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Original Research Article

Evaluating the feasibility of pangolin farming and its potential conservation impact

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ABSTRACT

Pangolins are threatened by overexploitation for local and international use. They are subject to an international commercial trade ban, and are also the focus of other interventions, including attempts at commercial captive breeding. The impact that the latter could have on the conservation of wild populations deserves consideration. We critically evaluate the feasibility of commercial captive breeding (or farming) of pangolins to displace wild collection and assess its potential conservation impact on pangolin

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conservation using a recently published framework developed for this purpose. Of the 17 conditions posited that need to be met for supply-side interventions to displace wild collection, we find that pangolins meet a maximum of only six conditions. This analysis suggests that pangolin farming will not displace wild collection in the near future. Major barriers include an inability to breed pangolins on a commercial scale and available data suggest that it would be unprofitable. The immediate impact of pangolin farming on conservation of the species' is unclear, but it is unlikely to benefit the conservation of wild populations. If commercial captive breeding were possible, it is uncertain how it would affect economic incentives for poaching, interactions between legal and illegal markets, stockpile policies, and how consumers and Traditional Chinese Medicine (TCM) practitioners would respond. To understand better the potential overall impact of pangolin farming on wild populations there is a need for further research on these uncertainties. The framework used has utility in analysing the potential impact of wildlife farming but there remains a need for a more robust approach to evaluate potential impacts of supply-side interventions.

1. Introduction

There are eight species of pangolin (Pholidota: Manidae), four native to Asia and four to Africa, all of which are threatened with extinction by overexploitation for local and international use (IUCN, 2018). While pangolins have historically been traded in large volumes, contemporary international pangolin trafficking mainly involves live and dead animals and scales from Africa and Asia and is primarily destined to China and Vietnam (Nijman et al., 2016; Challender and Waterman, 2017). There is a lack of data on wild populations, but the best available evidence indicates that populations have declined severely in recent decades in many parts of Asia (Zhang, 2009; Duckworth et al., 1999) and declines are inferred in Africa (e.g., Pietersen et al., 2016; Waterman et al., 2014a) because of overexploitation. Due to concerns about the impact of international trafficking, all species of pangolin were included in CITES, the Convention on International Trade in Endangered Species of Wild Fauna and Flora, Appendix I at CoP17 in 2016, establishing an international commercial trade ban for wild pangolins and their derivatives.

However, there are doubts about whether an international trade ban will be adequate to ensure the conservation of the species – bans can result in an increase in poaching and trafficking (e.g., black rhinoceros *Diceros bicornis*; Leader-Williams, 2003) – and there is a range of additional interventions that could be adopted. There is a growing literature on policy options for wildlife trade and trafficking, including additional national law enforcement measures, attempts to change consumer behaviour, the substitution of specific products with alternatives (including synthetic substitutes) and other so-called 'supply-side interventions', including domestication and wildlife farming (Biggs et al., 2013; Challender and MacMillan, 2014).

Notwithstanding the opinions of different actors on which options (or combinations thereof) might be most effective for pangolins, in practice different actors are already attempting some, including commercial captive breeding (or farming). We use these terms interchangeably, and define farming as 'the commercial captive production of wild species'. Although characteristically difficult to maintain and breed pangolins in captivity (Hua et al., 2015; Yang et al., 2007), pangolin farming is purportedly receiving significant financial investment (e.g., in China; D. Challender, unpubl. data), and comprises attempts to breed pangolins for their scales, and potentially meat, for consumer markets in Asia. This includes attempts to breed African pangolins, with farms having been established in Mozambique and Uganda (D. Challender, unpubl. data). To the knowledge of the authors, these facilities have been closed by the respective governments, purportedly due in part to concerns about the laundering of wild pangolins and their derivatives as captive-bred. CITES trade data indicate the export of 800 live white-bellied *Phataginus tricuspis*, black-bellied *P. tetradactyla* and giant pangolins *Smutsia gigantea* from Togo and Nigeria to China, Lao PDR and Vietnam between 2012 and 2015 for captive breeding and commercial purposes (Challender and Waterman, 2017).

The impact that commercial captive breeding may have on pangolin conservation deserves careful consideration. Opinions differ on how wildlife farming may affect wild populations. This is partly because there remains limited understanding of the conditions under which farming can aid conservation efforts and supply-side interventions have been implemented and evaluated for only a small number of species, including porcupines (Brooks et al., 2010), bears (Dutton et al., 2011), crocodiles (Hutton and Webb, 2003), lions (Williams and 't Sas-Rolfes, 2019), and a range of plant taxa (Phelps et al., 2014; Williams et al., 2014). The topic is complex and the literature is nascent, but early indications are that many factors require careful consideration and that impacts will differ between species and across geographies (Cooney et al., 2015). Attempts to develop a framework for assessing the possible impact of commercial captive breeding include Biggs et al. (2013) and Tensen (2016). Phelps et al. (2014) developed a supply-side framework in which they conceptualised the factors shaping wildlife harvest and trade and present 17 conditions that they assert shape supply-side interventions and their conservation outcomes. However, this framework has not been tested beyond the orchid trade.

The threats facing pangolins, investment in pangolin farming, and discussion of this issue in policy forums including CITES (see CITES, 2017), makes examination of pangolin farming a timely and policy-relevant case study in terms of furthering understanding of the conditions under which supply-side interventions may support species conservation efforts, or not. In this article, we critically evaluate the feasibility of farming to displace wild collection of pangolins using the framework developed by Phelps et al. (2014) and assess the potential conservation impact of pangolin farming. We draw on published and grey literature on the status of pangolins and their threats, natural history, husbandry and markets for pangolin products as well as literature on supply-side interventions, and evaluate available evidence against each condition. We have opted to use the framework developed by Phelps et al. (2014) because it is the most comprehensive in the published literature.

2. Results: conditions under which farming is likely to displace wild collection

The conditions proposed by Phelps et al. (2014) are included in Table 1 with corresponding justification. A summary of the evidence discussed is also presented as is categorisation of whether the 17 conditions are considered met, or not, or are uncertain for pangolins.

2.1. Biophysical conditions

2.1.1. Wild resource generally scarce

There is a lack of data on pangolin populations globally (Challender and Waterman, 2017). Available evidence indicates that the species are scarce in many parts of their geographic range, or that their status is uncertain (e.g., Baillie et al., 2014; Challender et al., 2014a; Pietersen et al., 2014a; Waterman et al., 2014a; Perera et al., 2017). We consider this condition met in some places, mainly in Asia but also parts of Africa, but otherwise it is uncertain.

