



## Review paper

# Under what circumstances can wildlife farming benefit species conservation?



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## HIGHLIGHTS

- Farmed wildlife products should be considered equal in quality, taste, and status.
- The demand for wildlife products cannot increase due to the legalized market.
- Wildlife farming should be more cost-efficient than poaching.
- Wildlife farms should not depend on wild populations for restocking.
- Laundering of illegal wildlife products into the commercial trade should be absent.

## ARTICLE INFO

### Article history:

Received 8 December 2015

Received in revised form 22 March 2016

Accepted 22 March 2016

Available online 12 April 2016

### Keywords:

Wildlife trade

Wildlife farming

Commercial breeding

Rhino horn

Bear bile

Tiger bone

Pet trade

Species conservation

## ABSTRACT

Wild animals and their derivatives are traded worldwide. Consequent poaching has been a main threat to species conservation. As current interventions and law enforcement cannot circumvent the resulting extinction of species, an alternative approach must be considered. It has been suggested that commercial breeding can keep the pressure off wild populations, referred to as wildlife farming. During this review, it is argued that wildlife farming can benefit species conservation only if the following criteria are met: (i) the legal products will form a substitute, and consumers show no preference for wild-caught animals; (ii) a substantial part of the demand is met, and the demand does not increase due to the legalized market; (iii) the legal products will be more cost-efficient, in order to combat the black market prices; (iv) wildlife farming does not rely on wild populations for restocking; (v) laundering of illegal products into the commercial trade is absent. For most species encountered in the wildlife trade, these criteria are unlikely to be met in reality and commercial breeding has the potential to have the opposite effect to what is desired for conservation. For some species, however, none of the criteria are violated, and wildlife farming can be considered a possible conservation tool as it may help to take the pressure off wild populations. For these species, future research should focus on the impact of legal products on the market dynamics, effective law enforcement that can prevent corruption, and wildlife forensics that enable the distinction between captive-bred and wild-caught species.

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## 1. Introduction

### 1.1. Illegal wildlife trade

Wild animals, plants and their derivatives are traded worldwide to meet demands for food, clothing, decorative items, traditional medicines, and pets (Challander et al., 2015; TRAFFIC, 2008). Although the trade in some wildlife products is regulated (CITES, 2014), the industry remains largely illicit (Rosen and Smith, 2010). The illegal trade in wildlife is estimated to value over 20 billion USD per year (South and Wyatt, 2011), making it the second-largest illegal business in the world (Wylor and Sheikh, 2008). Skins, pelts and fur are the main traded animal products, followed by elephant ivory, meat and other body parts, bones and teeth, and horns (Rosen and Smith, 2010). The high demand for these products and subsequent wildlife poaching has been one of the main threats to the conservation of species (Challander et al., 2015; Dinerstein et al., 2007; Naylor, 2005).

The scope of animal species involved in wildlife trading is large and covers most taxonomic groups (Rosen and Smith, 2010). For many of these species, illegal harvesting has had a catastrophic impact on their population numbers. To give an illustration, the demand for tiger skins and bones for traditional medicines has led to a total population decline of 97% in one century and local extinctions (Check, 2006). Pangolins are caught for their meat and scales, and poaching has led to a population decline of 94% in China and surrounding countries (Pietersen et al., 2014; Wu et al., 2004). Asiatic black bears (*Ursus thibetanus*), sun bears (*Helarctos malayanus*) and sloth bears (*Melursus ursinus*) are threatened by the demand for bile, which is used in Chinese and Southeast-Asian medicines, and which led to a global population decline of 49% and local extinctions (Foley et al., 2011; Servheen, 1994). Rhino horns are also in high demand for their use in Asian traditional medicines (Biggs et al., 2013; Milliken and Shaw, 2012), and subsequent poaching led to a global population decline of 85% in only 17 years (Ayling, 2012). In South Africa, home to 90% of the world's white rhinos (*Ceratotherium simum*), poaching has been doubling each year over the past five years (Biggs et al., 2013). Elephants are being poached for their ivory, which is used for decorative purposes (Stiles, 2004). Even though the international trade in ivory was banned in 1989, poaching has increased persistently (Underwood et al., 2013). Tanzania alone has lost 60% of its elephant population (65 000 individuals) in only 5 years due to poaching (Mathiesen, 2015).

### 1.2. Regulations and law enforcement

The market for wildlife products is of high value, which makes illegal trade difficult to combat. The International Convention on Trade in Endangered Species of Wild Flora and Fauna (CITES) is an international agreement among countries to regulate the trade in animal products. Additionally, the wildlife trade monitoring network (TRAFFIC) investigates the extent and impact of illegal wildlife trade on wild populations. Both organizations aim to ensure that wildlife harvesting and trade does not threaten the survival of wild species. CITES has divided circa 35 000 species over three appendices, which determine the degree to which trade is prohibited (CITES, 2014). Appendix I is for endangered species and allows no trade. Conservation efforts have been aimed to seize illegal wildlife resources, activate anti-poaching patrols, and raise awareness by community-based education. Some governments have responded to illegal poaching by increasingly severe law enforcement and militarization for wildlife-protection (Ayling, 2012). As for rhino poaching, a shoot-on-sight policy

**Table 1**

Criteria that have to be met in order for wildlife farming to serve a conservation purpose. Literature predicts that if the criteria cannot be met in reality, a commercialized trade in farmed animal products will have a negative influence on wildlife conservation. The criteria have been adjusted from Biggs et al. (2013) and extended with more detail.

