. For example the American Samoa EEZ Albacore and Yellowfin Longline Fishery is required to provide, as an action plan milestone "some evidence that the Commission is responding to the issue of SP albacore catch rates."

It is worth noting here that the MSC Fisheries Standard is not prescriptive on the governance structure in use, so that PI 3.1.1, for example, refers to 'legal and/or customary frameworks' so as to recognize different types of management frameworks, including 'accepted practice' and acknowledging the range of actors that can take part in such frameworks may include e.g., producer associations and indigenous groups (GSA 4.3 in Marine Stewardship Council [MSC], 2018).

Increased transparency, cooperation and trust may even result from the certificate audit itself (**Table 1**). The MSC Fisheries certification process requires that a third party auditor identify and bring together all sources of information and expertise so as to generate evidence to benchmark the fishery. This is done both by meeting groups of stakeholders, for example to identify data that are harder to locate from a desk-based scan, or through online publication of draft reports that are opened to public comment on the MSC website (Brown et al., 2016). Different stakeholders have the opportunity to see what information others have submitted, and must provide supporting evidence for their respective positions. The need for public documentation has helped illuminate shortcomings in data reporting by Western Australia (WA) fishery management that have since been addressed, resulting in increased knowledge sharing between managers and stakeholders (Bellchambers et al., 2016). Additionally, successful MSC certification for several WA State-managed fisheries ensured management institutions earned greater stakeholder trust (Bellchambers et al., 2016; van Putten et al., 2020; Robinson et al., 2021). This greater transparency, has led to strengthened institutional accountability, for example in South Africa, following the process of certification of the cape hake (*Merluccius capensis*) (Butterworth, 2016). Stratoudakis et al. (2015a) noted that use of a tool like the MSC Fisheries Standard means that stakeholder debate can focus more on finding solutions than on being divided on problems, since it allows benchmarking against an external, standardized framework.

Improved regulatory structures, increased compliance and exclusion of IUU operators often is built through incremental changes.

The Ben Tre hand gathered clam fishery in Vietnam, certified since 2009, is operated by local cooperatives of fishers who are involved in harvest, surveillance, and management of their areas. The goal of maintaining MSC certification for the Ben Tre fishery has reenforced collaborations with government agencies for strengthening regulations (Xuan and Seip-Markensteijn, 2019). The initial certification of the fishery required to meet a condition on regular external reviews of the sustainability of the fishery management structure. Based on the recommendations of the first review (Akroyd and Luu, 2013), local governments became more involved in solving or escalating issues of illegal fishing, patrolling by the Coast Guard and local police, and effectively sharing information on illegal activity between agencies and with cooperatives (Gascoigne et al., 2016). The province of Ben Tre has also announced a focus on installing tracking devices on fishing vessels to further monitor and reduce IUU fishing (Vietnam News Agency [VNA], 2020). Thus, beyond the incentive for compliance from the actors involved, pressure was added on non-compliant actors by taking initiatives to exclude them from the value chain. Building on these positive outcomes, in 2018, a 4-year EU-funded Oxfam project was launched, aiming at increasing the ability of small- scale producers to negotiate for their position in the value chain, reinforcing the incentive to maintain certification (Vietnam News Agency [VNA], 2018; Xuan and Seip-Markensteijn, 2019).

Incentivizing Multi-National Cooperation in Managing Transboundary Resources

When it comes to transboundary stocks or stocks managed through Regional Fisheries Management Organizations (RFMOs), it is notoriously difficult for political interests of all invested parties to align to reach a consensus on precautionary management, especially if there isn't an imminent threat to stock productivity. Indeed shared stocks appear to be declining more than other fisheries (Palacios-Abrantes et al., 2020), and, ever since the IPOA-IUU was first established, high seas and RFMO fisheries have remained a key focus of efforts to end IUU practices. In the case of Indian Ocean skipjack tuna (*Katsuwonus pelamis*), combined pressure from large retail brands sourcing tuna, NGOs (i.e., WWF), and harvesters interested in maintaining their certificate [Maldives Seafood Processors and Exporters Association and the International Pole and Line Foundation (IPNLF)], helped tip the balance toward all coastal states in the Indian Ocean Tuna Commission (IOTC) agreeing to 'well-defined harvest control rules' that met MSC requirements (Indian Ocean Tuna Commission [IOTC], 2016). This example illustrates how certification can provide an additional push to get stronger RFMO regulations over the finish line.

The WPSTA Western and Central Pacific skipjack and yellowfin free school purse seine received conditions under Principle 3 requiring improvements in MCS and transparency. The action plans developed to address them require that the certificate holders put pressure on the WCPFC RFMO member states to cooperate on issues such as data sharing, "evidence of flag state enforcement and controls on vessels fishing in the WCPFC Convention Area.", and engage in specific activities, such as "WPSTA will request meetings with China Overseas Fishery Association (COFA) to understand the most recent Compliance Monitoring Report (CMR)."

In some cases the necessary cooperation for a cohesive regulations of shared stocks is hard to reach and the fishery can see its certificate suspended as a result, such as the ISF Iceland mackerel fishery (Marine Stewardship Council [MSC], 2021; **Supplementary Table 2**).

SUPPORTING TRANSPARENT AND TRACEABLE SUPPLY CHAINS

One of the key strategies recommended in the IPOA-IUU, and in the many regional plans that followed since (e.g., UN World Food and Agriculture Organization [FAO], 2020c), is to achieve transparency and traceability throughout seafood supply chains. Traceability, or the collection and verification of information on the product's origin and movements, has gained increasing prominence in its ability to support efforts to prevent IUU products reaching markets. Examples of such efforts include the European Union Catch Certification, or the US NOAA 2018 Seafood Import Monitoring Program. The MSC is an example of a non-regulatory market measure. MSC traceability reporting checks begin at sea. To demonstrate legality, key data elements, such as the species or stock, gear type(s), catch location, quantity, crew information and vessel registration may be required. Information on origin can be collected by human observers, cameras, or automatic identification systems (AIS), though these are not legally required in many fisheries and seafood supply chains. In such cases paper records such as logbooks, catch certificates and landing declarations are common, but they are open to manipulation which is a risk considered in the MSC audit. Typically, they do not document information on catch movement such as transfers from harvest to transshipment vessels and the offloading in port to third-party sale agents, so they may prevent from demonstrating a product's 'CoC' and thus origin. A fishery assessor will determine whether the systems are sufficient to prevent mixing, substitution and misreporting, and publish their determination on the MSC website[4] for transparency. From this point onward, all actors in the supply chain that wish to trade products that can carry the MSC ecolabel must have a valid MSC Chain of Custody (Marine Stewardship Council [MSC], 2019b) certificate (**Figure 1**). The Chain of Custody Standard sets out requirements, including where there may be a risk of IUU fishing, to ensure certified products are effectively segregated from non-certified with each internal movement tracked and every transformation reconciled through an auditable record trail. A CoC certificate holder cannot source product from vessels on RFMO blacklists for IUU fishing (Marine Stewardship Council [MSC], 2019b). The process provides assurance a product came from an MSC certified sustainable fishery for a particular species, though not which specific fishery, as it does allow mixing of catch from different certified sources.

Closing the Gap: Strengthening Chain of Custody From Port to Processor

One of the ways in which IUU fish can enter legal supply chains is through weak monitoring and controls during landing in ports. Salmon fisheries in the Sea of Okhotsk in the Russia Far East, an area historically associated with high levels of IUU fishing (Lajus et al., 2018), have taken steps to ensure that MSC certified salmon caught in Russian waters and landed in Russian ports could be assured as coming from a certified sustainable and legal origin. As an additional assurance that all data gaps are closed, the conformity assessment body (CAB) performing the audit evaluated both the fishery and the first buyers with CoC certificates. The fishery assessment for the Zarya-Kolpakovsky Sobolevo West Kamchatka Salmon fishery included a review of product flow from catch to arrival at the processing facility and describes the efforts by companies in the fishery certificate to "enhance enforcement activities by supplying personnel, equipment, and funding to the authorities" to minimize the opportunity for illegal harvest in the beach regions and rivers where illegal fishing and harvest of salmon roe occur