There have been severe declines in Chinese pangolin *Manis pentadactyla* populations across most of its range. In China, up to 160,000 pangolins were harvested annually in the 1960–1980s (Zhang, 2009), seemingly culminating in the commercial extinction of the species. Wu et al. (2004) estimated that China's population declined by up to 94% between the 1960s and early 2000s, and the Chinese pangolin is Critically Endangered in China (Jiang et al., 2015). It is rare in Hong Kong (Challender et al., 2014b), extremely rare in Lao PDR and Vietnam (Nooren and Claridge, 2001; Duckworth et al., 1999), and while estimates suggest a population of 5000 animals in Nepal, it is believed to be declining (Jnawali et al., 2011). It is present in Bangladesh, but has reportedly been extirpated from some regions by poaching (Trageser et al., 2017). On Hainan Island, China the species is of very low abundance (Nash et al., 2016), but the nominal subspecies in Taiwan, the Formosan pangolin has recovered from historical reductions in some places (Pei, 2010). The Chinese pangolin is categorised as Critically Endangered on the IUCN Red List of Threatened Species (hereafter 'Red List') due to past and future declines attributable to overexploitation (Challender et al., 2014b).

The other Asian species are scarce in at least part of their range. The Sunda pangolin *Manis javanica* is extremely rare in the north of its range in Cambodia, Thailand, Vietnam, and Lao PDR where unverified reports from villagers in the 1990s suggested populations had declined by up to 99% between the 1960s and 1990s (Duckworth et al., 1999). It is present in Peninsular Malaysia but declining in some areas due to poaching (Chong et al., 2016). The population in Singapore is possibly stable but facing increasing threats from urban development (Lee et al., 2018). The Sunda pangolin continues to be trafficked within and from Indonesia in large numbers (Nijman, 2015; see 2.2.2.). It is categorised as Critically Endangered on the Red List (Challender et al., 2014a).

Little is known about the Philippine pangolin *Manis culionensis*. It is endemic to the Palawan faunal region in the Philippines, and is considered to be rarer in the south of its range (Lagrada et al., 2014). Reports suggest that harvesting the species now requires increased hunting effort, due to population declines from overexploitation (Lagrada et al., 2014). It is listed as Endangered on the Red List (Lagrada et al., 2014).

There is limited information on the status of the Indian pangolin *Manis crassicaudata*, native to South Asia, but there is evidence of population declines and increasing rarity in parts of its range. Irshad et al. (2015) report that in the Potohar Plateau, Pakistan (a large part of the species' range in the country), mean population density declined by 80% between 2010 and 2012 due to targeted poaching for international trafficking (see also Mahmood et al., 2012). The species is widely distributed in India but is subject to poaching and international trafficking (see Mohapatra et al., 2015). Populations are considered to be in decline in Nepal (Jnawali et al., 2011). It is of variable abundance in Sri Lanka, but also suspected to be in decline (Perera et al., 2017). It is categorised as Endangered on the Red List due to past, ongoing and predicted population declines (Baillie et al., 2014).

Less information is available for African pangolins. However, Ingram et al. (2018) estimated annual exploitation for local use in Central Africa to involve 0.4–2.7 million pangolins (with 0.4 million more likely), mainly white-bellied pangolins, suggesting that this species may be relatively common in this region. Yet, all four species, the white-bellied, black-bellied, giant pangolin, and Temminck's ground pangolin *Smutsia temminckii*, are threatened with extinction based on present levels of harvesting, being listed as Vulnerable on the Red List on the basis of inferred past and future population declines because of overexploitation (Pietersen et al., 2014a; Waterman et al., 2014a,b,c). This is due to the impact of hunting (where it is legal) and/or poaching for wild meat and traditional African medicine (TAM) (Anadu et al., 1988; Boakye et al., 2014, 2016; Soewu

Table 1
General conditions that need to be met for supply-side interventions to displace wild-caught collection (taken from Phelps et al., 2014) and whether these conditions are considered to be met, or not, or are uncertain for pangolins.

Condition	Justification[a]	Summary of evidence	Condition met for pangolins?
Biophysical			
Wild resource generally scarce	Rarity means harvest burdens and costs are likely greater, which increases the attractiveness of farming Price is likely to be higher because of rarity or perceived rarity	Pangolins are scarce or increasingly rare in large parts of Asia Scaled hunting data suggests that the white-bellied pangolin may be relatively common in Central Africa, but increasing rarity is inferred from exploitation rates, including for international trafficking Temminck's ground, giant and black-bellied pangolins are naturally rare	Yes/ Uncertain
Target species subject to destructive harvest	Increases the threat of unsustainable harvest, and both depletes the wild resource and increases rarity	Consumptive use necessitates destructive harvest There are no known instances of continuously monitored wild populations with a demonstrated stable or increasing population from which permitted and sustainable harvest may be made	Yes
Access to the wild resource uncertain or irregular	Farming may provide more reliable access and prove more attractive to market participants	Regulation prohibits access in most range states but hunting/poaching, trafficking and illegal sale and consumption of pangolin products demonstrates access to market participants along supply chains Law enforcement activities disrupt trafficking flows and access to market participants may not be guaranteed Increasing scarcity suggests access will become increasingly irregular over time	No
Market			
Targeted species of relatively high-value	Farming needs to be financially attractive	Pangolins hold high financial value along local and international trade chains Retail prices in key consumer markets in Asia appear to be increasing Prices are increasing in parts of Africa	Yes
High demand for the target species	Market size needs to be large enough to make farming economically viable	Substantial demand for consumption of meat and scales exists in Asia, particularly in China and Vietnam, and in Africa, especially in Central and West Africa	Yes
Markets developed and accessible	Producers need to be able to readily access customers	Markets exist in China, Vietnam and elsewhere in Asia; access is typically prohibited by regulation, but some market participants secure access by operating illegally Exceptions include a legal market for scales in China which is restricted through a certification mechanism In Africa, markets exist in most range states but access is typically prohibited by regulation; exceptions include Gabon and Sierra Leone where black- and white-bellied pangolins can be harvested and traded with seasonal restrictions International markets are inaccessible for commercial trade in wild pangolins as all pangolin species are included in CITES Appendix I; these markets are accessible where captive-bred specimens are concerned in accordance with CITES rules	Yes/No
Demand for the target species reliable and not easily saturated	Market fluctuations can limit the financial viability of commercialisation and farming Market saturation can drive down prices and make farming unattractive	Demand appears reliable for meat and scales in key markets in Asia and in Africa Determining market saturation is challenging	Yes
Farmed and wild specimens easily distinguishable in the market place	Consumers and traders must differentiate among types of products, which may require certification	Wild and captive-bred pangolins and their derivatives cannot easily be distinguished China introduced a certification system for scales in 2007 but it is undermined by illegal trade	No
Target species are not easily substituted	If consumers accept substitutes (similar species, synthetic substitute) or are unaware a substitution has occurred, then farming may not be financially viable	There is little empirical research on consumer preferences in Asia, but the various pangolin species appear to be substitutes A range of substitute products exist for scales in TCM and TAM	Uncertain
Farmed specimens available for the same price or cheaper than wild-collected alternatives	Farmed specimens available for the same price or cheaper than wild collected alternatives	There is little available data on farming costs but it is unlikely to be cheaper than wild collection based on known costs of rearing pangolins in captivity with adequate husbandry	No