Criteria	Detailed explanations
1. Legal products will form substitute	1.1 Consumers show no preference for wild-caught animals 1.2 Quality and taste is considered equal to wild animal products 1.3 Consumer's behaviour is not driven by status related to rare and wild animals
2. Demand is met and does not increase	2.1 Wildlife farming can cover a substantial part of the demand 2.2 Demand will not increase due to the legalized market 2.3 Consumers' demand will not shift to different species
3. Legal products will be more cost-efficient	3.1 Wildlife farming is cost-efficient enough to combat the black market prices 3.2 The biology of the species allows for cheap housing in artificial environments 3.3 Species' reproduction rate is high enough to allow a high output
4. No re-stocking from the wild	3.3 Farmed products can outcompete the illegal market 4.1 Next generations are bred in captivity only 4.2 Captive animals are not replaced with wild individuals
5. Laundering is absent	5.1 Laundering of illegal products is absent 5.2 False licences and permits are avoided 5.3 Other species cannot be disguised as captive-bred species 5.4 Captive-bred products can be distinguished from wild products

costs the lives of hundreds of poachers per year in South Africa (Humphreys and Smith, 2011). However, despite CITES regulations and anti-poaching efforts, the illegal trade in many endangered species has been increasing (Challander and MacMillan, 2014; Drury, 2011; Rosen and Smith, 2010). It seems that the current interventions and law enforcements are insufficient to avoid poaching (Abbott and van Kooten, 2010; Pietersen et al., 2014; Rosen and Smith, 2010; Wellsmith, 2011). In order to circumvent the extinction of species as a result of poaching, an alternative approach must be considered to control the illegal wildlife trade.

### 1.3. Wildlife farming

It has been argued that commercial breeding and legalized trade can keep the pressure off wild populations (Jiang et al., 2007; Mitra, 2005). Some species are already commercially bred to meet the high demand for their products (Table 2), and this is referred to as wildlife farming (Bulte and Damania, 2005). CITES prohibits the commercial trade of species that are threatened with extinction (Appendix I), but permits the captive-breeding and artificial propagation of some of these species. Currently, 25 Appendix I species are registered for the allowance of commercial captive-breeding (Challander et al., 2015). Although wildlife farms have started for economic reasons only, conservationists hope that competition with the black market, as farmed products enter the market, will decrease the profit of poachers and leave them with less economic motivation to harvest wild animals (Brown and Layton, 2001; Bulte and Damania, 2005; Mitra, 2005).

It has been proposed that a legal trade in animal products can prevent poaching if the following criteria are realized: (i) the demand will be met by legitimate products and cannot increase as a result of legalization and increased accessibility, (ii) the legal supply will be a substitute for products retrieved from wild populations, (iii) a legal supply will be more cost-effective than illegal products, and (iv) laundering of illegal supplies under the cover of legal trade must be avoided (Biggs et al., 2013). Although wildlife farming may be considered largely unethical, as animals are kept in small enclosures, and suffer from malnutrition, inbreeding depression and stress (Pugh, 1998; Lau, 2003; Robertson, 2013), it has been decided to disregard these aspects and focus solely on its potential impact on wild populations.

## 2. Methodology

The literature was obtained using Google Scholar, Scopus and TRAFFIC database searches. The following keywords were used to find the required literature: wildlife farming, commercial breeding, captive breeding, sustainable utilization, side-supply, and wildlife trade. For a more specific search the following words were used: traditional Chinese medicine, bush meat, fur industry, rhino horn, tiger bone, bear bile, crocodile farming, musk, and 'pet trade' in combination with birds, reptiles and amphibians. We extracted the following information from each paper: (1) the impact of wildlife trade on species' conservation; (2) the potential for wildlife farming; (3) any mention of demand, consumer's preference, captive breeding, re-stocking, and laundering; (4) any threats or possible solution with regards to the wildlife farming. The references used during this review covered the years 1937–2015. The data was extracted from 76 peer-reviewed publications, 37 NGO reports (e.g. CITES and TRAFFIC), 10 books, 3 web-pages, and 2 magazines. During this review it was attempted to weigh up all arguments in favour of wildlife farming against the criteria outlined (Table 1).

### 3. Conservation criteria for wildlife farming

#### 3.1. The demand is met and does not increase

##### 3.1.1. Favouring arguments

Wildlife farming is a growing industry, where the objective is to meet the high and often increasing demand for animal products (Williams et al., 2015). Commercial breeding can be beneficial to species conservation if the demand is met by legal supply, so as to replace the need to extract these products from the wild (Biggs et al., 2013). The fact that the demand cannot be met for most species (Bulte and Damania, 2005) does not mean that wildlife farming cannot have any positive impact on wild populations. Theoretically, any percentage of the demand that can be covered by wildlife farming avoids suppliers to extract the total demand from the wild (Jori et al., 1995; Lapointe et al., 2007). The farming of silver foxes (*Vulpes vulpes*) and minks (*Mustela vison*), to supply the fur industry, has formerly reduced the offtake of animals from the wild in the United States (Ashbrook, 1937). For some animals, the demand is so high that some believe that conservation will not be possible without wildlife farming (Parry-Jones, 2001). For example, a seahorse farming development in centre in Lampung, Malaysia, is promoted to take pressure of the wild population, as seahorses are currently caught in their hundreds of thousands annually for their use in traditional medicines (Vincent, 1996).

##### 3.1.2. Counter-arguments

Unfortunately, the demand for most wildlife products by far exceeds what commercial breeding can currently or realistically offer (Brooks et al., 2010; Lyons and Natusch, 2011; Mockrin et al., 2005; Nijman and Shephard, 2009). For instance, musk deer, *Moschus spp.*, are bred in captivity to provide musk to the market in traditional medicine, yet farms are currently only capable to meet 0.3%–1.2% of the demand, and it is considered unlikely that domestic demand will ever be met (Parry-Jones and Wu, 2001). Similarly, despite the fact that 12 000 bears are held in Asian farms for the production of bile, demand has been increasing, and commercial trade is unlikely to become sustainable (Foley et al., 2011; Garshelis and Steinmetz, 2005; Kikuchi, 2012). The demand for rhino horn and subsequent poaching has increased as well, which has been attributed to human population growth and the increasing consumer market, the rapid growth of the Asian economy and greater income for most consumers, and the settlement of middleman traders in key source countries in Africa (Drury, 2009; Milliken and Shaw, 2012). The same has been observed for elephant ivory, for which demand has been increasing since 1990 concurrent with increasing economic wealth (Stiles, 2004).