[4]fisheries.msc.org

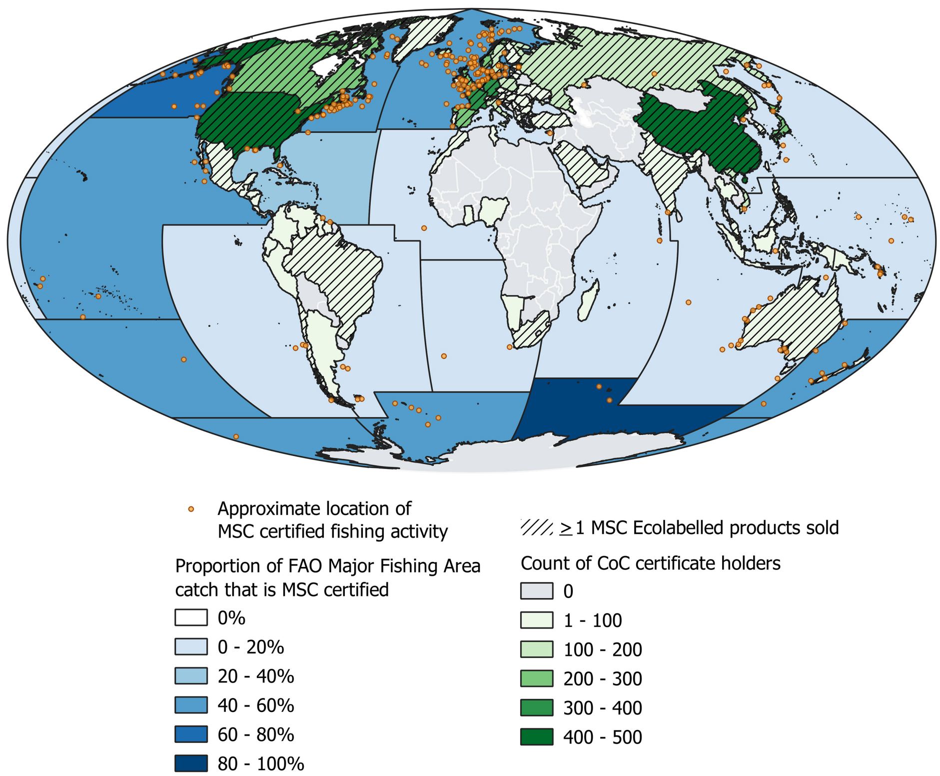

FIGURE 1 | Global distribution of MSC certificate holders at sea (fisheries) and on land (supply chain) and consumer-facing ecolabelled products sold. Count of Chain of Custody (CoC) certificate holders per country as of 15 September 2020, eco-labeled products sold from 1 April 2019 through 31 March 2020, certified fishery reported landings as of 31 March 2020 as a proportion of FAO 2018 marine capture per FAO major fishing area (UN World Food and Agriculture Organization [FAO], 2020d), excluding inland, farmed, plants and mammals. Approximate centroid point locations for MSC certified fisheries (https://fisheries.msc.org/en/fisheries/) as of 31 March 2020. Data description available at Marine Stewardship Council [MSC] (2020b).

(MRAG Americas, 2020). The additional enhanced enforcements include restricted landing ports where documentations are cross-checked between landing and arrival at processing facilities to ensure a "robust CoC to mitigate the risk of product from a non-certified source entering the supply chain" alongside the various activities undertaken by the buyer to check the legal and certified status of each fishing parcel received at their facilities.

Tamper-Proof Catch Data Transferred Along the Supply Chain

The Convention for the Conservation of Antarctic Marine Living Resources (CCAMLR) was established to manage the Southern Ocean. Its mandate includes management of toothfish stocks (*Dissostichus* spp.). As an early participant in the MSC Fisheries program, significant efforts to eliminate IUU from the member states' fisheries were made to support the application for certification (Baird, 2005; Agnew, 2008).Vessel inspection results are shared with other member states to facilitate cooperation in enforcement actions. Catch Documentation Schemes (CDS), barcodes and satellite technology are used to capture tamper-proof information that is accessible by port states to monitor landings and ensure only legally caught toothfish can be landed and sold into legal supply chains. CCAMLR maintains a public list of legal vessels, making it harder for vessels engaged in illegal fishing to land their catch and pass it off as legally caught. MSC Chain of Custody certification (Andrews and Medley, 2018) allowed for example the legal toothfish fishery in South Georgia to re-gain social acceptability after intense consumer awareness campaigns against illegal harvests had greatly reduced marketability for toothfish (van Putten et al., 2020; Robinson et al., 2021). CDSs can be used to fulfill customs control and document legal provenance of seafood products, and have common objectives to the MSC Chain of Custody certification, while not constituting a traceability system *per se* (UN World Food and Agriculture Organization [FAO], 2016b). As more countries and regions look to CDSs to protect their markets from IUU products, progress remains slow with varying levels of commitment and differences in approaches to implementation. CCAMLR's success is in part due to its multilateral approach, as evidence suggests that they can be more effective at reducing the benefits gained from IUU fishing (ICTSD). For example, without coordination and harmonization between the flag state and port state there may be inconsistency in what data are collected and how data are captured and reviewed. The Chain of Custody certification process, verifying the "custodial sequence that occurs as ownership or control of the material supply is transferred from one custodian to another in the supply chain," can be a driver to overcome this issue. The CoC Standard requires accurate documentation and reviews the capability of all businesses in a given supply chain to maintain it through periodic audits and *ad hoc* investigations. This closes data gaps from one jurisdiction's scheme to another while enhancing a level playing field by applying the same requirements to actors entering global markets from outside of import control schemes.

In addition, forensic techniques for product authentication such as DNA barcoding help close the net on IUU product laundering and seafood fraud in the supply chain. MSC conduct frequent product sampling for DNA testing, to detect species substitution and product mislabeling (Barendse et al., 2019) and is exploring use of genetic and stable isotope techniques to further trace seafood products' provenance back to specific areas or fish populations (Cusa et al., in review).

BEYOND ENVIRONMENTAL CONCERNS: ETHICAL AND SOCIAL DIMENSIONS OF ECOLABELING

As an incentive-based approach to improve fishing practices, it is important to consider the socioeconomic implications of environmental requirements.

Socioeconomic, Environmental, and Ethical Issues in Shark Finning

This emerges, for example, with regards to shark finning – the practice of removing fins from sharks and discarding their bodies at sea – widely condemned due to its cruelty, wastefulness, and unsustainability (Spiegel, 2001) and illegal in many countries and RFMOs. The challenge facing sustainable seafood standard-setters is how to produce requirements that contribute meaningfully to shark conservation, avoid inequitable barriers to entry to the program, whilst also taking into consideration all views from diverse stakeholders on a highly emotive and polarizing issue.

Marine Stewardship Council does not allow shark finning certification in scope, while it provides requirements to regulate legal shark fisheries (**Table 1**). Fins can make up a large proportion of the income of fishers involved in sustainable shark fisheries, and blanket bans on selling shark fins, that do not distinguish if the source was from a legal or shark finning fishery, can negatively impact these fishers' livelihoods (Shiffman and Hueter, 2017; Simpfendorfer and Dulvy, 2017). Additionally, finning bans do not guarantee decreased shark mortality (Clarke et al., 2013), particularly where subsistence is the primary driver of shark mortality, as is common in low income communities (Dulvy et al., 2017; Glaus et al., 2018; Karnad et al., 2019), and could simply raise the market value in the black market fin trade. Lack of reporting further undermines conservation efforts that rely on accurate estimates of mortality (Edwards, 2006). Combining sustainable and well-managed shark fisheries with well-enforced finning regulations may ensure supply of legally and sustainably harvested fins, reducing the incentive for illegal, unsustainable harvests. Herein lies an opportunity for eco-certification to contribute significantly to eliminate the IUU component of these fisheries.

Current MSC information requirements contribute to addressing the gap in independently verified catch records, with 20 MSC fisheries having already made improvements mainly in monitoring and research of shark and ray bycatch (**Supplementary Table 4**). If evidence of shark finning is detected during an audit or assessment, a fishery will face suspension unless it can show the offending vessel has been expelled from the certificate. Yet, given the complex intersection of environmental concerns and socioeconomic constraints for this type of fishery, MSC is conducting global public consultations with stakeholders as part of the current MSC Fisheries Standard Review (Marine Stewardship Council [MSC], 2020c).

Eliminating Forced and Child Labor

Though MSC's focus has been on environmental sustainability, with social dimensions only covered regarding fair participation in fisheries governance, a zero-tolerance position was taken on forced and child labor.

A growing body of work points to a connection between illegal fishing and labor practices (Tickler et al., 2018; EJF, 2019; Mackay et al., 2020). As stocks become depleted and the costs of fishing increases, illicit operators attempt to improve margins through exploitative labor practices which then lead to worsened stock health and further labor abuses in a vicious cycle to maintain margins. Bioeconomic modeling of the feedback between environmental degradation from fishing activity and human rights demonstrates that reduced costs, enabled via human rights and labor abuses, can lead to environmental decline in fisheries (Lewis et al., 2017). Market based standard and audit tools can potentially contribute to eliminating forced labor and IUU practices. However, options to do this through certification standards are currently limited.

Marine Stewardship Council established that operations where there has been a conviction for egregious labor violations are 'out of scope,' i.e., they are simply not eligible to hold a certificate. These provisions are not based on environmental sustainability principles. Rather, they are the expression of an ethical stance taken by the MSC Board of Trustees. To further support this intent, MSC recently added a requirement that at-sea operations self-report on mitigation measures. New requirements include that each Chain of Custody registered site is evaluated based on its activities and country's labor risk. Unless they are found to be low risk, sites must pass a third-party labor audit program in order to maintain their MSC certification.