Table 1 (*continued*)

Condition	Justification[a]	Summary of evidence	Condition met for pangolins?
Farming offers comparable or better profit margins than wild-collected alternatives	Farming needs to be financially competitive with wild harvest	There is little available data on farming costs, but it is unlikely to yield a comparable or better profit margin based on known costs of rearing pangolins in captivity with adequate husbandry	No
Farmed specimens can be produced at a large scale.	Farmed specimens can be produced at a large scale	Pangolins cannot be produced in captivity on a large scale; formulating artificial diets is challenging and costly, pangolins are highly susceptible to stress-induced immune suppression, and there is inadequate knowledge of reproductive biology of most species	No
Quality of farmed specimens good or better than wild-collected specimens	Substitution may depend on ensuring that farmed specimens are of comparable quality or potency	Little available evidence because pangolins have not been bred in captivity on a commercial scale	Uncertain
There is no (or limited) consumer preference for wild specimens	If consumers prefer wild over farmed specimens then these may not be substitutable goods	There is little research on revealed preferences for pangolin products but a preference for wild pangolin meat in Asia has been reported Research suggests a stated preference for wild over alternative medical materials in China (though not specific to pangolins)	No/ Uncertain
Few (or reasonable) barriers to farming	Lower costs of production helps ensure economic viability of farming Reduces time to commercialisation Often includes land-tenure security because farming requires investment and long-term management Facilitates broader participation, including potentially by former harvesters Greater effort (e.g., for difficult-to-farm species) may be justified for high-value products	Barriers include an inability to readily breed pangolins on a commercial scale and legislation preventing market access in most range and consumer states	No
Regulatory			
Target species subject to harvest or trade restrictions that are well enforced.	Increases detection and burdens of illegal activity, pushing wild-harvesters out of the market or creating greater incentives for farming; may not be possible in low-governance environments and may create incentives for black-market trade and corruption	Harvest and trade restrictions are generally not well enforced in range states in Asia and Africa China's certification system for scales is undermined by illegal trade	No
Farming establishments are adequately monitored	Reduces laundering of wild specimens via wildlife farming	It is impossible to rule out adequate monitoring but problems are reported with farms in countries where pangolin farming is being, or may be being attempted	Uncertain

[a] Taken from Phelps et al. (2014).

and Sodeinde, 2015) and the potential impact of international trafficking of African pangolin scales to Asian markets (Challender and Waterman, 2017; Heinrich et al., 2017). There are no estimates of tropical African pangolin populations. Akpona et al. (2008) estimated that white-bellied pangolins in Benin occur at a density of 0.84 individuals/km^2 in remnant natural forest. Temminck's ground pangolin, which occurs in East and Southern Africa is naturally scarce, occurring at estimated densities of 0.11–0.22 individuals/km^2 in Southern Africa (Heath and Coulson, 1997; Pietersen et al., 2014b). The population of mature individuals in South Africa is estimated at 16,000–24,000 animals (Pietersen et al., 2016). There is little knowledge of the abundance of the giant and black-bellied pangolin, but they are understood to be rare (Waterman et al., 2014a, c).

2.1.2. Target species subject to destructive harvest

Pangolins are targeted for local consumption and use in traditional medicines, which includes a range of body parts (e.g., scales, blood, viscera) across their ranges (e.g., Boakye et al., 2014; Mohapatra et al., 2015). International trafficking involves mainly live and dead animals and scales (Challender and Waterman, 2017; Nijman et al., 2016). We consider this condition met because most consumptive use necessitates destructive harvest and to the best knowledge of the authors, there are no wild populations that are continuously monitored and are demonstrably stable or increasing such that permitted and sustainable harvest may be made.

2.1.3. Access to the wild resource uncertain or irregular

If access to wild pangolins is uncertain or irregular, farming may provide access that is more reliable. This does not appear to be the case for pangolins because despite regulatory barriers, market participants along supply chains are able to access wild pangolins, though this may be interrupted by law enforcement efforts (e.g., seizures).

Access to natural resources is typically governed by regulation (e.g., national laws), but it is also influenced by factors such as ease of access and socio-economic and cultural drivers (e.g., the needs of local people to hunt for food and generate income; Roe et al., 2002). Pangolins are protected by law in virtually all range states, which typically prohibits exploitation, including hunting and trade (IUCN SSC Pangolin Specialist Group, 2016). Exceptions include Burundi and Equatorial Guinea where there is no legislation protecting the species, and Gabon and Sierra Leone, where hunting and trade of the black- and white-bellied pangolins is permitted, but restricted by season. Access to wild pangolins for international commercial trade is prohibited as all eight species are included in CITES Appendix I.

Despite regulatory barriers, hunting (where legal), poaching, and trafficking of commercial shipments of pangolins and their parts, and the illegal sale and consumption thereof indicates access to market participants along supply chains. This is evidenced by the presence of pangolins in wild meat and *muthi* (traditional medicine in Southern Africa) markets in sub-Saharan Africa (Boakye et al., 2014, 2016), in markets in Asia (Nijman et al., 2016; Xu et al., 2016), and seizures (Challender et al., 2015). However, seizures interrupt trafficking flows suggesting that access to all market participants is not guaranteed. The increasing scarcity of pangolins in parts of their range (see 2.1.1.) suggests that access will become increasingly irregular or limited in the future.

Various pangolin range states in Africa and Asia have stockpiles, primarily of scales (see Challender and Waterman, 2017), which if procurable by market participants and sold legally, would increase certainty of access until a point of depletion. However, with the exception of China (see 2.2.2.) access to such stockpiles is uncertain and currently under discussion in CITES (CITES, 2017), while the existence of stockpiles in some range states is uncertain.

2.2. Market conditions

2.2.1. Targeted species of relatively high-value

Pangolins hold a high financial value along local and international trade and trafficking chains. They are among the most highly valued species in African wild meat markets (Mambeya et al., 2018), in illicit trade in southern Africa (Challender and Hywood, 2012) and in key consumer markets in Asia (Nijman et al., 2016; Xu et al., 2016). Although prices vary geographically, scales can sell for USD 200 kg^{-1} in *muthi* markets in South Africa (D. Pietersen, unpubl. data) and individual animals can sell for up to USD 1500 in Namibia (B. Nebe, unpubl. data). Prices are also increasing in parts of Africa, in rural and urban areas (e.g., Gabon; Mambeya et al., 2018). In China and Vietnam, evidence suggests that retail prices of meat and scales have increased substantially in the last decade: in China retail prices for meat and scales in 2013 were USD 300 kg^{-1} and approximately USD 800 kg^{-1} respectively (Challender et al., 2015; Xu et al., 2016). The value of pangolin products is also high relative to other goods, at least in some instances. Research in Vietnam in 2013 determined that pangolin meat was the most expensive wild meat available in the majority of restaurants frequented in Ho Chi Minh City (Challender et al., 2015).