Another major concern is that wildlife farming and legalized trade is likely to increase demand further. Firstly, allowing trade in wildlife products will legitimize their consumption, counteract the ethical unacceptance of buying illegal wildlife products, and encourage more consumers to buy the products as it is now considered acceptable (Abbott and van Kooten, 2010; Bulte and Damania, 2005; Drury, 2009; Stiles, 2004). This is referred to as the stigma effect, which implies that legal trade will remove the negative attitude towards the consumption of wildlife products, which can be expected to further stimulate demand (Fischer, 2004).

The reduction of stigma is more likely to relate to decorative goods such as ivory and skins, than to consumable goods like horns and bones. Awareness campaigns, and the resulting negative attitudes by consumers has proven to reduce demand for wildlife products in the past, such as seal fur (Myers and Summerville, 2004), shark fins (Lack and Sant, 2011) and elephant ivory (Andrew, 1997). For such species, it is likely that law-abiding consumers will begin to participate in the market of wildlife products if it were to become legalized, which will lead to a higher demand (Fischer, 2004).

It has been suggested that demand for wild tiger products will be unaffected if tiger farming is legalized, unless a stigma effect is enforced with a monopoly chapter (Abbott and van Kooten, 2010). When farmed prices are kept high by a monopoly firm, they can prevent illegal products from entering the market (Abbott and van Kooten, 2010). This would require regulatory restrictions, certified products, and monitoring by an outside certifier. However, wildlife farming is not a monopoly industry and is unlikely to become so in the future, and many wildlife industries are currently controlled by multiple criminal networks (Bulte and Damania, 2005). It is better described as an oligopolistic market, in which prices are set by intense competition (Bulte and Damania, 2005). Conventional economics predict that producers will increase the volume of the market to maintain profit as imperfect competition remains with the cartels (Kirkpatrick and Emerton, 2010). This has been the case for bear bile, for which an expanding supply from farmed stocks led to a larger market (Servheen, 1994). Also, the farmed breeding of tigers has increased product availability in China, and tiger parts are now being used in a larger variety of medicines, as well as in wine (EIA, 2013). Because real-life examples of the economic impact of wildlife farming are scarce, conservationists have often relied on model-based approaches (Abbott and van Kooten, 2010; Bulte and Damania, 2005; Fischer, 2004; McAllister et al., 2009; Phelps et al., 2013). It is most often predicted that, due to an imperfect self-regulating market, the demand for wildlife products will not be displaced by commercial breeding. Furthermore, demand is likely to increase, which will intensify the pressure on wild populations.

##### 3.1.3. Potential for conservation

Legalized wildlife farming should not be considered until the impact on the market and consumers' demand is clarified (Bulte and Damania, 2005). This mainly counts for endangered species, as a legalized trade in farmed animal products has the potential for being detrimental to species conservation by increasing demand (Servheen, 1994; Abbot van Kooten 2011).

Competition between the wildlife farming industry and the existing wildlife trade is likely to result in lowered prices and staggering profits for farmers, which allows the market for illegally poached products to continue and even prevail, which would be detrimental for wild populations (Swanson and Barbier, 1992). However, the rise of commercial farming does not inevitably have to lead to lower product prices. The farming of American alligator (*Alligator mississippiensis*) for the production of leather did, for instance, not lead to lower product prices and a higher demand (Moyle, 2013).

To avoid an increase in demand, governments could subsidize farmed products and keep prices high, to enable successful competition on the market (Abbott and van Kooten, 2010). The Canadian government, for instance, released fur farmers from taxes, lowered licence fees for fur farmers, and increased export fees for wild pelts (Colpitts, 1997). Furthermore, regulatory restrictions against wild products and awareness campaigns in favour of farmed products should be initiated. Certified labels such as 'conservation friendly' could be considered to achieve this. In this scenario, a stigma effect is enforced with a monopoly chapter, which gives wildlife farming the potential to outcompete illegal products (Abbott and van Kooten, 2010). When commercially-bred products dominate the market and demand does not increase, wildlife farms could become a benefit to conservation (Bulte and Damania, 2005).

### 3.2. Legal supply will substitute for products retrieved from wild animals

#### 3.2.1. Favouring arguments

Animals and plants, or their derivatives, produced in commercial farms have the potential to replace the market that retrieves these from the wild (Brown and Layton, 2001; Bulte and Damania, 2005; Mitra, 2005). Cane rats (*Thryonomys swinderianus*), for instance, are hunted for their meat and captive-bred animals form a good substitute which is considered of equal quality by consumers (Jori et al., 1995). Comparatively, farmed crocodile products have replaced the wild crocodile harvest by offering consumers a better and cheaper option (Macgregor, 2006). Wild populations of some crocodilians are recovering after 30 years of hunting restrictions and enforced trade in commercially-bred skin products (Thorbjarnarson, 1999; Moyle, 2013). Fur farmers also promote their products to be of better quality, as traditional trapping often damages the pelt (Colpitts, 1997).