Yet, this remains an area where best practice for effectively identifying these activities is still being developed. Indeed, only a small number of third-party auditing initiatives have been established to assess labor issues. Many are at early stages of development such as the Responsible Fishing Vessel Scheme (RFVS) (IntraFish, 2020), or only applicable to a specific subset of the industry – such as the Fairtrade USA Capture Fisheries Standard (Fair Trade USA [FTUSA], 2017). The efficacy of certification schemes to drive improved labor conditions in capture fisheries has been questioned (Praxis Labs, 2019). Perceived limitations include the complexities involved in undertaking comprehensive audits while vessels are at sea, the level of assurance that can be provided from labor audits conducted at port and resources required to undertake audits that provide acceptable levels of assurance. There is a need for better understanding of the practicality and effectiveness of standards and certification for labor practices. The compilation of self-declarations from all certified entities may provide a unique opportunity for a large-scale, standardized overview of the state of play (Tindall et al., in preparation), and a first step to build on for further action.

DISCUSSION

Just like other types of illegal wildlife harvest, IUU fisheries have serious environmental, social and economic consequences. Solutions must engage the full stakeholder community and work across the whole supply chain.

The international community has identified root causes of IUUs in the failure of appropriate regulatory mandates, particularly in high seas, weak enforcement of existing regulations, and appropriate documentation of activities at sea (and sometimes on land). These points highlight the resource and physical limitations of MCS, so that compliance needs to be incentivized in other ways. These may include cross jurisdiction cross national and cross sector collaboration, which can be beyond the reach of a single authority but accomplished when there is industry cooperation, such as the case of the MSC global network of certificate holders (**Figure 1**).

Here we compiled lessons learned from anecdotes, published peer reviewed and gray literature and analyses of MSC certificates, providing a perspective on the range of direct and indirect mechanisms through which the MSC program can incentivize change, across fisheries striving to meet best practice, or even once certified, in turn creating pressure for other harvester and supply chain companies to improve.

A perspective of how the MSC program helps address IUU fisheries we propose that, to address **ILLEGAL** fishing the main mechanisms offered by the MSC program include:

- The Chain of Custody requirements can prevent illegally caught fish from entering the certified product streams.
- Requirements for inclusive governance give a transparent and inclusive mechanism for stakeholders to raise issues about Illegal catch, and the fishery governance processes must provide transparent responses to concerns that are raised.
- The requirement that jurisdictions of shared stocks must share information can incentivize coordinated monitoring and enforcement efforts, improving likelihood for detection of illegal fishing.
- The requirements for effective MCS implementation, including catch documentation for all vessels, ensures appropriate systems of detection of illegal activities are put in place.

To address **UNREPORTED** fishing the main mechanisms in the MSC program include:

- Chain of custody and catch documentation provisions can prevent legal but unreported catch from entering the certified product stream.
- The necessity for segregating harvest from uncertified capture starting at sea, rather than at landing site, works with the chain of custody and catch documentation in further deterring unreported catch.
- By requiring jurisdictions of shared stocks to share information, incentives are provided for coordinating assessments and better detection of mis-reporting across jurisdictions.

To address **UNREGULATED** fishing the main mechanisms in the MSC program include:

- Fisheries working to meet the Fisheries Standard Principle 3 requirements can lead to strengthening regulatory processes. Particularly, this applies to requirements for explicit legal and/or customary frameworks for management, full definition of roles and responsibilities for all aspects of fisheries governance, explicit decision-making processes and evidence for enforcement and compliance.
- The need for sound assessments of stock status creates incentives for biologically based reference points, and, in turn, require jurisdictions to develop full regulatory frameworks, first to set reference points and harvest control rules, then to monitor their enforcement.
- The requirements for effective MCS implementation, including catch documentation schemes, help collect more comprehensive data to inform status assessments and set effective management reference points.

Other Tools and Strategies

There are circumstances where eco-certification may not be a highly effective tool.

By their very nature, IUU practices are difficult to document and monitor, which in itself may be a challenge to addressing them. New proposed methods may assist in using qualitative sources (Donlan et al., 2020), and emerging technologies (e.g., Global Fishing Watch, 2020), though these must consider ethical implications of data ownership (Toonen and Bush, 2020) and fair and inclusive definitions of legal frameworks and implementation of MCS systems (Song et al., 2020).

Despite the MSC Fisheries Sustainability requirements allowing for 'customary and informal legal frameworks,' and use of non-conventional resource assessments (Marine Stewardship Council [MSC], 2016), or risk-based evaluations of impact in data limited cases, and though ongoing global outreach initiatives provide training on the MSC program and improvement tools in many languages, fishery certification occurs most often in northern Europe and north Americas (**Figure 1**). This geographic pattern is likely to reflect the interplay of socioeconomic, policy and market-related factors that are not favorable to the ecolabeling incentive model (at least not yet). For example, wildlife harvest targeted to specific traditional uses, such as shark fins or manta ray gill plates, is difficult to eradicate because it has a steady demand, it occurs in low-income communities, and bans can have the counterproductive effect of increasing its market price and thus the incentive to defy regulations (Shiffman and Hammerschlag, 2016; Booth et al., 2020). In these cases, all other challenges aside, certification is unlikely to provide a commensurate economic incentive. Even when wildlife is more valuable alive to attract tourism than traded as meat (Mustika et al., 2020), local communities excluded from that industry might see no better option than illegal fishing.

NGOs and grassroots organizations have been working on a range of strategies, from educating and raising awareness to reduce demand, to capacity building to strengthen enforcement, to campaigns for stronger trading regulations and seeking options for alternative livelihoods (e.g., the GSRI strategy[5]). Given the local nature of socioeconomic dynamics of wildlife harvest and the global nature of supply chain pathways, and multiple jurisdictions and actors involved, different tools will need to work together (Booth et al., 2020).

Past and Future

The MSC Fisheries Standard emerged in 1998 from the intent to operationalize the FAO Code of Conduct for Responsible Fisheries (Agnew, 2019). Both Fishery and Chain of Custody Standards have been reviewed and revised on a 5-year basis, incorporating changes in scientific advice, as well as input from all the stakeholders that contribute to the program. In the last decade increasing attention has been placed on including human dimensions in fisheries management (De Young et al., 2008), and the seafood sustainability movement has embraced a more complex notion of sustainability interventions (Kittinger et al., 2017; Bush et al., 2018). It would seem a natural progression therefore that a program focused on environmental sustainability will also grapple with ethical issues such as human rights violations or complex socioecological tradeoffs such as shark finning. As stakeholders' expectations broaden, the program is asked to engage with legal and socioeconomic contexts that may reach beyond its area of influence, or require evolving toward innovative approaches, for example in creating a pathway to sustainability for the many fisheries that do not yet have the resources, capacity, data, and institutions to meet the MSC sustainability requirements (Marine Stewardship Council [MSC], 2019b).

Eco-certification with an assured chain of custody provides a range of direct and indirect mechanisms of addressing IUU practices. It can not only shift the financial incentive for illegal activities and fraud, but also facilitate a culture of compliance with existing regulations through increased dialogue with and trust in institutions. It requires fair and transparent data sharing which improves reporting of information and can bolster stakeholder cooperation, in turn further reinforcing cultural compliance norms. Where regulations are absent or insufficient, it creates an incentive to improve the management framework, by aligning the interests of different stakeholders from harvesters, managers, local NGOs, to other actors all across the supply chain. It also provides a mechanism for industry, from harvester to supply chain actors, to fully document their activities within a cohesive framework, beyond what regulations are in place where the fish were caught, landed, transported, or sold.

Addressing IUU practices, especially on the high seas, or in low-income countries with weak institutions, is extremely difficult, and requires a range of strategies and organizations working on multiple fronts, from local grass-roots NGOs working for education and awareness, to institutional reform, in national and international policy fora to market-based incentives. The recent global covid-19 pandemic demonstrated global value chains can have serious impacts on local communities (Knight et al., 2020), but market mechanisms can also reach across the globe to generate positive change. We propose, based on the information and anecdotes available to date, that ecolabeling programs such as the MSC are one valuable intervention in a range of complementary tools that need to be brought together to bring us a step closer to eliminating illegal, unregulated and unreported fisheries.

DATA AVAILABILITY STATEMENT

The datasets analyzed for this study were manually extracted from MSC fishery public certificate reports (PCRs) that can openly be accessed from https://fisheries.msc.org/en/fisheries/. The specific data analyzed and fisheries whose reports were used can be found in **Supplementary Tables 2,3**.

AUTHOR CONTRIBUTIONS

CL, RC, JR, OO, and DS ideated the work. CL, JR, OO, SL, LK, SYL, and LB wrote the first draft. All the authors edited the manuscript. CL, SG, TG, LK, and SL executed the data collection and analyses. CL created the tables. LK created the figure. All authors contributed to the article and approved the submitted version.

ACKNOWLEDGMENTS

We would like to thank Kate Dewar, Tim Davies and Stefano Mariani, and the two reviewers for helpful feedback on a draft version of the manuscript.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fevo.2021.637228/full#supplementary-material

[5] http://fscdn.wcs.org/2016/02/10/1cxcak0agd_GSRI_GlobalPrioritiesForConservingSharksAndRays_web_singles.pdf?_ga=2.112043584.596836061.1606895663-190274890.1606895663

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Conflict of Interest: CL, LB, LK, SL, SYL, OO, DS, and RC are currently employed by the Marine Stewardship Council (MSC).