2.2.2. High demand for the target species

Pangolins and their derivatives can be considered to be in substantial demand in Asia and Africa, though the clandestine nature of trafficking makes accurately estimating market size difficult. In China, scales are used as an ingredient in traditional Chinese medicine (TCM) to purportedly help lactating women secrete milk, and to improve blood circulation and cure skin diseases (Chinese Pharmacopeia Commission, 2015). They are also used to treat syndromes associated with breast cancer and lymphoma (Yu and Hong, 2016). There is a sizeable legal market for scales in China. Since 2009, an average of 26.6 tonnes of scales certified under a government certification system have been released onto a legal market annually from government stockpiles (China Biodiversity Conservation and Green Development Foundation, 2016). This equates to scales from an estimated 72,000 Sunda pangolins (see Challender and Waterman, 2017 for conversion methods). However, it seems reasonable to assume that the quantity of scales purchased annually in China is larger than the government quota, based on uncertified scales being widely available in retail outlets, albeit illegally (Xu et al., 2016). The situation is similar in Vietnam where scales are sold illegally and are widely available (Challender et al., 2015). Scales are also regularly available in Southeast Asian countries that have markets catering to Chinese clientele, including Lao PDR and Myanmar (Krishnasamy et al., 2018; Nijman et al., 2016). In other parts of Asia, scales are used at a local (i.e. household and village) level but quantifying demand across the region is challenging.

Demand for pangolin meat appears substantial in Asia, particularly in China and Vietnam. Evidence suggests that it is consumed by affluent consumers, either within kin or peer-groups, by business elites, and by government officials in high-end urban restaurants (Shairp et al., 2016; Zhang and Yin, 2014; Wu and Ma, 2007). There are reports, but less evidence, of meat consumption in other urban metropolises, e.g., in Thailand and Malaysia (Geraldine, 2017). Although not an indicator of demand, Challender et al. (2015) estimated that in the period 2000–2013 up to 130,000 seized pangolins, either live, dead or de-scaled and eviscerated, were likely destined for meat consumption in Asian markets, equating to ~9000 animals/year. Beyond urban centres, pangolins are still consumed as a protein source by local communities, indigenous peoples and plantation workers (e.g., in Indonesia and Malaysia; Azhar et al., 2013). However, there is evidence in parts of Asia (e.g. Indonesia, Malaysia and Vietnam) that local consumption is foregone in favour of selling pangolins to trafficking networks because of the high prices that they fetch (MacMillan and Nguyen, 2014; Nuwer and Bell, 2014; G. Semiadi, unpubl. data).

Pangolins remain in substantial demand in parts of Africa for wild meat and traditional medicine (Baiyewu et al., 2018; Boakye et al., 2014, 2016), and African pangolin scales are in demand in Asia. Pangolin meat and scales have been consumed historically across Africa, which continues today, especially in West and Central Africa (Anadu et al., 1988; Angelici et al., 1999; Boakye et al., 2014, 2016; Fa et al., 2006: see 2.1.1.). Although not evident until around 2008 (see Challender and Hywood, 2012), the apparent increase in seizures and volumes of African pangolin scales being trafficked to Asia (Ingram et al., 2019; Heinrich et al., 2017) suggests there is substantial demand for African pangolin scales in Asian markets, which appear to be substitutes. This follows declines in Asian pangolin populations (see 2.1.1.), but is likely facilitated in part by increasing economic ties between many African countries and China (Wang and Bio-tchané, 2008).

2.2.3. Markets developed and accessible

For farming to displace wild collection, Phelps et al. (2014) assert that markets need to be developed and accessible so that farmers can access consumers. In Asia, sizeable markets for pangolin products exist in China and Vietnam, and elsewhere (see 2.2.2.). These markets are currently inaccessible in theory due to regulatory barriers prohibiting the use of wild pangolins (see 2.1.3.). However, they are evidently accessible to market actors operating illegally as demonstrated by ongoing trafficking and sale of pangolin products (Heinrich et al., 2017; Xu et al., 2016).

An exception is China where a legal market exists for scales (see 2.2.2.) but access is restricted by regulation. The manufacture of medicines containing scales, and retail of such medicines and scales from Chinese government stockpiles is restricted by a certification system designed to preclude wild-caught Chinese pangolins from entering trade and to ensure that only certified scales are distributed. Certification includes the use of stickers on packaging containing scales and medicines containing scales. Use of certified scales is restricted to clinical use in 716 designated hospitals, and ~200 pharmaceutical companies have licenses to produce patented Chinese medicines containing scales (China Biodiversity Conservation and Green Development Foundation, 2016). However, market participants operating illegally have access to this market and uncertified scales are widely available in pharmacies, traditional medicines shops and unlicensed hospitals in China (Xu et al., 2016; Wu and Ma, 2007).

A similar situation occurs in Vietnam. Despite markets existing for pangolin meat and scales, in principle they are inaccessible due to regulations prohibiting the use of pangolin products (Decree 06/2019/ND-CP). However, despite no legal source of pangolins for commercial use in Vietnam (see Challender and Waterman, 2017), market participants operating illegally evidently access markets and pangolin products remain widely available (Challender et al., 2015; Shairp et al., 2016).

In Africa, domestic markets for pangolin meat and/or other body parts for traditional medicines exist in most range states (Soewu and Adekanola, 2011; Soewu and Sodeinde, 2015). Regulation presents a barrier to access in most countries (see 2.1.3.), but as in Asia, market participants operate illegally, and pangolins are poached, trafficked and sold in many countries (e.g., Boakye et al., 2014, 2016). In Gabon and Sierra Leone, markets are accessible because hunting and trade in black- and white-bellied pangolins is permissible in certain seasons.

Access to international markets for wild pangolins traded commercially is prohibited as pangolins are included in CITES Appendix I. International trade is plausible within CITES rules, i.e., in accordance with Articles III, VI, and VII of the Convention and associated resolutions. Currently, there are no registered captive breeding operations with the CITES Secretariat for pangolins in accordance with Res. Conf. 12.10 (Rev. CoP15).

2.2.4. Demand for the target species reliable and not easily saturated

Demand for pangolin products appears reliable in key markets in Asia and Africa (see 2.2.2.), but assessing market saturation is difficult due to the clandestine nature of trafficking and consumption occurring on a large geographic scale. In China, newly affluent and younger consumers reportedly contribute towards market growth for medicines that include pangolin derivatives (China Biodiversity Conservation and Green Development Foundation, 2016). The promotion of TCM by the Chinese government, including the enactment of a law in 2017 requiring local governments to open TCM departments in all general hospitals, and the positioning of TCM as a source of economic growth in China (The Economist, 2017), suggests that demand for scales could increase in the future. Less information is available on demand for meat but it appears persistent (at least based on trafficking dynamics) and has taken place over the last 30 years (Wu and Ma, 2007).