The pet industry is another main driver of the wildlife trade and has pressured wild populations worldwide across many taxa (Rosen and Smith, 2010). The collection of wild birds for the pet trade, for instance, is the main threat for 34 bird species in Asia (BirdLife International, 2001). Farming of pet-birds has been proposed as a valuable conservation tool to lower the pressure on wild bird populations (Jepson and Ladle, 2005). Bird-keepers have no preference for wild-caught over captive-bred birds, which means that wildlife farming can become an effective substitute (Jepson and Ladle, 2005). Captive breeding is also considered as a conservation tool for reptiles and amphibians encountered in the pet trade, which are currently mainly taken from the wild (Zhou and Jiang, 2004; Nijman and Shephard, 2009; Lyons and Natusch, 2011). Some reptile species can be bred efficiently enough to cover the full market demand, which would notably decrease the pressure on wild populations (Mattioli et al., 2006). Other mentioned benefits of commercial breeding are that it can finance research and education programmes, establish successful breeding techniques for future reintroduction programmes, and provide livelihoods for local communities (Mattioli et al., 2006; Ganzhorn et al., 2015).

Wildlife farming has also been suggested to combat the black market in Chinese traditional medicines (Parry-Jones, 2001; Lapointe et al., 2007; Biggs et al., 2013). Tigers, for instance, are captive bred in large numbers to supply bones to the market in traditional medicines (Nowell and Xu, 2007). International bans prohibit farm owners from trading tiger products, although some believe that allowing a legalized trade in farmed tiger products will reduce illegal poaching of wild tigers (Jiang et al., 2007; Mitra, 2005). However, opinions seem divided, as it is feared that farmed products cannot form a substitute for all species that are encountered in the wildlife trade for traditional medicines (Dinerstein et al., 2007; Hunter et al., 2013).

#### 3.2.2. Counter arguments

The main problem is that the use of animal products is deep-rooted in many cultures, mainly for traditional medicines, which makes the industry difficult to eradicate (Ayling, 2012; Zimmerman, 2003). For instance, although many Asian countries have removed rhino horn from their traditional medicine pharmacopoeias as there is no scientific evidence for any medical value (Milliken and Shaw, 2012), the demand for rhino horn has not declined (Ayling, 2012). This shows that spiritual beliefs outweigh scientific reasoning, which is the underlying problem of the second criterion stating that farmed products should satisfy consumers' needs, thereby substituting for products retrieved from the wild (Biggs et al., 2013). The main issue is that consumers of traditional medicines often prefer wild over farmed animal products because they have a higher spiritual value and are believed to generate more medical strength (Hall et al., 2008; Kirkpatrick and Emerton, 2010). For example, 71% of the consumers of tiger derivatives prefer wild over farmed products (Gratwicke et al., 2008). Similarly, consumers of bear bile prefer wild over farmed products because of believed differences in medicinal effectiveness (Dutton et al., 2011). As long as the consumers' preference for wild animal products remains, farmed products cannot offer a substitute, and poaching will remain a threat (Bulte and Damania, 2005).

Consumer preference is also based on quality and taste, which is believed to be different between wild and farmed species. Wild meat, for instance, is very popular in Vietnam, and high demand has led to the overexploitation of wildlife (Drury, 2011). Some species are being captive bred to meet the demand for meat, including turtles, snakes, porcupines, and monkeys, yet with little success because farmed meat is considered inferior, as consumers claim it to be of lower quality

and lesser taste (Drury, 2009, 2011). This causes the demand for wild animals to remain constant despite the availability of farmed alternatives (Shi and Parham, 2000). This has been most apparent for Asian turtles, for which the nutritional properties of wild animals are believed to be much higher than those of captive-bred animals (Haitao et al., 2007). As a result, the last remaining wild populations of many endangered turtle species are being exploited to the point of extinction (Haitao et al., 2007). Similarly, the quantity of wild orchids on Asian markets was unaffected by the flood of farmed plants, as the preference for wild specimens remained persistent (Phelps et al., 2013).

Additionally, because wildlife products are often seen as a status symbol, wild animals are considered superior because of their rarity and high expense (Chen, 2015; Courchamp et al., 2006; Drury, 2009; Fischer, 2004; Gault et al., 2008). Because rare species are associated with status it increases the consumer's willingness to pay, which further increases the demand (Courchamp et al., 2006). In a study on the demand for sturgeon caviar, consumers were asked to taste two caviars and indicate their preference: they were told that one originated from a rare species and one from a common one. Even though the caviars were identical, 70.2% of the consumers preferred the caviar of the rare species (Gault et al., 2008). The wild meat industry in Vietnam is also strongly associated with social status, and regular consumers are generally business people, finance professionals, and government officials (Drury, 2011). The result is an increase in the market price for endangered animals, which leads to greater efforts to exploit the last remaining individuals (Hall et al., 2008). This has also been the case for butterflies caught for decorative purposes in Papua New Guinea, for which the price paid directly relates to the rarity of the species (Slone et al., 1997).

The exotic pet industry also demonstrates that people will pay considerably more for rare animals (Courchamp et al., 2006). The price that bird collectors pay for rare parrots such as Hyacinth macaws, *Anodorhynchus hyacinthinus*, and Spix's Macaws, *Caynopsitta spixii*, went up to over US\$ 20 000 after these species became extremely rare in the wild, further increasing poaching pressure (Wright et al., 2001). Two newly described reptiles (the turtle *Chelodina mccordi* and the gecko *Goniurosaurus luii*) were rapidly collected to near-extinction due to their rarity and willingness of eager pet owners to pay up to US\$ 2000 for a single individual (Stuart et al., 2006). Also in the trophy hunting industry rare animals are higher valued (Lindsey et al., 2007). In South Africa, hunters will pay up to 26% percent more for rare antelopes such as sable, *Hippotragus niger*, than for common antelopes such as impala, *Aepyceros melampus*, or kudu, *Tragelaphus strepsiceros* (African Sky Hunting, 2015). Consumer preference for rare species leads to the fear that if farmed animal products become easily accessible, consumers will change their interest and crave products from rarer animals (Chen, 2015). For instance, the demand for tiger parts has already shifted to snow leopards, *Panthera uncia*, and clouded leopards, *Neofelis nebulosi* (Henry, 2004; Nowell and Xu, 2007).