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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ORIGINAL RESEARCH
published: 28 April 2022
doi: 10.3389/fevo.2022.640961

Temporal and Spatial Stability on the Population Structure of Consumed and Illegally Traded Big-Headed Amazon River Turtle in the Negro River Basin, Central Amazon, Brazil

Juarez C. B. Pezzuti[1,2]*, *Tamires Oliveira*[2], *Jackson Pantoja-Lima*[3], *George Henrique Rebêlo*[2,4] and *Daniely Félix-Silva*[2]

[1] Núcleo de Altos Estudos Amazônicos-NAEA, Universidade Federal do Pará (UFPA), Belém, Brazil, [2] Network on Diversity, Conservation and Use of Wildlife in Amazonia (REDEFAUNA), Belém, Brazil, [3] Amazonas Federal Institute, Manaus, Brazil, [4] National Institute of Amazon Research (INPA), Manaus, Brazil

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Edited by:
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Qinghai University, China
Pratheesh C. Mammen,
Kerala State Disaster Management Authority (SDMA), India

***Correspondence:**
Juarez C. B. Pezzuti
juarez.pezzuti@gmail.com

Specialty section:
This article was submitted to Conservation and Restoration Ecology,
a section of the journal Frontiers in Ecology and Evolution

Received: 12 December 2020
Accepted: 17 March 2022
Published: 28 April 2022

Citation:
Pezzuti JCB, Oliveira T, Pantoja-Lima J, Rebêlo GH and Félix-Silva D (2022) Temporal and Spatial Stability on the Population Structure of Consumed and Illegally Traded Big-Headed Amazon River Turtle in the Negro River Basin, Central Amazon, Brazil. Front. Ecol. Evol. 10:640961. doi: 10.3389/fevo.2022.640961

Freshwater turtles are a valuable food resource for riverine human communities and have been historically overharvested throughout all major tropical large river basins, with consequent gradual population decreases. Even species considered to be abundant are declining, and in many cases were brought to a condition of near extinction. The collection of adult females during breeding season on nesting beaches is considered a major factor in population decline and subsequent loss of food sources for humans. There is growing consensus that adult females constitute the category which turtle populations can least afford to lose. In the Negro River Basin, the podocnemidid big-headed Amazon River turtle, *Peltocephalus dumerilianus*, is heavily exploited for consumption and poached for illegal trade among riverine communities and cities. Between 1997 and 2002 and in 2019, we measured live turtles and carapaces of big-headed turtles in the city of Barcelos and its surroundings, and among the riverine families living in the Jaú National Park. We compared body sizes and sex ratios between areas, periods, and between consumed and traded individuals. We found no differences between areas, even those close to Barcelos and the ones belonging to remote areas where pressure levels are lower. The individuals consumed in Jaú National Park are larger than those poached for illegal trade in both areas. There was an increase in average size between 1997 and 2002. Sex ratio was slightly skewed toward males, which were larger, and did not differ between areas and periods. Results indicate stability on size of harvested populations, which may be supporting current extraction levels. Data suggest this could be related to the absence of adult female capture during nesting for this species. We recommend protection strategies for other Amazon Podocnemidid species that focus on the protection of nesting beaches and surrounding areas where adults occupy, specifically in areas under communal protection.

Keywords: river turtle, *Peltocephalus*, sustainability, use, Amazon, Negro River, trade

INTRODUCTION

The Podocnemidid Amazon river turtles have been used for food by Amazon people long before European's arrival in South America (Carvajal, 1543; Prestes-Carneiro et al., 2016). *Peltocephalus dumerilianus* (Schweigger, 1812), known as the big-headed Amazon River Turtle (hereafter big-headed), is intensively exploited in the Negro River basin, being part of the illegal regional trade (Rebêlo and Lugli, 1996; Rebêlo and Pezzuti, 2000; Rebêlo et al., 2006; Pezzuti et al., 2010; Schneider et al., 2011). This species is the second largest podocnemid in the Amazon (**Figure 1**), smaller only to the giant Amazon river turtle (*Podocnemis expansa*), and can weigh up to 16 kg (Pritchard and Trebbau, 1984; De La Ossa and Vogt, 2011).

The big-headed utilization of the Negro River is especially interesting due to its biological and socio-cultural characteristics. Unlike other Amazonian podocnemidids, the big-headed females nest inside the Igapó forest, in earth mounds created from fallen trees. Occasionally, they also nest on sandbanks, beaches, or ravines on the banks of water bodies (Vogt et al., 1994; Félix-Silva, 2004; Vogt, 2008). Thus, there is no capture of female big-headed during nesting (Pezzuti et al., 2004; Schneider et al., 2011), as occurs annually with the other podocnemidids (Fachín-Terán et al., 2003; Pezzuti et al., 2010; Pantoja-Lima et al., 2014). Generally, the nesting moment is the most vulnerable for chelonians and, for larger species, it represents a context in which adult females are particularly susceptible to their natural predators. Historically, the intense harvest of Amazonian podocnemidids nesting females lasted for almost 200 years, generating a large source of food, energy, and wealth for the Colonial Empire, the Brazilian Empire, and the United States of Brazil at the beginning of the Republic (Bates, 1864; Silva Coutinho, 1868; Gilmore, 1986). This likely caused the inevitable decline of the Giant Amazonian turtle populations, followed by the smaller species, until the collapse of chelonian harvesting as a relevant economic activity (Smith, 1974; Mittermeier, 1975; Johns, 1987; Pezzuti et al., 2004; Rebêlo et al., 2006).

Monitoring population structure is a crucial parameter in wildlife management (Caughley and Sinclair, 1994). The evaluation of size structure of big-headed populations through space represents an opportunity to assess the impact on Podocnemid without this key aspect of capturing of adult females during nesting. In the present study, we investigated the size distribution and sex ratio of big-headed Amazon River turtles caught for consumption and for sale in different areas along the Negro river and over two periods, with an interval of more than 20 years between samplings. Our main purpose was to detect possible variation on population size distribution and sex ratio of harvested turtles within two dimensions: over time and across geographic areas.

A

B

FIGURE 1 | (A) *Peltocephalus dumerilianus*, the big-headed Amazon River Turtle; **(B)** a quantity of big-headed turtles caught in Jaú National Park and destined for the illegal trade.

MATERIALS AND METHODS

Study Area

This study was carried out in two regions of the lower and middle Negro River in the Brazilian Amazon, in the city of Barcelos and in the National Park of Jaú (PNJ), in the state of Amazonas (**Figure 2**). Aside from the urban area of Barcelos, the area is characterized by well-preserved primary forests where