Demand for pangolin parts and derivatives appears reliable in Africa. In Central Africa, between 1975 and 2014 the proportion of pangolins expressed as a proportion of all vertebrates hunted increased from 0.04% to 1.83% (Ingram et al., 2018). Pangolin meat is also one of the most sought-after in Central and West Africa, fetching some of the highest prices of bush meats (Mambeya et al., 2018; Willcox and Nambu, 2007). Factors including unsuccessful livestock farming in this region, combined with perceptions of bush meat as healthy (van Vliet and Mbazza, 2011), means that hunting of local fauna, including pangolins, to meet local protein needs is expected to increase as the human population grows. Pangolins feature prominently in medicines of numerous cultures in Africa and there is little expectation that this will decrease or cease in the near future (Boakye et al., 2014, 2016; Soewu and Adekanola, 2011). In southern Africa, Temminck's ground pangolin continues to be harvested for trade in *muthi* markets (Pietersen et al., 2014a) and use by rural communities (Baiyewu et al., 2018).

2.2.5. Farmed and wild specimens easily distinguishable in the market place

For farming to displace wild collection of pangolins, farmed and wild derivatives ought to be distinguishable to market actors (e.g., producers, processors, and retailers) (Belcher and Schreckenberg, 2007). This would be necessary to ensure traceability in supply chains and to prevent wild products being 'laundered' as captive-bred (Fischer, 2004). Wild and captive-

bred pangolins and their derivatives, including scales, cannot be distinguished based on morphological characteristics alone. With the exception of China's certification system – but which is undermined by illegal trade (see 2.2.3.) – there are no established systems for differentiating between wild and captive-bred pangolins or their parts. Under a scenario where pangolin farming were feasible, additional certification systems would need to be devised for other markets and products to avoid laundering, and such systems would need to be effectively implemented and enforced.

2.2.6. Target species are not easily substituted

Farming may not be financially viable if consumers, and TCM practitioners, are willing to accept substitutes for pangolin products. This is uncertain and there is a lack of empirical research on consumer preferences (e.g., for wild vs. farmed pangolin products) in China, Vietnam and other markets for scales, and the extent to which substitutes would be accepted. Evidence suggests that consumers and practitioners do not have fidelity to scales from particular pangolin species. The official pharmacopeia in China and Vietnam prescribe scales from the Chinese pangolin only, but research suggests that Sunda pangolin scales are used in the manufacture of medicines in China, and potentially African pangolins (Liu et al., 2015). The import of large quantities of African pangolin scales by TCM companies in China in recent years (Heinrich et al., 2016) and the trafficking of large volumes of these scales supports this assertion.

Several substitutes exist for pangolin scales. Research in the 1990s recommended dried seeds of the cowherb plant *Vaccaria segetalis* ('Wang bu liu xing') and reported the same level of purported medical efficacy as scales (Wang, 2008). Hsieh (2005) compared pangolin scales and cowherb seeds on lactation performance, immuno-modulation and anti-tumor effects in rats, and reported that the latter performed equally or better than pangolin scales. Domestic pig (*Sus scrofa domesticus*) hooves have also been proposed and Hou et al. (2000) report greater efficacy of pangolin scales compared to pig hooves in increasing the weight of juvenile mice, as a proxy for milk production. Luo et al. (2011) reported that purported antithrombotic and anticoagulation effects of scales could be achieved using horns of Cervidae and Bovidae species. Bensky et al. (2004) recognised the thorns of Chinese honey locust *Gleditsia sinensis* ('Zao Jiao Ci') and cockleshells ('Wa Leng Zi') as substitutes. Notwithstanding these potential alternatives, there is a need for research on whether these and other substitutes would be acceptable to consumers and TCM practitioners. Research in the 1990s revealed that despite agreement with a ban on the use of scales in TCM by doctors in Taiwan, the deep-rooted nature of TCM meant that they had reservations about the effectiveness and use of substitutes (Wang, 2008).

Empirical evidence is limited but the different species of pangolin appear to be meat substitutes based on observed trafficking dynamics. For example, descaled and eviscerated Sunda pangolins have been trafficked in large quantities from Southeast Asia to China (Challender et al., 2015; Nijman, 2015), where historically Chinese pangolins were consumed (Zhang, 2009). The substitutability of pangolin meat with other products is uncertain. Research suggests that urban consumption of pangolin meat in Asia is associated with luxury, illegality (purchasing a product traded illegally), rarity and reinforcement of social status (Shairp et al., 2016; see 2.2.2.) and any substitute would likely need to provide similar benefits to consumers.

There are few studies on substitution of pangolin products in Africa. Soewu and Adekanola (2011) document substitutes for certain uses (e.g., pythons are a substitute for pangolin scales in medicines treating rheumatism). In many African range states, pangolin meat is consumed daily at a household or village level to meet protein needs (Boakye et al., 2016), though there are reports of an emerging luxury, urban demand for pangolins among Asian migrants in parts of Africa (e.g., Uganda; Anon, unpubl. data) which may alter future demand characteristics.

2.2.7. Farmed specimens available for the same price or cheaper than wild-collected alternatives and farming offers comparable or better profit margins than do wild-collected alternatives

There is little publicly available information or data on the number of farms or number of pangolins within farms where they are known to exist (e.g., China), and little associated information exists on protocols, costs or welfare standards. In other institutions globally (e.g., zoos), maintaining pangolins in captivity with high standards of welfare and veterinary care is generally costly suggesting that farming pangolins will be more expensive, and produce lower profit margins (if profitable) than collection from the wild. Although high welfare standards may not necessarily apply to animals being farmed, meaning cost estimates of zoo operations may be inflated, this approach has utility in recognising that high welfare standards for pangolins are needed, given difficulties associated with maintaining the animals in captivity (see 2.2.8).

The estimated cost of rearing a single Sunda pangolin at Singapore Zoo is USD 7000/year, including daily husbandry, food and veterinary care. The initial cost of housing construction is USD ~7500 per animal, discounting the cost of relevant research (e.g., into enclosure design) prior to housing construction. Comparable costs of rearing and enclosure construction for an Indian pangolin at Nandankanan Zoo, India are USD 3000/year and USD 6500 respectively (Table 2). Excluding housing construction costs, assuming a farmed male Sunda pangolin could reach full adult weight (~7.5 kg) within four years (a generous growth estimate) and that the meat and scales of the animal were sold in China, this would generate a return of USD 2850, but result in a loss of USD 25,150 (Table 2). This would be even higher when taking a discount factor (the opportunity cost of forgone interest) into account. Using the same scenario for an Indian pangolin (adult weight = ~10 kg) would generate USD 4530, but result in an undiscounted loss of USD 16,470 (Table 2). These losses would be even higher due to likely unsuccessful captive breeding attempts and high rates of juvenile mortality (see 2.2.8.) resulting in higher production costs per unit (animal).