### 3.2.3. Potential for conservation

As long as the preference for wild animals remains, wildlife farming will not be able to substitute for products retrieved from the wild. Due to consumer preference for wild and rare species, farmed products form a separate, parallel market (Chen, 2015; Drury, 2009; Phelps et al., 2013). Mainly consumers of traditional medicines and bush meat show a strong preference for wild over captive bred products (Nooren and Claridge, 2001; Gratwicke et al., 2008; Hall et al., 2008; Kirkpatrick and Emerton, 2010; Drury, 2011). This is, however, not the case for all species and facets of the wildlife trade. The preference for wild animal products, for spiritual or status reasons, is generally not applicable to the pet and fur industry (Colpitts, 1997; Jepson and Ladle, 2005; Mattioli et al., 2006; Moyle, 2013). For such markets, wildlife farmers could offset competition by promoting the quality of their products, by for instance offering special breeds of pets (Jepson and Ladle, 2005), or animals free of infectious diseases (Still, 2003).

For the markets in traditional medicines and wild meat, it is important to change the attitude of consumers by education programs, as it is considered likely that many consumers are not aware that the products they buy are obtained in an uncontrolled industry with overexploitation of species to the point of extinction (Still, 2003). Stricter law enforcement can also help to create awareness amongst consumers, and in the case of illegal tiger parts this has led to a shift in the market to easier attainable lion *Panthera leo* products (Williams et al., 2015). There has been a sharp rise in the amount of lion bones exported from South Africa to Asia (from 59 skeletons in 2008 to 573 in 2011) to serve as a substitute for the market in tiger bones (Gratwicke et al., 2008; Williams et al., 2015). Most of these bones originate from breeding farms, which are intended to support the lion hunting industry (Lindsey et al., 2012). If commercially bred lion bones could form a substitute for wild tiger bones, it could have positive conservation impact. However, this new market must be controlled with extreme caution because it has the potential to give value to wild lion bones for poor, rural communities (Williams et al., 2015). Cases of poached lions and illegally traded skeletons have already been described (Macleod, 2012; Miller, 2009).

## 3.3. Legal supply will be more cost-effective

### 3.3.1. Favouring arguments

In order to outcompete the illegal trade, captive breeding for animal products should be more cost-effective than retrieving these products from the wild (Biggs et al., 2013). For certain species, wildlife farming will be economically beneficial because the collection of specimens from the wild can be risky and time costly (Brooks et al., 2010). Furthermore, captive populations have the potential to accomplish a higher output than wild populations, depending on the species' mating system. For some species, a higher rate of reproduction can be achieved in captivity by removing juveniles from

their family group prematurely (Shepherdson, 1994). In cane rat farms, for instance, animals are re-mated when the previous litter is still weaned, which leads to year-round breeding success (Adu et al., 1999).

Reptiles also have a high potential to breed effectively in captivity, as long as species have a high fertility, a *r*-oriented mating system (high number of eggs per clutch with minimal care) over a *K*-oriented mating system (low number of eggs per clutch with maximum care), and a fast growth rate (Mattioli et al., 2006). Crocodiles, for instance, lay large amounts of eggs of which only few survive to adulthood in the wild (Moyle, 2013). This makes that the harvest of a permitted amount of eggs for wildlife farming will not have a negative impact on the wild population, but result in a very high output for the captive population (Moyle, 2013). Frogs and other amphibians, on the other hand, grow slowly and require high maintenance costs, which are not desirable traits for farming (Helfrich et al., 2009).

### 3.3.2. Counter-arguments

Unfortunately, it is rarely the case that breeding farms are more cost-efficient than poaching, due to feeding, housing and production costs (Gratwicke et al., 2008; Kirkpatrick and Emerton, 2010; Mockrin et al., 2005; Nogueira and Nogueira-Filho, 2011). The main problems faced by wildlife farming are the animals' social behaviour, energy requirements, reproductive rate, growth rate, and space requirements (Mockrin et al., 2005). These can be explained by means of some examples; (i) Social behaviour can become a problem when an animal is highly territorial and intolerant of other individuals in its close surroundings. The paca, *Agouti paca*, for instance, is in high demand for its meat and has been proposed as a candidate for wildlife farming. However, captive breeding rarely succeeds due to its complicated social structure, which makes wildlife farming non-viable (Emmons, 1987); (ii) Energetic requirements of species can make them expensive to rear in captivity, which is mainly the case for carnivores and frugivores (Mockrin et al., 2005). Farming of bull frogs, *Rana catesbeiana*, in Indonesia was meant to uplift export production of frog legs and take the pressure off native species, but many farms closed down due to high maintenance costs (Kusrini and Alford, 2006); (iii) The reproductive and growth rates of animals is often too slow to produce meat or derivatives at an economically viable rate (Mockrin et al., 2005). Green pythons, *Morelia viridis*, for instance, are in high demand as pets. Because of their long reproductive cycle and the fact that they only turn green at a length of 65 cm, it is unlikely that they can be bred fast enough to meet the high demand (Lyons and Natusch, 2011). Captive breeding or sustainable harvesting has also been proposed for rhinos in Africa (Biggs et al., 2013). However, rhinos rarely produce fertile offspring in captivity, only reach sexual adulthood between 6 and 8 years of age, and only have one young per litter (Patton et al., 1999; Swaisgood et al., 2006). Additionally, horns of young adults grow by only 6 cm per year on average, and the rate even decreases with age (Pienaar et al., 1991). Although rhino horn harvesting could have economic benefits, it will never produce horn at a rate fast enough to meet the demand from Asia (Kotze, 2014); (iv) A final problem faced by wildlife farmers is that the space requirements of many species cannot be met in captivity. Pangolins are hunted for their meat and although captive breeding could form an important tool to protect wild populations, their specialized behaviour and high dependence of natural ecosystems prevent successful farming (Hua et al., 2015). These examples show that commercial farming is not an option for many animals threatened by the wildlife trade.