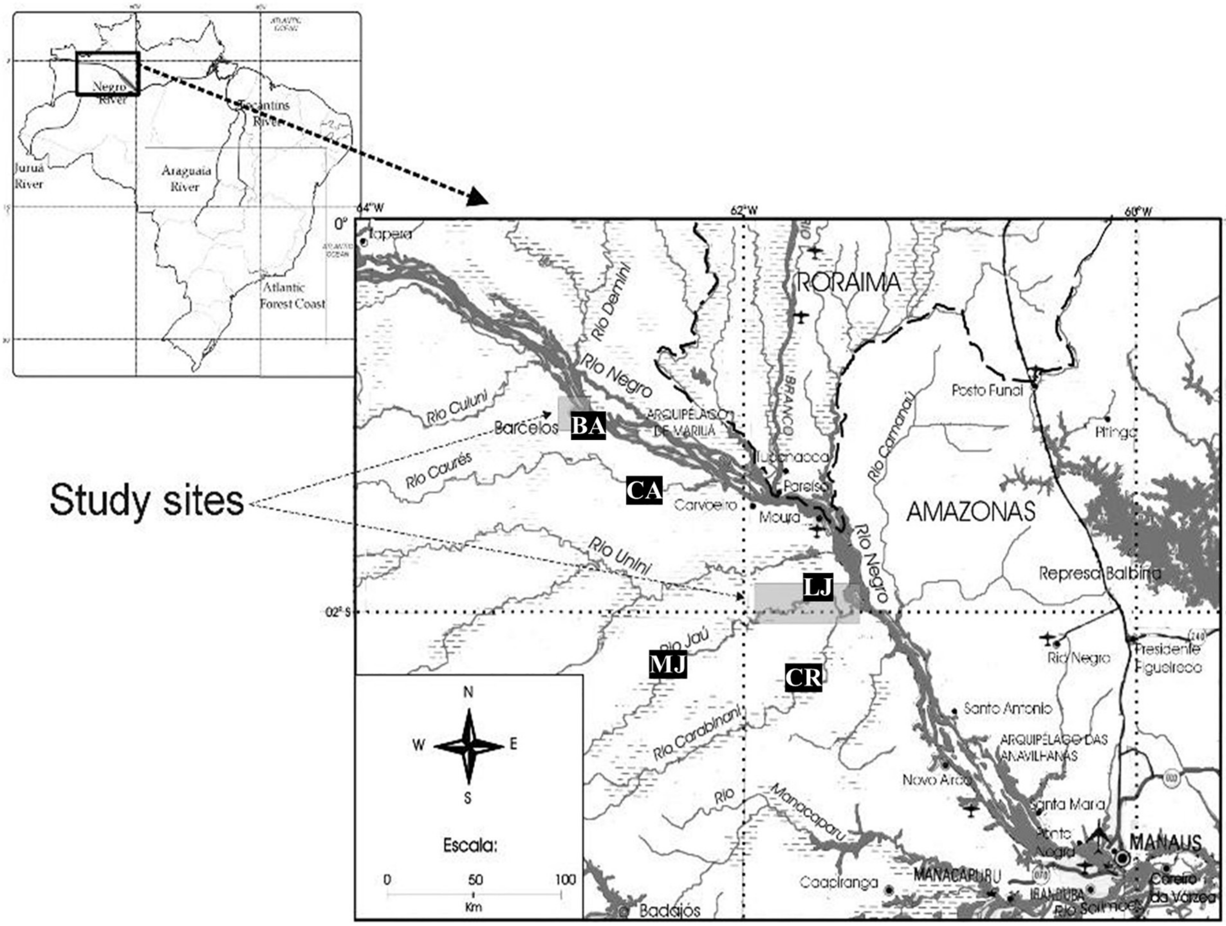

FIGURE 2 | Study area in the middle of the Negro River, Amazonas, Brazil.

basic extractive activities take place, such as gathering of non-timber forest products (particularly Brazil Nuts), subsistence hunting, and small-scale agriculture. The region has a large expanse of Igapó seasonally flooded forests that sustains a high diversity and abundance of aquatic organisms, where basic extractive activities take place, serving as the base of the regional diet (Da Silva and Begossi, 2009). The city of Barcelos, with nearly 25,000 inhabitants (IBGE, 2020), is located on the right bank of the Negro River, 405 km northwest from the city of Manaus, in the state of Amazonas. The main source of income for the local population of this city are extractive activities, especially ornamental fishing. The proximity to the Mariuá archipelago, the largest river archipelago in the world, gives this region a high biological diversity and abundance of aquatic resources (Machado, 2001; Latrubesse and Stevaux, 2015). The PNJ is located on the right bank of the lower Negro River and is equivalent to IUCN Category II Protected Area (Sistema Nacional de Unidades de Conservação [SNUC], 2000). The park includes an area of 2,272,000 ha that protects almost the entire basin of the Jaú River, a typical blackwater river whose main tributary is the Carabinani River. Both the Jaú and the Carabinani rivers are characterized by the presence of rapids that, in the dry season, separate these rivers into low (downstream of the waterfalls) and medium (upstream of the waterfalls) portions. The local inhabitants are descendants of rubber tappers and live on basic subsistence activities such as slash-and-burn agriculture, subsistence fishing and hunting, and collecting of Brazil nuts (Pezzuti et al., 2010).

Proceedings

Sampling was carried out between 1997 and 2002, and in 2019. During the first period, 18 trips were made to PNJ (June and November 1997, January, May, and October 1998, March 1999, February, April, July, and September 2000, February, June, August and November 2001, and February, June, August and December 2002) in order to conduct interviews with fishermen (Rebêlo and Pezzuti, 2000; Pezzuti et al., 2010) and participant observation (Rebêlo et al., 2006). Each fieldtrip lasted between 2–3 weeks. In November 2019, we returned to PNJ on a trip lasting 12 days. We were able to measure carapaces of live animals held captive in small pens called "*currais,*" and of animals eaten, whose shells were thrown along the edges of the residents' yards. To have comparable datasets between the two periods, we visited the same communities from Lower and Middle Jaú and carefully searched for shells along the gardens and collective areas in the community to assure that most of the shells of consumed big-headeds, if not all, were measured. Thus, we were able to measure shells of individuals caught and eaten during the year of 2019. Therefore, it was possible to obtain an unprecedented series of animals measured, over more than 20 years, allowing for a robust temporal analysis of harvested big-headed individuals. Following the biometrics protocol widely used for turtles, we measured the straight carapace length and CRC (Pritchard and Trebbau, 1984; Vogt, 2008) of living animals and shells, with the aid of a large caliper (Hagloff, 1,000 m). When this tool was not available, the curved carapace length (CCC) was measured with a small measuring tape. From there, we used a Spearman Correlation to estimate the CRC (r = 0.97). Living males and females were distinguished following Rueda-Almonacid et al. (2007), with females presenting a wider opening of the cloacal scutes, and males with greater pre-cloacal tail length and thicker tail base (Rueda-Almonacid et al., 2007). Barcelos city and its surroundings were visited during 2000–2001 in the same months aforementioned, where we spent between 1 and 2 weeks carrying out the same procedures. Although prohibited, there was no enforcement to prevent turtle poaching in the city throughout the period considered, and animals are frequently encountered for sale. Big-headed turtles could be found on markets, fishermen houses, harbors, and small boats just after fishermen's arrival at the city. Turtle carapaces were also found scattered on gardens, unoccupied grounds, areas surrounding harbors, and other city neighborhoods. In specific situations, after years of contact with the residents, we also had the opportunity to carry out biometrics of loads of animals destined for commercialization outside the PNJ, and of animals newly arrived for commercialization in Barcelos. We measured all live individuals and carapaces of eaten animals present in households' respective gardens in the sites visited, except for Barcelos.

For the intended comparisons, the region was subdivided into five locations, two of which are located on the Negro River (Barcelos City and Caurés river) and three located within the PNJ (Carabinani river, lower Jaú river, and middle Jaú river). Below, we briefly describe the study area human population and a subjective classification of the river turtle harvesting pressure for each area. This was based on our observations and interaction with local dwellers (including poachers) and park staff, and considered the traveling distance, the presence of rapids making the journey more difficult and time consuming, and the overall perception on remoteness and harvesting intensity by local dwellers and poachers.

Middle Jaú—Inhabited by small and sparsely distributed riverside communities. Infrequently accessed by poachers, due to the rapids that make access difficult during most of the year. Low pressure.

Carabinani—Uninhabited but subject to harvest by poachers in unknown frequency. Low pressure.

Lower Jaú—Inhabited by small and sparsely distributed communities; more frequented by turtle poachers than Middle Jaú. Average pressure.

Caurés—Inhabited and frequently visited by poachers, mainly from Barcelos—average to high pressure.

Barcelos—Urban area and illegal market; receive turtles from surroundings—high pressure.

The big-headed is almost exclusively captured with a single technique, regionally called *baliza*. The technique consists of attaching bait made with pieces of fish (approximately 0.5–1 kg) to poles fixed to the bottom of flooded forests or close to the riverbanks. Then, the attracted turtles are harpooned at the carapace with minimum damage to the animal, since the harpoon used is small and has no barbs (Pezzuti et al., 2004). The few exceptions occur when animals are occasionally caught with other hunting techniques by residents of the PNJ. Thus, there was no methodological bias regarding differences in yield and selectivity of catches in size or sex.

To obtain a natural baseline of big-headeds for comparison, experimental turtle fisheries were conducted in April, July, and September 2000 and February 2001 in the Carabinani River region, the main tributary of the right bank of the Jaú River (Pezzuti, 2003). We chose Carabinani following local dwellers' suggestion for an area with low harvesting pressure and greater animal abundance. Each of these turtle sampling trips lasted at least 20 days, in which three pairs formed by a biologist and senior fishermen made up a fishing unit. Fisheries were made using the *baliza* method and carried out for the entire day (around 10–12 h). The capture effort ranged from 54 to 58 fisheries per trip, totalizing 224 days of capture effort.

Analysis

We aimed to assess whether the size distribution and sex ratio of animals varied spatially and temporally. We hypothesized that these size distributions differ between the animals consumed, traded, and those from our experimental catches due to differences in hunting pressure and fishermen's selectivity for larger animals for both consumption and trade. In addition, we expected that a depletion effect (Antunes et al., 2016; Tregidgo et al., 2017) from different pressure levels would lead to distinct size distributions and, thus, that the animals from Barcelos city and the closer Caurés river would be smaller and with a reduced proportion of adults. In contrast, turtles from Jaú and Carabinani, mainly those from middle Jaú, should be the larger. Similarly, we investigated to determine if sex ratios would be different between

TABLE 1 | Descriptive statistics of the distribution of measurements of the straight carapace length (SCL, mm) of big-headed (*Peltocephalus dumerilianus*) from the Negro River basin, Amazonas, Brazil, between 1997 and 2019 (SD = standard deviation).