In contrast, poaching wild pangolins and transporting them to end markets is seemingly less costly. This is especially likely where the rural poor undertake poaching because they may have few income opportunities, may be self-employed and

Table 2
Indicative costs of rearing a Sunda (*Manis javanica*) and Indian pangolin (*Manis crassicaudata*) in captivity, estimated total retail value in China, and estimated profit. All costs and prices are in USD and total cost and profit estimates ignore the effect of discounting over time.

Institution	Species	Husbandry cost (rearing/year)	Period of care (years)	Total rearing cost	Adult weight (kg)	Weight of scales (kg)	Retail price of scales/kg[a]	Retail price of meat/kg[a]	Total retail value: meat + scales	Profit[b]
Singapore Zoo, Singapore	Sunda pangolin	7000[c]	4	28,000	7.5	0.36[d]	750	300	7 kg x 300/kg + 0.5 kg x 750/kg = 2850	−25,150
Nandankanan Zoo, India	Indian pangolin	3000[c]	7	21,000	10	3.4[e]	750	300	6.6 kg x 300/ kg + 3.4 kg x 750/ kg = 4530	−16,470

[a] Based on Challender et al. (2015).
[b] Based on subtracting total retail value from total rearing cost, but excludes processing and transport costs.
[c] Includes daily husbandry, food and veterinary services. Housing construction costs an additional USD ~7500 (Singapore Zoo) and USD 6500 (Nandankanan Zoo).
[d] Based on Zhou et al. (2012).
[e] Based on Mohapatra et al. (2015).

opportunity costs are low. Costs will also be comparably low where pangolins are more common (e.g., parts of West and Central Africa), because less time is required to find and poach the animals. It can take poachers only a few hours to find one or more pangolins in parts of West and Central Africa (D. Pietersen, pers. obs.). Yet, poachers and traffickers face the risk of being caught and associated penalties. Interactions between economic incentives for poaching and law enforcement have not been modelled for pangolins specifically, but will likely differ depending on property rights and associated enforcement strategies and effort, and thereby probability of detection, and the organisational structure of illegal supply (e.g., individuals vs. gangs; Milner-Gulland and Leader-Williams, 1992). Penalties in most pangolin range states include a prison sentence (ranging from 14 days to 30 years) and a fine (range = USD 6–760,000) though there are notable challenges to effective law enforcement (see Challender and Waterman, 2017 and 2.3.1.).

Other costs include equipment (e.g., snares) and transport, both of which are relatively low. Local transport costs are low where poachers make use of motorcycles or boats to access pangolin habitat, even in remote locations. International shipping is also inexpensive. It costs less than USD 5000 to transport a 20-foot container by sea from Lomé, Togo to southern China, with costs for part of a container proportionally less (World Freight Rates, 2019). African pangolin scales are typically trafficked to Asia using this method. On this evidence, the unit cost of producing a single pangolin or quantity of scales and/or transporting it to end markets, locally, nationally or internationally, will likely be cheaper for wild pangolins, while unsubsidised farming would be unprofitable (Table 2).

2.2.8. Farmed specimens can be produced at a large scale

For farming to substantially displace wild collection of pangolins, farmed animals need to be produced on a large scale. This is not currently feasible. Pangolins are difficult to maintain and challenging to breed in captivity. Most attempts at maintaining the animals in captivity have failed, and recent attempts to do so have resulted in most animals dying in less than two years (Hua et al., 2015), though there are exceptions – an Indian pangolin lived to 19 years in captivity (Weigl, 2005). Difficulties identified include providing an adequate diet, high susceptibility to stress-induced immune suppression, and lack of knowledge of reproductive biology, especially of female reproductive cycles and weaning (Cen et al., 2010; Yang et al., 2007).

Replicating natural diets has proven difficult and expensive. A few well-resourced institutions have been successful in maintaining and breeding small numbers of Chinese and Sunda pangolins on artificial diets (Cabana et al., 2017). However, problems remain with adapting animals to these diets, and malnutrition and associated stress are major impediments to successfully maintaining pangolins in captivity (Yang et al., 2007). Pangolins also have high disease prevalence; common diseases and causes of death in captivity are gastrointestinal diseases, including haemorrhagic ulcers related to diet and stress, pneumonia, skin diseases and parasites (Khatri-Chhetri et al., 2016; Clark et al., 2009). They also require suitable and stable temperatures and humidity due to poor temperature self-regulation (Pietersen, 2013): if inappropriate, this can lead to stress, immune suppression and death.

There is a poor understanding of reproductive biology for most pangolin species (Hua et al., 2015). Reported and plausible gestation periods vary from 140 to 372 days (Yang et al., 2007; Chin et al., 2012) and one offspring is typically born at parturition. Research suggests that some species have specific breeding seasons (e.g., Chinese) but others do not (e.g., Sunda) and may breed all year round (Zhang et al., 2015, 2016). Long gestation periods and observations of Temminck's ground pangolin suggest it may only reproduce every second year (see Pietersen et al., 2016), limiting productivity if this species were to be bred in captivity. There is limited evidence of successful captive breeding to the second generation (Hua et al., 2015; Zhang et al., 2015, 2016).

2.2.9. Quality of farmed specimens as good as or better than wild-collected specimens

To ensure substitutability between wild and farmed pangolins, specimens would need to be of comparable, or better, quality. Making this comparison is difficult because to the knowledge of the authors, pangolins have not been bred on a commercial scale.

2.2.10. There is no (or limited) consumer preference for wild specimens

There is no research on revealed preferences for pangolin products among consumers. Existing research in China and Vietnam has suggested a potential preference for wild pangolin meat, linked to attributes including status, rarity and high price (Shairp et al., 2016; Drury, 2009), and that pangolin meat is a luxury commodity; thus farmed meat may not be a full substitute. The lack of research applies to pangolin scales and medicines including pangolin scales. However, while recognising heterogeneity in markets for different wildlife products, Liu et al. (2016) found that consumers in China have a stated preference for medicinal products sourced from the wild and used in TCM over alternatives, including farm-sourced materials, due to perceived greater efficacy, which may apply to pangolin scales and associated products.

There is little relevant research on African pangolins because consumption involves wild animals (e.g., Boakye et al., 2016), and there is no reason at present to believe that there would be a preference for farmed pangolins in Africa.

2.2.11. Few (or reasonable) barriers to farming

Barriers to farming may prevent it being viable. Barriers include an inability to maintain pangolins in captivity and readily breed second-generation animals (see 2.2.8.), and market access in most range states, which is prohibited by legislation.