When wildlife farming comes with several additional production costs, it can create imperfect competition in the market (Bulte and Damania, 2005). For instance, to produce a kilogram of tiger bones in captivity is 50%–300% more expensive than to retrieve this from a poached tiger (EIA, 2013), which means that the illegal hunting of wild tigers will remain an attractive alternative (Bulte and Damania, 2005). A comparison made for ivory prices revealed that legally harvested tusks were sold for approximately US\$ 450 per kilogram, whilst illegal tusks were sold for only a third of that price (Fischer, 2004). For the same reason, parrots are still illegally smuggled into the USA because they can be sold for less money than commercially bred birds (Wright et al., 2001). The high expense of wildlife farming raises the question whether the market in illegal animal products can be replaced (Nogueira and Nogueira-Filho, 2011).

Even if farmed products were to become cheaper in the future, there is a risk that competition with illegal suppliers will result in higher market prices and subsequently a higher poaching pressure (Bulte and Damania, 2005). More importantly, the illegal market in wildlife products is controlled by a small numbers of traders and criminal groups who make high profits, and large numbers of poachers who earn comparatively little and have no influence on market prices (Meacham, 1997; WPSI, 2015). This means that fluctuations in market prices, even if they were to decrease, will have little impact on poachers, who often lack any other form of income (Gibson, 1999). What a poacher receives for a dead tiger or rhino is unmatched by the income of any average job in the third world. For instance, an elephant tusk will bring in money comparable to 10 times the average annual income in poor African nations (Gettleman, 2012). Rhino poachers are normally payed a once-off amount that does not relate to the horn's value, size or mass and is therefore not directly influenced by market prices (Milliken et al., 1993; Rachlow and Berger, 2015). So even when wildlife farming is able to compete with the illegal trade, poachers will not have any motive to stop their activities. The money is simply too good, and the risks are relatively low (Bulte and Damania, 2005; Warchol, 2004; Wyler and Sheikh, 2008).

### 3.3.3. Potential for conservation

The high costs for wildlife farmers make it unlikely that they can compete with prices offered by poachers (Mockrin et al., 2005). Other types of interventions, such as control regulations and subsidies for farmed products, will further increase the costs of wildlife farming compared to poaching, making it even less financially efficient (Hartwick and Olewiler, 1986). All of the above-mentioned factors predict that commercial breeding cannot sufficiently compete with the illegal wildlife

trade, due to the high costs of wildlife farming and imperfect competition. It is unlikely that wildlife farming will discourage poachers from retrieving products from the wild, as it will always remain an economically attractive option. However, these arguments are not applicable to all species encountered in the wildlife trade. Generally, small animals with fast reproductive and growth rates can be bred cheap and efficiently in captivity.

### 3.4. Legal trade without laundering of illegal supplies is possible

#### 3.4.1. Favouring arguments

The last criterion that has to be met in order for wildlife farming to have a conservation benefit is that the laundering of illegal products into the legal market is avoided (Biggs et al., 2013). It is predicted that wildlife poaching will be highest if laundering occurs simultaneously with a legal commercial trade, in which case an outright trade ban will be most beneficial for species conservation (Bulte and Damania, 2005; Fischer, 2004). In the complete absence of laundering, on the other hand, wildlife farming could be beneficial to conservation (Abbott and van Kooten, 2010). The trade in alligator skins has been free from illegal laundering since 1990, due to a tagging system reinforced by CITES (Hutton and Webb, 2003). The trade in lion bones from captive breeding facilities in South Africa also seems to be sustainable, as the bones are a by-product from a legal hunting industry and export permits are required to take trophies across the border (Williams et al., 2015).

#### 3.4.2. Counter-arguments

Another criteria is that wildlife farmers should not depend on wild populations to replenish their captive stocks (Mockrin et al., 2005). The Ethiopian civiculture, for which thousands of African civets *Civettictis civetta* are bred for the production of musk, still replaces each dead civet with one from the wild (Abebe, 2003). In Ghana, 90% of cane rat farms are still dependent on catching wild animals due to problems with safe-guarding the breeding stock (Adu et al., 1999). Likewise, over half of all porcupine farmers in Vietnam stated that their founding stock was of wild origin and that they continuously add wild individuals to their captive populations (Brooks et al., 2010). Some porcupine farms are even involved in direct wild-caught sells, as the demand for meat cannot be met by their breeding stock alone (Brooks et al., 2010). The same has occurred for reptiles that are being traded for the pet industry, as the number of exported reptiles was found to be much higher than breeding farms could ever produce (Nijman and Shephard, 2009). As an example, 76% of the traders in green pythons in Indonesia supplied wild pythons to breeding farms to add to the stock or sell directly under the guise of captive breeding (Lyons and Natusch, 2011). In the case of the Siamese crocodile, *Crocodylus siamensis*, continuous restocking of the captive breeding population with wild-caught individuals led to local extinctions (Bezuijen et al., 2013). These wildlife farming practises continue to put pressure on wild populations. Consequently, wildlife farming can only be sustainable if laundering is absent as well as ongoing dependency on wild populations.