Year	N	Average	*SD*	Amplitude (minimum-maximum)
1997	4	357.095	60.382	301.536–435.891
1998	35	380.435	57.118	254.216–465.466
1999	14	357.198	50.976	275.341–482.366
2000	377	324.955	69.645	146.000–520.000
2001	377	340.272	60.359	146.901–483.946
2002	98	351.893	63.411	143.000–511.941
2019	88	386.911	48.952	288.649–509.768
Total	993			

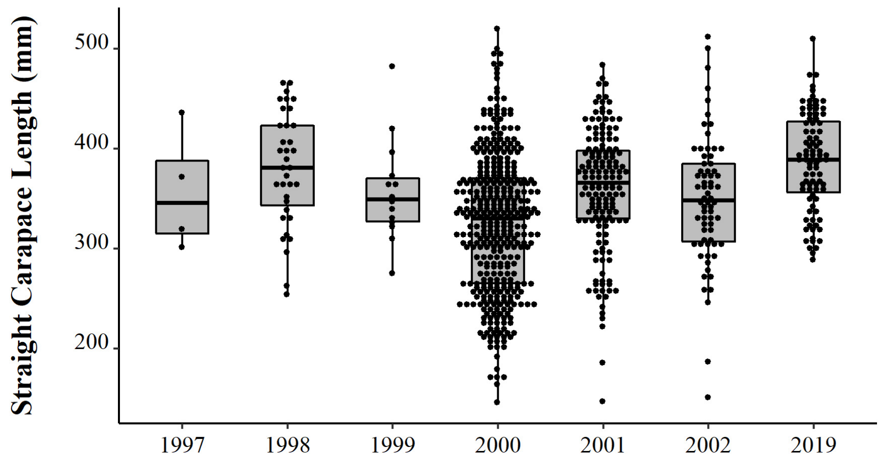

FIGURE 3 | Size distribution (points) and descriptive statistical (boxplot) of body size (SCL, mm) of big-headed (*Peltocephalus dumerilianus*) from the PNJ collected between 1997 and 2019.

study sites or change over time considering that males grow larger in this species and are thus preferred (Pritchard and Trebbau, 1984; Pezzuti, 2003).

We performed a Permutational Multivariate Analysis of Variance (PERMANOVA) using Euclidean Distance for each treatment group using CRC as the response variable to compare size variations between years, sex, purpose (consumption, commercialization, experimental capture), seasons (rainy or dry), and localities (Barcelos, Caurés river, Carabinani river, lower Jaú river, middle Jaú river) (Clarke, 1993; Anderson, 2005). The PERMANOVA is a geometric partitioning of variation based on a chosen dissimilarity measure. This analysis allows heterogeneous dispersions among groups and unbalanced designs, avoiding the assumption of normality due to the distribution-free inferences acquired by the permutations (Anderson and Walsh, 2013; Anderson, 2014). The Euclidean Distance is commonly used to build a resemblance matrix with morphometric measurements (Velez-Zuazo et al., 2014; Miorando et al., 2015). For comparisons of sex ratio between the same parameters above, the Chi-square test of various proportions was also used. The analyzes were performed using the Bioestat software (Ayres et al., 2007) and R (R Development Core Team, 2010). For comparisons between years and periods we used just the individuals harvested within PNJ.

RESULTS

We obtained a total of 993 carapaces measured from live or eaten individuals. Experimental catches were non-selective in size. Individuals caught ranged in size between 0.6 and 16 kg, which allowed for the intended comparisons between experimental catch size with the distribution of consumed and traded animals. The size distribution varied consistently between years (**Table 1** and **Figure 3**), with emphasis on 2019 when we registered the largest individuals. We observed a trend of increase in body size over the 22 years (PERMANOVA, Pseudo-$F = 14.13$, $p = 0.0001$). The years 1997 and 1999 did not differ from the others, probably due to the small sample size ($N = 4$ and 14, respectively). The size of the animals collected in 2019 were larger than those from all other years, except for 1998, which also surpassed 2000, 2001, and 2002 (PERMANOVA pair-wise < 0.05, **Supplementary Material 1**). The animals from 2001 and 2002 were also larger than the ones from 2000.

Comparing the data from the first collection interval (from 1997 to 2002) with the data from the second set of data collected in 2019, we observed that the animals from 2019 are significantly larger (PERMANOVA, Pseudo-$F = 58.88$, $p = 0.0001$, **Figure 4**). When comparing just the animals destined for commercialization, the animals from the PNJ were smaller than the animals from Barcelos (PERMANOVA, Pseudo-$F = 5.61$, $p = 0.01$, **Figure 5**). Males are larger than the females (PERMANOVA, Pseudo-$F = 182.95$, $p = 0.0001$, **Figure 6**), and individuals captured during the rainy season were larger than individuals captured in the dry season (PERMANOVA, Pseudo-$F = 9.67$, $p = 0.02$, **Figure 7**).

We observed contrast between the sizes of the animals captured experimentally, the animals intended for consumption by the residents, and the animals selected for sale (PERMANOVA, Pseudo-$F = 36.81$, $p = 0.0001$, **Table 2** and **Figure 8**). The animals from the experimental fishery are smaller and those with a greater range of size distribution, followed by animals intended for commercialization, which have a lesser size range. The animals destined for consumption by the residents are larger than those caught in experimental fisheries and those destined for sale (PERMANOVA pair-wise < 0.05, **Supplementary Material 1**). However, they present a greater range in the distribution concerning the animals consumed. We emphasize that almost all the animals destined for consumption come from the PNJ, which is essential for interpreting these results. Comparing the sizes between the five locations, the results show substantial differences (PERMANOVA, Pseudo-$F = 9.21$, $p = 0.0001$, **Figure 9**). The largest animals are those from the Jaú River, especially those from the middle stretch of

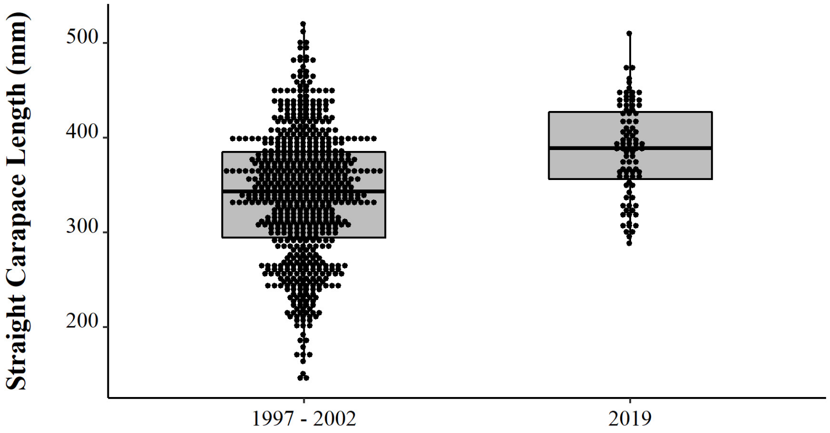

FIGURE 4 | Temporal distribution (points) and descriptive statistical (boxplot) of body size (SCL, mm) of Big-headed (*Peltocephalus dumerilianus*) from the PNJ collected in both sample periods (1997–2002 and 2019).

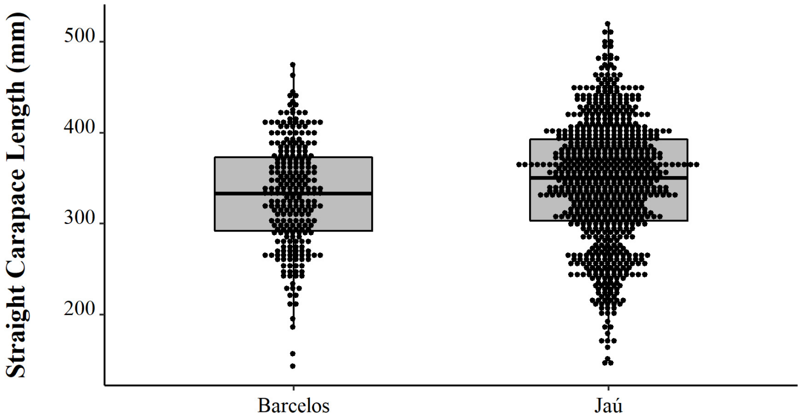

FIGURE 5 | Spatial distribution (points) and descriptive statistics (boxplot) of body size (SCL, mm) of Big-headed (*Peltocephalus dumerilianus*) intended for commercialization, from the Jaú River and the city of Barcelos, Rio Negro, Amazonas between 1997 and 2002.