2.3. Regulatory conditions

2.3.1. Target species subject to harvest or trade restrictions that are well enforced

Harvest and trade controls exist in almost all pangolin range states (see 2.1.3.) and virtually all range and consumer states are Parties to CITES. These controls are not well enforced by many (if not, most) range states (Challender and Waterman, 2017) and China's certification system for scales is undermined by illegal trade (Xu et al., 2016). Globally, seizures involving pangolins over the past two decades demonstrate pervasive illegal trade, increasingly involving African pangolins (Heinrich et al., 2017). Identified enforcement challenges in pangolin range and consumer states include a lack of equipment and resources, and capacity among enforcement agencies and personnel (Challender and Waterman, 2017). Poorly resourced enforcement agencies are up against well-resourced and organised criminal networks which traffic pangolins and their parts and which possess the knowledge to avoid detection and alter trafficking routes (Heinrich et al., 2017). Corruption is also a problem (Wyatt et al., 2017) and trafficking networks have the ability to bribe officials undermining harvest and trade controls and the rule of law (Felbab-Brown, 2018).

2.3.2. Farming establishments are adequately monitored

Adequate monitoring of commercial captive breeding facilities (farms) is necessary to prevent laundering, and generic guidance exists for this purpose (Lyons et al., 2016). In pangolin range states where farming is or may be attempted, farms would, therefore, need to be monitored appropriately. This includes China where media reports indicate that seized pangolins may be sold as stock to pangolin farms (Liang, 2017). Monitoring and laundering problems have been reported for other species in relevant jurisdictions (e.g., porcupines in Vietnam; Brooks et al., 2010). It is impossible to rule out adequate monitoring, but examples of laundering (e.g., Brooks et al., 2010), and the undermining of government monitoring (e.g., by extortion and weak systems) in a range of sectors in Asia (Wyatt et al., 2017), combined with organised criminality and corruption associated with pangolin trafficking suggest that inadequate monitoring of pangolins farms is possible (see CITES, 2017).

3. Discussion

3.1. Feasibility of pangolin farming to displace wild collection and potential conservation impact

Application of Phelps et al.'s (2014) framework to pangolins indicates that the species unambiguously only meet between four and six of the 17 conditions (Table 1), suggesting that farming is very unlikely to displace wild collection in the near future and is unlikely to have a positive impact on pangolin conservation. Pangolins are subject to destructive harvest which seemingly increases the threat of unsustainable harvest and the rarity of the species, and thereby the attractiveness of farming. Declines in populations of Asian pangolins have been documented (Zhang, 2009), demonstrating the impact of overexploitation, and current offtake for local use and international trafficking may be unsustainable in many places, including in Africa, based on harvest rates and the species' life histories. This scarcity includes China where pangolin populations have declined severely and commercial captive breeding is being attempted. The same applies to Lao PDR and Vietnam though there is less certainty over attempts to farm the species in these countries. Pangolin farming may be attractive in China under an assumption that it will prove cheaper and more reliable than sourcing wild animals in the long-

term, further assuming that challenges to commercial breeding could be overcome, especially following the prohibition on international commercial trade under CITES. Farming may also be attractive because pangolins hold high financial value and there is ostensibly substantial demand in key markets. It is possible that scales from captive-bred pangolins could be included in the Chinese government's certification system in the future under a hypothetical scenario where commercial breeding was feasible.

Pangolins did not meet nine conditions. Despite the scarcity of the species in some parts of their ranges and legislation typically prohibiting exploitation and trade, market actors along international supply chains are demonstrably able to obtain pangolins and their parts and thereby gain market access, albeit illegally (Boakye et al., 2016; Xu et al., 2016). Thus, market access is not sufficiently irregular that market participants cannot access pangolin products, though reliability of access likely differs among actors and within and between range states and consumer markets. There is a lack of research on poaching incentives for pangolins, but the fact that wild animals can be sourced in places suggests that poaching from the wild would likely continue even in the advent of successful farming – and possibly at unsustainable levels. This is because of the high financial value of the animals, generally poor enforcement of harvest controls, and because of substantial demand and a potential preference from consumers and TCM practitioners for wild-sourced derivatives (Liu et al., 2016).

Critically, there are barriers to farming. They include the inability to readily breed pangolins in captivity on a commercial scale due to dietary problems and associated stress-induced immune suppression, and an inadequate understanding of pangolin reproductive biology for most species. Legislation in most range states and consumer markets also prohibits the trade in pangolins. Moreover, available evidence indicates that where pangolins are maintained in captivity and bred in small numbers, the cost of rearing is high. Although data are not available from reported commercial breeding facilities in China, current indicative comparison of available rearing costs and costs of sourcing wild animals suggests that it is likely cheaper to source wild pangolins and transport them to local, national or international markets.

Further, it is not possible to distinguish between wild-sourced and captive-bred pangolin derivatives based on morphology, and under a scenario where commercial breeding of pangolins were possible, any future farming efforts would need to be accompanied by well-implemented certification and traceability systems; however, it is uncertain whether monitoring would be adequate. This is analogous to the current situation in China, but where illegal trade undermines the certification system. Evidence from commercial captive breeding of other species suggests that any such system has the potential to be undermined by laundering (Brooks et al., 2010). More broadly, harvest and trade controls are generally not well enforced in pangolin range states and key consumer markets, and could therefore be undermined by criminal networks and corrupt officials engaged in poaching, trafficking and laundering of pangolin derivatives.

There is also uncertainty regarding whether pangolins meet a number of key conditions. These include whether pangolin products are easily substitutable. Despite a range of potential substitutes for scales, there is little empirical research on consumer preferences, and the same applies to meat. Similarly, it is uncertain to what extent consumers and TCM practitioners would accept pangolin products (especially scales) from commercially captive-bred animals. On the contrary, evidence suggests that there may be a preference for wild pangolin products. This implies that farmed pangolin products may not always act as satisfactory substitutes and there is a need for further research on consumer preferences.

The inadequate number of specific conditions met in Phelps et al. (2014) supply-side framework suggest that farming is very unlikely to meaningfully displace wild collection of pangolins in the near future. The immediate conservation impact of pangolin farming on wild populations is unclear, but is dependent in part on the scale and geographic location of farms, for which there is little available information beyond farms that exist in China and potentially in Lao PDR and Vietnam. It is plausible that commercial captive breeding facilities are affecting pangolins in a number of ways. This includes the possibility that wild pangolins are being sourced to stock farms legally (i.e. within CITES rules – see Introduction) or illegally, which could be incentivising hunting or poaching, contributing to potentially unsustainable harvest. It is also possible that farming enterprises are acquiring trafficked scales in speculation that they may be able to sell (or launder) them in the future, which could be incentivising poaching and trafficking.