Unfortunately, laundering is a criminalized business that has occurred for most species that are targeted by the wildlife trade (Adu et al., 1999; Brooks et al., 2010; Haitao et al., 2007; Lyons and Natusch, 2011; McAllister et al., 2009; Nijman and Shephard, 2009; Stiles, 2004). For wildlife traders, captive breeding often offers a perfect guise as CITES permits the trade of commercially bred animals for Appendix II species. CITES regulations indicate that only the second generation (F2) from captive-breeding operations can be legally traded (CITES, 2014). However, enforcement of these regulations is often lacking (Challander et al., 2015; Keane et al., 2008) and it is difficult for importing countries to differentiate between wild and captive-bred specimens (Challander et al., 2015; Lyons and Natusch, 2011; Williams et al., 2015). CITES-listed species are even sometimes concealed among similar-looking non-CITES species (Rosen and Smith, 2010).

In the case of the reptile trade in Asia, many species sold as captive-bred could not be found in breeding facilities during inspections (Nijman and Shephard, 2009). The same occurs for the Papuan hornbill, *Rhyticeros plicatus*, for which the amount of exported 'captive-bred' birds far exceeds what breeding facilities can hold or yield, given the species' slow reproductive rate (Nijman et al., 2012). Moreover, the existence of commercial breeding for many frog and chameleon species has never been confirmed and seems unlikely to be economically viable due to low reproductive success in captivity (Helfrich et al., 2009). Nevertheless, they are being traded as pets in their thousands under the guise of captive breeding (Nijman and Shepherd, 2010; Todd, 2011). Crab-eating macaques, *Macaca fascicularis*, are commercially bred in China to supply test animals to the pharmaceutical industry, which caused other Asian countries to traffic wild-caught macaques to China to be able to export them as 'captive-bred' to other continents (Eudey, 2008). Trophy permits are also often misused, and there has been proof that rhinos and lions have been exported from South Africa to Asia as trophies to be able to sell them on the black market as traditional medicines (Williams et al., 2015).

Corruption and the current lack of regional enforcement of wildlife harvest regulations allow the laundering of poached products into the commercial wildlife trade (Phelps et al., 2013). Chinese breeding farms are known to play a big part in the illegal trade of tiger bones, and their activities are rarely uncovered due to corrupt police officers and government officials (Abbott and van Kooten, 2010; Nowell and Xu, 2007). It is predicted that a legal market for tiger bones will allow laundering of wild products and increase the poaching pressure on wild tigers (Gratwicke et al., 2008). Corruption also plays a part in the African trophy hunting industry, where game rangers are often paid off to overlook poaching and more hunting permits are granted by government officials than are allowed by existing quotas (Lewis and Jackson, 2005). The Indonesian python traders circumvent laws and regulations by paying off officials in order to sell wild pythons on the legal pet trade market (Lyons and Natusch, 2011). The laundering of illegal products under the guise of legal trade has also occurred for elephant



**Table 2**

Criteria that are not met by species that have been considered for wildlife farming as a conservation tool: (1) farmed products must provide a substitute for wild products, (2) the demand for wildlife products does not increase; (3) legalized farming is more cost-efficient than illegal poaching; (4) wildlife farms do not rely on wild population for re-stocking; (5) laundering of illegal products into the wildlife farming industry is prohibited. The criteria have been adjusted from Biggs et al. (2013) and extended with more detail.

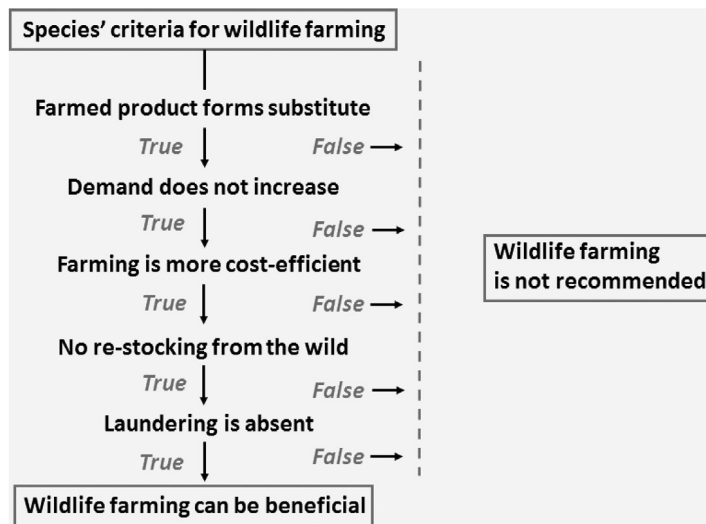
Species	Product	Criteria not met	Reference	
Tiger	<i>Panthera tigris</i>	Bones	1, 2, 3, 5	Dinerstein et al. (2007) Nowell and Xu (2007) Nyhus et al. (2010) Abbott and van Kooten (2010)
Bear	<i>Ursus</i> spp.	Bile	1, 2, 4	Servheen (1994) Dutton et al. (2011)
Porcupine	<i>Hystrix brachyura</i>	Meat	4, 5	Brooks et al. (2010)
Green python	<i>Morelia viridis</i>	Pet	4, 5	Lyons and Natusch (2011)
Burmese pythons	<i>Python molurus</i>	Pet	4, 5	Nijman and Shephard (2009)
Spiny turtle	<i>Heosemys spinosa</i>	Pet	3	Nijman and Shephard (2009)
Reptiles	<i>Furcifer</i> spp. and more	Pet	3	Mattioli et al. (2006)
Pangolin	<i>Manis</i> spp.	Meat	3	Hua et al. (2015)
Paca	<i>Caniculus paca</i>	Meat	3	Emmons (1987)
Chinese turtles	Several spp.	Meat	4	Shi et al. (2007)
Siamese crocodile	<i>Crocodylus siamensis</i>	Leather	4	Bezuijen et al. (2013)
Civet	<i>Civettictis civetta</i>	Musk	4	Abebe (2003)
Cane rat	<i>Thryonomys swinderianus</i>	Meat	4	Adu et al. (1999)
Emerald monitor	<i>Varanus prasinus</i>	Pet	5	Nijman and Shephard (2009)
Timor monitors	<i>Varanus timorensis</i>	Pet	5	Nijman and Shephard (2009)
Macaque	<i>Macaca fascicularis</i>	Testing	5	Eudey (2008)
Reptiles	<i>Phelsuma</i> spp. and more	Pet	None	Mattioli et al. (2006)
Capybara	<i>Hydrochoerus hydrochaeris</i>	Meat	None	Emmons (1987)
Musk deer	<i>Moschus</i> spp.	Musk	None	Parry-Jones and Wu (2001)
Lions	<i>Panthera leo</i>	Bones	None	Lindsey et al. (2012)
Alligator	<i>Alligator mississippiensis</i>	Leather	None	Moyle (2013)
Nile crocodile	<i>Crocodylus niloticus</i>	Leather	None	Revol (1995)
Butterflies	Several spp.	Decorative	None	Gordon and Ayiamba (2003)
Birds	Several spp.	Pet	None	Jepson and Ladle (2005)
Foxes	<i>Vulpes vulpes</i>	Fur	None	Ashbrook (1937)
Mink	<i>Neovison vison</i>	Fur	None	Ashbrook (1937)