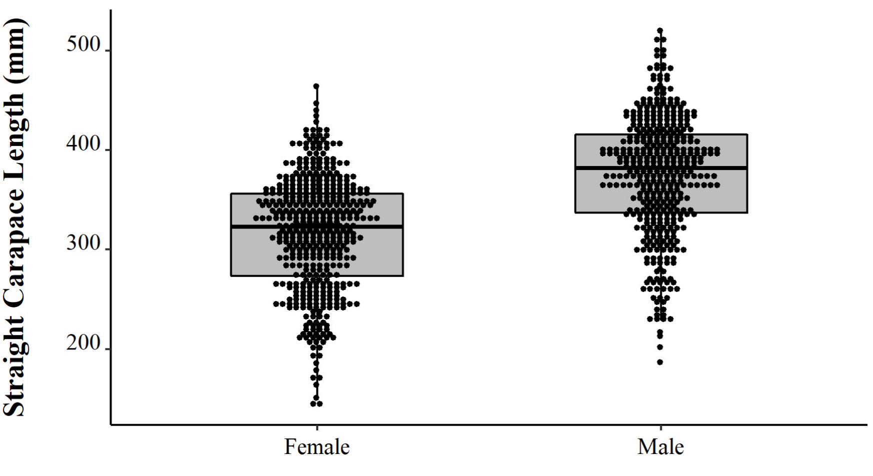

FIGURE 6 | Temporal distribution (points) and descriptive statistical (boxplot) of body size (SCL, mm) of the male and female Big-headed (*Peltocephalus dumerilianus*) from the Jaú collected between 1997 and 2019.

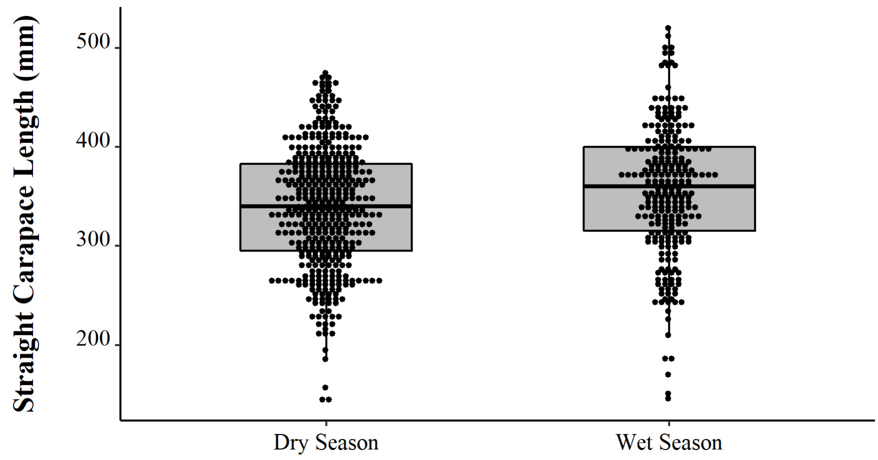

FIGURE 7 | Distributions (points) and descriptive statistics (boxplot) of body size (SCL, mm) and Big-headed (*Peltocephalus dumerilianus*) from the Negro River, Amazonas, obtained between 1997 and 2019, captured in the dry and rainy seasons.

the river, which is the most remote area. Caurés and Barcelos individuals were significantly smaller than those from the other locations, with no difference between each other (PERMANOVA pair-wise < 0.05, **Supplementary Material 1**).

When considering the animals' sex ratio, no significant differences were detected between the animals from the Jaú and Barcelos, or between those consumed and destined for commercialization, nor between the animals captured in the dry and rainy season. When comparing the sex ratios of animals from experimental capture to animals captured for consumption and sale, we observe a higher proportion of females in the first group, while in animals intended for consumption and sale, the pattern is reversed, with a significant proportion of males ($\Sigma 2 = 33{,}228$, $p = 0.0001$; **Table 3**).

DISCUSSION

Historical records note reduction in abundance and average size of Amazon River turtle populations, especially the larger and gregarious *Podocnemis expansa* (Bates, 1864; Silva Coutinho, 1868; Ferreira, 1972), and a further shift to target smaller species (Johns, 1987; Rebêlo and Pezzuti, 2000). In the study area, fishermen have been selective and are consuming and trading large-sized individuals in a proportion that is different from the size composition reflected in direct captures. This poaching pattern has been maintained for at least the last two decades, and probably for a considerably longer non-monitored period.

There are extensive remote areas where harvesting is absent, and others where there is occasional and or sporadic harvesting, a central feature of a source-sink system of large proportions. In this context, the apparent resilience of the population under study could be due to the replacement of individuals migrating from source areas to the regions where harvesting takes place. However, despite observed differences within some monitored areas, harvested individuals are mainly large-sized adult individuals. In addition, while we anticipated a reduction in the size of the harvested animals over time, we observed a stable pattern both within the first 6-year monitoring period of all harvested places and in the second monitoring period 20 years later. Moreover, we observed the largest animals in 2019.

The animals sampled in Barcelos come from the Negro River and nearby tributaries. Both urban fishermen and those from surrounding riverine settlements sell turtles in town. Data indicate that it is not necessary to go very far from human population centers to capture large adult individuals. Thus, larger animals in Barcelos (a selection of animals for sale in the city) compared to animals in the PNJ (animals intended for consumption and sale) show two factors: firstly, there is a selection for larger animals, which yields more meat and reaches a higher market value; secondly, it is possible for urban fishermen to select larger animals for commercialization, even larger than those of PNJ (a National Park, with restricted access), where we expect a lower capture pressure. On the other hand, it is interesting to note that the animals consumed within the PNJ are larger than those captured for commercialization. Both have a larger size distribution than the animals from experimental fishing, confirming fishermen's selection of larger animals for consumption and sale, but we did not expect that the animals consumed would be larger than those sold within the PNJ. On the other hand, our comparisons also clearly indicate differences

TABLE 2 | Descriptive statistics of the rectilinear carapace length (SCL, mm) of big-headed (*Peltocephalus dumerilianus*) captured experimentally, intended for consumption and commercialization, between 2002 and 2019, in the Rio Negro region, Amazonas, Brazil (SD = standard deviation).

	N	Average	*SD*	Amplitude (minimum-maximum)
1. Comercial	358	343.01	57.29	143.00–482.37
2. Consumption	330	362.14	67.98	146.00–520.00
3. Experimental fishing	312	317.95	65.04	164.00–480.00
Total	1,000	341.51	65.77	143.00–520.00

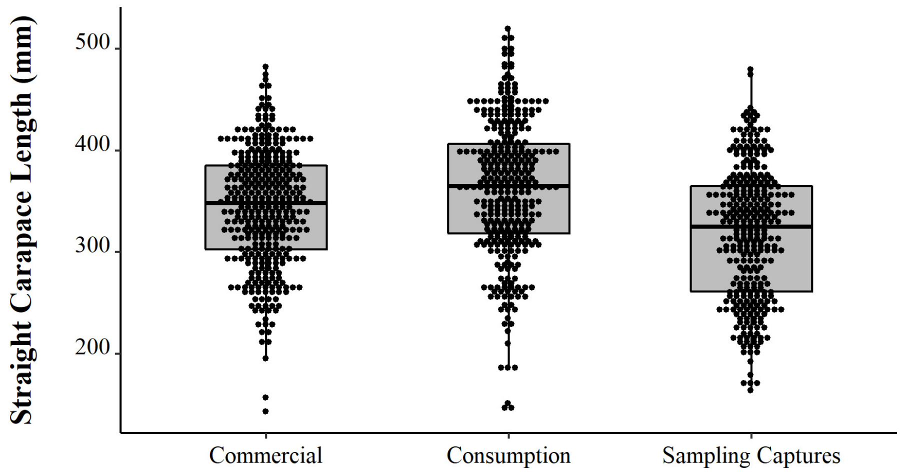

FIGURE 8 | Distributions (points) and descriptive statistics (boxplot) of body size (SCL, mm) of Big-headed (*Peltocephalus dumerilianus*) captured experimentally, intended for consumption, and commercialization, between 1997 and 2002, in the region of the Negro River, Amazonas, Brazil.

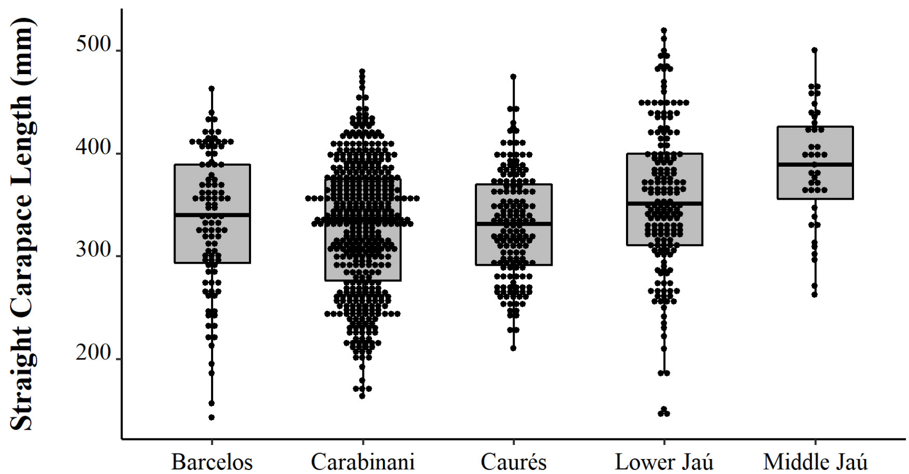

FIGURE 9 | Spatial distribution (points) and descriptive statistics (boxplot) of body size (SCL, mm) of Big-headed (*Peltocephalus dumerilianus*) in different locations of the Negro River region, Amazonas, between 1997 and 2002.

between locations in congruence with our expectations, with smaller animals coming from higher pressure locations, such as Caurés and Barcelos. Considering the predominant absence of any management system nor regular enforcement effort, and the dependence of poor families to wage opportunities and other income sources, an increase in poaching levels is likely to have deeper effects on target populations.