3.2. What if pangolin farming was commercially feasible?

Notwithstanding this evaluation, there is much uncertainty about what may happen in the future. Investors in pangolin farming are seeking to overcome current barriers to captive breeding to ensure that future commercial production is possible. This likely includes the use of technology and innovative methods that could change the economic competitiveness of farming. Were these barriers overcome it would be expected that commercial breeders would seek to scale up operations and lower the marginal costs of production (which would differ between producers) as much as possible, and which, at least in theory, could result in pangolin farming being profitable. If this was the case, it is uncertain what impact it would have. It would be dependent on the scale and location of farms as well as economic incentives for wild harvesting and how legal and illegal markets for pangolin products would interact and compete (e.g., through price vs. through quantity; Bulte and Damania, 2005). It is not known how farming would affect current stockpile policies either, most notably in China but also elsewhere, but which could have implications for the competitiveness of farming and wild harvesting ('t Sas-Rolfes et al., 2014). Unless well-implemented and enforced certification systems were established, or existing systems improved, the advent of farming would complicate law enforcement efforts and there is a risk that laundering would occur.

Theoretically, the introduction of farmed pangolin products could exert a downward pressure on prices for wild scales and meat, if farmed products were considered substitutes by consumers and TCM practitioners, and ultimately lead to less

poaching (Challender and MacMillan, 2014). However, this is uncertain and it would depend, in part, on how consumers respond. Some consumers may prefer wild products (Liu et al., 2016) and thereby reject farmed products, resulting in parallel markets, with consumers willing to pay a premium price for wild products. Regarding scales, TCM practitioners mediate supply and demand in some cases and it is uncertain how they would respond to farmed products. There was a reluctance among TCM practitioners to use substitutes due to concerns over their efficacy in Taiwan in the 1990s (Wang, 2008) and there is thus a need for research on potential responses. Other uncertainties include whether farming would de-stigmatize the consumption of pangolin products more broadly, and lead to an increase in demand for wild-harvested meat and/or scales (Fischer, 2004).

To the knowledge of the authors, attempts to farm pangolins are currently only taking place in Asia. However, farms have previously been established in Mozambique and Uganda and the potential re-establishment of farms in Africa warrants consideration. The above uncertainties apply to Africa as well as Asia, including the potential impact of consumer preferences for wild vs. farmed products. This is important in the context of population growth in parts of Africa, which could result in increased demand for pangolins. There is also demand, and some potential preference, for pangolins from Asian migrant workers in various parts of Africa (e.g., Gabon; Mambeya et al., 2018) and there are reports of developing luxury markets for bush meat, including pangolins, in different parts of Africa (e.g., Uganda; Anon, pers. comm.). With increasing Chinese investment in Africa (Wang and Bio-tchané, 2008) and construction of China's Belt and Road Initiative (BRI) in different parts of the continent, which includes the promotion of TCM, demand for pangolins could increase. With the exception of Mambeya et al. (2018), there is little empirical research on such markets, associated demand or consumer preferences.

To understand better the potential overall impact of commercial pangolin farming there is a need for further research. This includes understanding economic incentives for harvesting wild pangolins; how legal and illegal markets may interact and compete if commercial captive breeding of pangolins were possible and potential impacts on stockpile policies; the nature of consumer demand (e.g., price elasticities and cross-price elasticity of demand), consumer preferences, and the acceptability of potential substitutes by consumers and TCM practitioners.

3.3. Frameworks for evaluating supply-side interventions

Phelps et al. (2014) posit that 17 conditions need to be met in order for supply-side interventions to displace wild collection of species. Although this framework has demonstrated utility for analysing the potential outcome of supply-side interventions, it does have a number of limitations. The framework implies that conditions need to be met in absolute terms (i.e. are binary) but this is unrealistic. For example, the profitability of wildlife farming will depend on the marginal costs of production, which will differ between producers and change over time, but this is not captured. Hence, in our analyses we introduced a third category of 'uncertain' and our categorisations were not mutually exclusive. Second, the framework uses potentially confusing economic terminology. Phelps et al. (2014) refer to 'high' demand but it is unclear whether this refers to high prices or high quantities or both. We interpreted high to mean quantities purchased and consumed. Phelps et al. also use the term 'market size' and 'size of demand' as if they are interchangeable: they are not. In economics, market size typically refers to actual trade volumes (expressed in monetary terms), whereas demand reflects the range of all potential volumes across a full range of potential prices and associated quantities purchased. Phelps et al. also assert that markets should be 'developed and accessible', but this is inaccurate. In economic terms, if there is demand for a given product, entrepreneurs tend to act to meet that demand and markets emerge spontaneously, provided there are no barriers to entry: the absence of an existing developed market does not preclude the success of supply-side interventions.

Phelps et al. (2014) state that their framework is a starting point for broader enquiry of supply-side interventions. However, despite the utility of the framework as a line of inquiry, there is a need for a more robust approach to evaluate the potential impact of such interventions. The lack of an established standardized means of assessment may be in part due to the context-specific nature of supply-side interventions and their inherent complexity. Predicting outcomes necessitates an in-depth understanding, not only of all the relevant specific biological factors relating to the species concerned, but also of the actors (e.g., producers, traders and consumers) involved (see Williams and 't Sas-Rolfes, 2019) and how they might respond under different scenarios under which an intervention such as farming is introduced.

Predicting supply-side intervention outcomes also necessitates understanding the institutional and governance context and extent of competition determined by market structures and processes. Institutional factors such as property rights will influence economic and other incentives for wild harvest, and consumer preferences will determine critical responsive changes in market prices and consequent incentives for further action by all competing market supply participants, legal and illegal (Cooney et al., 2015). Stockpiles, legal and illegal, and stockpile policies will also critically affect the outcomes of potential interventions. The relative importance of these different factors is often difficult to determine and weight appropriately in a generic assessment framework, especially one that relies on simple binary assessments of variable, interacting and evolving parameters.

There remains a need for a more robust generic framework to provide guidance on the potential outcomes of supply-side interventions in biodiversity conservation. Ultimately, however, such assessments should be informed by interdisciplinary input from relevant experts and stakeholders and subject to rigorous analyses offered by techniques such as participatory scenario planning. Such assessments could help inform potential outcomes of supply-side interventions for both pangolins and other species.

4. Conclusion

Pangolins are threatened with extinction from overexploitation. Although subject to an international commercial trade ban, they are also the focus of attempts at farming. Using Phelps et al.'s (2014) framework, pangolins meet only a maximum of six of the 17 conditions required for farming to displace wild collection. It is therefore very unlikely that farming will displace wild collection in the near future and have a positive impact on the conservation of wild pangolins. Major barriers to farming include an inability to breed pangolins on a commercial scale; available evidence suggests that it will be cheaper to acquire wild pangolins and that unsubsidised farming would be unprofitable. It is possible that the existence of farms is incentivising poaching and trafficking of pangolins and potentially the laundering of derivatives. Under a hypothetical scenario where commercial captive breeding were possible at scale, there is a risk that laundering would occur without well implemented monitoring and certification systems, and the advent of farming would likely complicate law enforcement efforts. To understand better the overall impact of pangolin farming on wild populations, both in the immediate and long-term, additional research is required.

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