Only species for which data is present were added to this table, and references were added when they provided data on the violation of the criteria. 'None' means that there is no current proof that any of the criteria are violated, although data is present, which make these species plausible for wildlife farming.

ivory (Fischer, 2004). Illegal ivory was sold along with legal ivory by government officials in Tanzania and Kenya, which had a catastrophic impact on the countries' elephant populations (Stiles, 2004). Laundering as a result of a legalized trade led to the near-extinction of crocodiles in Thailand, turtles in China, and bears in Asia (Drury, 2009; Haitao et al., 2007; Meacham, 1997). Poor governance, corruption and laundering is likely to become the major obstacle for a proposed commercial trade in rhino horn. Corrupt officials and rhino breeders in South Africa (which is home to the largest white rhino population and the first country in which rhinos were bred commercially; Biggs et al., 2013) have used CITES trophy permits to sell horns on the Asian black market (Ayling, 2012). Stockpiles of rhino horns have disappeared from government offices where any form of security seemed absent (Kotze, 2014). Permits and law enforcement are unlikely to stop laundering from occurring. As a comparison, illicit diamonds still comprise a considerable fraction of the global diamond trade (Ndumbe and Cole, 2005), and some 3%–15% of the diamond industry still consists of so-called 'blood diamonds' (Fishman, 2013).

### 3.4.3. Potential for conservation

Laundering of illegal wildlife products into the market of legalized, commercially-bred products could enhance poaching pressure on wild populations and lead to over-exploitation. As long as laundering of illegally retrieved wildlife products cannot be prevented, commercial breeding and a legalized trade should be avoided. An alternative is to make a clear distinction between the captive-bred and wild stock, by for instance CITES tags (Hutton and Webb, 2003), discriminatory body features (Zhou et al., 2014), or genetic markers (Alacs et al., 2009). Femur morphometric characteristics, for instance, differ considerably between wild and captive animals due to a dissimilar diet and movement activity (Xia et al., 2011). Wildlife forensic is another promising field to distinguish captive-bred from wild specimens, which involves phylogenetics, phylogeography, and the detection of genes that are selected for in captivity (Belyaev et al., 1981; Gross, 1994). The distinction of legalized products by genetic forensic studies can form the basis of a sustainable and regulated wildlife trade,



**Fig. 1.** Criteria that have to be met for wildlife farming to be suitable as a conservation tool: (1) farmed products must provide a substitute for wild products, (2) the demand for wildlife products does not increase; (3) legalized farming is more cost-efficient than illegal poaching; (4) wildlife farms do not rely on wild population for re-stocking; (5) laundering of illegal products into the wildlife farming industry is prohibited. The criteria have been adjusted from Biggs et al. (2013) and extended with more detail.

to combat the black market in animal products (Alacs et al., 2009). It must be kept in mind, however, that forensic studies have high financial costs, which might make it an unrealistic option in the nearby future (Hartwick and Olewiler, 1986).

#### 4. Conclusions

For many species, commercial breeding and a legalized trade in farmed products will have the opposite effect to what is desired for conservation. Main reasons are the consumers' preference for wild products, the ongoing dependency on the wild population, and laundering of illegal products into the legal wildlife trade. Furthermore, wildlife farming could only work as a conservation tool when the demand is not increased by the legal trade and when farming becomes more cost-efficient than illegal harvest. A summary of the available data shows that wildlife farming can have a negative impact on wild populations of certain species, if the following criteria are not met: (1) farmed products must provide a substitute for wild products, (2) the demand for wildlife products does not increase; (3) legalized farming is more cost-efficient than illegal poaching; (4) wildlife farms do not rely on wild population for re-stocking; and (5) laundering of illegal products into the wildlife farming industry is prohibited (Table 1; Fig. 1). When none of the criteria are violated, wildlife farming can be considered a possible conservation tool as it may help to take the pressure off wild populations. For the species that do not meet the criteria to benefit from wildlife farming (Table 2), a trade ban can be considered to suppress the demand, depress the market and eliminate export opportunities (Wright et al., 2001; McAllister et al., 2009; von Meibom et al., 2010). Trade bans can, however, only work in the absence of corruption (Ganzhorn et al., 2015). Future research should focus on the impact of legal products on the market dynamics, effective law enforcement that can prevent corruption, and wildlife forensics that enable the distinction between captive-bred and wild-caught species.

#### Acknowledgements

I would sincerely like to thank prof. Yoshan Moodley, prof. Peter Teske and dr. Pierre-Alexandre Rastorgueff for providing valuable discussions and corrections during the writing of this article.

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