The sex ratio recorded in experimental fishing, without any interference from selection for consumption, sale, or disposal, is the one that tends to better reflect, among the sets of animals considered here, the actual proportion of males and females in the wild. A similar result was observed by De La Ossa and Vogt (2011) in the two rivers near Barcelos. The set of harvested animals over the two periods, 1997–2002 and later in 2019, show a balance between both sexes, with a slight deviation in favor of males. In our sample, among the animals captured and selected by the fishermen for consumption and sale, there is a slight predominance of males, which can be explained by the fact that they are larger in this species. Parra-Henao et al. (2019) observed a strong predominance of males (66.7%) in a tributary of the upper river Orinoco in Colombian territory. However, the sample was small and may not reflect the sex ratio composition in the region. Even though there is a predilection for females for consumption in the region for other Podocnemidids (Pezzuti et al., 2010), the choice is for larger animals, as it is something inherent to the method. When fishing with *baliza*, the fisherman cannot see the animal and does not know the sex of the animal that is eating the bait before harpooning it and bringing it up. The existence of a different mobility pattern between genders, with greater travel distances and living area for females (De La Ossa and Vogt, 2011), may be one of the factors that contribute to the lower

TABLE 3 | Sex ratio of Big-headed individuals (*Peltocephalus dumerilianus*) examined in the Negro River basin, Amazonas, between 1997 and 2019.

	Female		Male		χ^2	p
	N	%	N	%		
Commercial	169	48.42	180	51.58	2.977	0.0971
Consumption	353	54.14	299	45.86		
PARNA Jaú	404	54.01	344	45.99	4.116	0.0505
Barcelos	118	46.64	135	53.36		
Dry season	183	49.59	186	50.41	2.475	0.1342
Rainy season	149	50	149	50		
Sampling captures	204	65.38	108	34.62	33.288	0.0001*
Consumption	149	43.82	191	56.18		
Commercial	169	48.42	180	51.58		

Data from individuals examined between 1997 and 2002.

capture of females, as they move to more isolated points in the flooded forest in search of suitable places for nesting, which occurs in the ebb of the Amazon rivers (Vogt et al., 1994). The findings suggest a tendency to capture the most desired larger male adult individuals, with no observed changes over a 20-year period.

The big-headed is the least studied Podocnemidid, and there is little information about the population structure of these animals. The number of animals measured over this period far exceeds the samples presented in the few studies available. Pritchard and Trebbau (1984) provide biometric data for six individuals from the upper Rio Negro (San Carlos, Venezuela), four individuals from French Guiana, two from the Orinoco, and four from unknown sources. In a sample consisting of 165 individuals from the Itu and Cumicuri rivers, near Barcelos, De La Ossa and Vogt (2011) found an average carapace size of 376.80 and 387.60 mm for males, and 244.80 and 258.50 mm for females, respectively. Males are within our sample size range, but females are considerably smaller. In the small sample of Parra-Henao et al. (2019), the average size is 415.20 mm for males and 287.40 mm for females, which is also within the spectrum of the sample presented here. We certainly have the largest size records of the species, including an individual reaching 520 mm. Parra-Henao et al. (2019) use 260 mm of CRC for the species' minimum sexual maturity size, mentioning Rueda-Almonacid et al. (2007). However, checking the original study, we could not confirm this information. The decision to mention it was due to the importance of this parameter.

Apparently, the pressure on the big-headed has remained, despite significant improvement in infrastructure and staffing, compared to the first period (1997–2001), when monitoring the consumption of turtles in the park was more intense. This is evident in the biometric analysis and observation of more than 90 shells found discarded and not yet decomposed and whole, indicating animals recently consumed. Our experience is that the shells decompose in a few months. According to information and evidence available about the previous period (1997–2002), in addition to new information obtained from the residents and current managers of the PNJ, the big-headeds, the tracajás (*Podocnemis unifilis*), and irapucas (*P. erytrochephala*) continue to be an important component of the traditional diet for riverine residents in the park. These animals are also clandestinely transported and traded outside the protected area. The poaching of river turtles, including big-headeds, prevailed over the 20 years of sampling interval (Fabio Osolins, personal communication).

Thus, observing a larger size structure after the 20-year interval is a positive indication of stability of average animal sizes despite continuous poaching. In the PNJ, as already mentioned, we observed stability and even a slight trend toward an increase in size of the animals consumed. On the other hand, we do not have recent data from the other locations on the Rio Negro obtained in the 1990s and early 2000s. These areas are less protected than the PNJ, and therefore, the pressure of capture may have intensified substantially.

The population of big-headed investigated occupy vast floodplains of the Negro River (Pezzuti, 2003; De La Ossa and Vogt, 2011), which are in an excellent state of conservation (Montero et al., 2014). In Barcelos, there is a huge tangle of river channels, forming the most extensive river archipelago in the world, the Mariuá, and just below the Mariua, there is a large expanse of seasonally flooded Anavilhanas forests (Latrubesse and Stevaux, 2015). In the PNJ, the environments used by animals are also extensive and complex (Ferreira, 1997). The wetlands are capable of harboring large populations of aquatic animals, especially herbivores, such as the big-headed (Perez-Emán and Paolillo, 1997; De La Ossa et al., 2011), whose trophic position at the base of the food chain may also have contributed to the biological success of the species, as well as apparent resilience in the face of the fishing pressure by riverside dwellers. This vastness of well-preserved natural areas and the landscape complexity, with a wide range of niches, may contribute to the findings of the present study.

The capture of adult females during reproduction is considered a critical factor affecting turtle populations worldwide (Klemens, 2000; Moll and Moll, 2004; Roberts, 2010), and population models indicate that conservation efforts should address measures to reduce the mortality of subadult and adult females (Crouse et al., 1987; Heppell, 1998; Crouse, 1999; Mogollones et al., 2010). For Amazonian species, there is abundant historical evidence of the unsustainability and decimation of *Podocnemis* populations, previously quite abundant (Bates, 1864; Silva Coutinho, 1868; Ferreira, 1972; Smith, 1974). Relevant empirical evidence of the effectiveness of protecting adult females came from communal areas along a large stretch of the Juruá River, a major whitewater Amazon tributary. After 40 years of conservation efforts aimed at protecting nesting beaches and surroundings, the population of *P. expansa* showed an 11.4-fold increase in the number of nests in monitored areas, with expressive increase in the number of nests of *P. unifilis* and *P. sextuberculata* as well (Campos-Silva et al., 2017).

Still, it is important to acknowledge that the resource is being used on an open-access basis. As Brazil currently lacks legislation for wildlife management and law enforcement capacity to restrain poaching, the future of this valuable resource is uncertain and deserves attention. No formal or informal rules nor management actions are taking place. Despite Brazil's legal framework recognizing the rights of traditional communities that depend on natural resources, wildlife use is not yet regulated in the country and harvesting practices are considered illegal, except for Indigenous groups within federally demarcated lands. Local families, who have subsisted on fish and game for centuries, when found by command-and-control agents in possession of wild animals or meat, are treated as poachers and subject to fines, forfeiture of materials, or arrest (Antunes et al., 2019). This context is a major bottleneck for management procedures, such as the establishment of quotas, a zoning system, or other participatory processes. In addition, it does not allow for the opportunity of interaction between diverse stakeholders that could otherwise work together toward the construction of species management plans. There are interesting examples community-based initiatives showing recovery of Amazon River turtle populations (Campos-Silva et al., 2017; Pezzuti et al., 2018), which attest to the potential of sustainable management.

CONCLUSION

The size of harvested big-headed turtles in Negro River basin presented a slight trend of increase between 1997 and 2019. Size distribution between directly caught animals differed and were smaller than animals destined for consumption and trade. There were differences between areas possibly subject to different pressure, but all sites were represented by large-sized adults. Fishermen tended to select larger individuals, and to consume and trade a larger proportion of males, which are bigger than females in this species.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The project was submitted and previously approved by the Brazilian Institute of Environment and Natural Renewable Resources/IBAMA.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct, and intellectual contribution to the work, and approved it for publication.

FUNDING

This study was funded by the World Wildlife Fund (WWF, Nature and Society Program). A National Research Council (CNPq) Ph.D. scholarship was granted to JP. Vitoria Amazonica Foundation and Chico Mendes Institute for Biodiversity Conservation (ICMBIO) gave logistical support for the fieldtrips. The Brazilian Institute of Environment and Renewable Natural Resources (IBAMA) authorized this research for the first period, and ICMBIO for the second. The publication fee was provided by the University of Parà (Process No. 23073.017634/2022-67).

ACKNOWLEDGMENTS

We are deeply thankful to Barcelos and Jaú riverine fishermen and their families, whose hospitality and confidence were essential for the data collection.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fevo.2022.640961/full#supplementary-material

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