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Perspective



Using the 2020 global pandemic as a springboard to highlight the need for amphibian conservation in eastern Asia

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ABSTRACT

Emerging infectious diseases are on the rise in many different taxa, including, among others, the amphibian batrachochytrids, the snake fungal disease and the Severe Acute Respiratory Syndrome coronavirus 2 (SARS-CoV-2) virus, responsible for Coronavirus disease 2019 (COVID-19) in mammals. Following the onset of the pandemic linked to COVID-19, eastern Asia has shown strong leadership, taking actions to regulate the trade of potential vector species in several regions. These actions were taken in response to an increase in public awareness, and the need for a quick reaction to mitigate against further pandemics. However, trade restrictions rarely affect amphibians, despite the risk of pathogen transmission, directly, or indirectly through habitat destruction and the loss of vector consumption. Thus, species that help alleviate the risk of zoonoses or provide biological control are not protected. Hence, in view of the global amphibian decline and the risk of zoonoses, we support the current wildlife trade regulations and support measures to safeguard wildlife from overexploitation. The current period of regulation overhaul should be used as a springboard for amphibian conservation. To mitigate risks, we suggest the following stipulations specifically for amphibians. I) Restrictions to amphibian farming in eastern Asia, in relation to pathogen transmission and the establishment of invasive species. II)

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Regulation of the amphibian pet trade, with a focus on potential vector species. III) Expansion of the wildlife trade ban, to limit the wildlife-human-pet interface. The resulting actions will benefit both human and wildlife populations, as they will lead to a decrease in the risk of zoonoses and better protection of the environment.

Significance statement: There is an increasing number of emerging infectious diseases impacting all species, including amphibians, reptiles and mammals. The latest threat to humans is the virus responsible for COVID-19, and the resulting pandemic. Countries in eastern Asia have taken steps to regulate wildlife trade and prevent further zoonoses thereby decreasing the risk of pathogens arising from wild species. However, as amphibians are generally excluded from regulations we support specific trade restrictions: I) Restrictions to amphibian farming; II) regulation of the amphibian pet trade; III) expansion of the wildlife trade ban. These restrictions will benefit both human and wildlife populations by decreasing the risks of zoonoses and better protecting the environment.

1. Background

Emerging infectious diseases are on the rise in many different taxa. For example, batrachochytrids (*Batrachochytrium dendrobatidis* and *B. salamandrivorans*) have devastated amphibian populations worldwide (Scheele et al., 2019), the snake fungal disease (caused by *Ophidiomyces ophiodiicola*) is impacting snakes (Lorch et al., 2016), and the SARS-CoV-2 virus is responsible for COVID-19 in humans and other mammals (Leroy et al., 2020). Thus far, impacts of the 2020 pandemic resulting from COVID-19 have proven more detrimental to human health and the global economy than any other disease in contemporary history (Chakraborty and Maity, 2020). Zoonoses are becoming increasingly common and are having progressively greater impacts on human societies (Jones et al., 2008). The factors responsible for the recent spread of zoonoses include the increase in human-wildlife interaction caused by both human encroachment on natural habitats (Allen et al., 2017; Borzée et al., 2020b) and the increasing animal trade (Aguirre, 2017; Allen et al., 2017; Marco et al., 2020). However, in just a few months, the COVID-19 pandemic may have changed global attitudes about the wildlife trade and its impact on nature conservation (Corlett et al., 2020). Resulting actions such as trade bans can be used as springboards by the conservation community to make inroads into wildlife conservation.

Several animal taxa, including mammals and reptiles, have been (sometimes questionably) implicated in the transfer of the SARS-CoV-2 virus to human populations (Li et al., 2020). In response, and in an unprecedentedly rapid action of global environmental leadership, the government of the People's Republic of China (hereafter China) took the initiative to impose a wildlife trade ban that included the majority of wild vertebrates consumed in China (Li, 2020; Xinhua, 2020). Prior to the pandemic, only 402 species were on the List of Wild Animals Under State Priority Conservation and banned from consumption, resulting in hundreds of non-listed species as potentially consumable. This number however increased following the trade ban and there are now only 18 species that can be legally traded and bred for consumption or other consumables such as skins and furs (Ministry of Agriculture and Rural Affairs of the People's Republic of China, 2020; Shanshui Nature Conservation Center, 2020a; Yang et al., 2020). This initial ban was quickly followed by a proposal for a similar ban from the Ministry of Agriculture and Rural Development in Vietnam, under different specifications (Tatarski, 2020). Likewise, the Republic of Korea (hereafter R Korea) benefited from the shift in public opinion following the 2020 pandemic to ban the import of two invasive freshwater turtles, bringing the total of banned species to four testudinids and one anuran (R Korea; Ministry of Environment, 2020a). Within China, both Jiangxi and Hunan provinces have recently developed special programs and incentives to stop the trade of wildlife, and the city of Wuhan has placed a total ban on the commercial wildlife trade.

These trade bans are considered by many to be a critical step towards reducing the risk of zoonoses and further pandemics, and trade regulations for amphibians are equally important because of the risk of direct and indirect transmission from amphibians intended for consumption and the pet trade (Jensen and Camp, 2003; Gratwicke et al., 2009; Schloegel et al., 2009). Namely, several species of mycobacteria are

zoonotic, and arbovirus have shown the potential for zoonoses (Denismore and Green, 2007). In addition, the bans are considered an important move forward for animal conservation because biological resource use is listed as a driver of decline for numerous species listed as threatened by The International Union for Conservation of Nature (IUCN) Red List of Threatened Species (Maxwell et al., 2016; IUCN, 2020). These bans, and stricter regulations, have been shown to have the potential to provide a much-needed respite that could promote the recovery of animal populations that are harvested in the wild (Schindler and Hilborn, 2015). The decrease in harvesting pressures on species and the reduced contact between wildlife and humans could also lower the risk of zoonoses. This is especially true for amphibians, as they naturally control a wide variety of vectors of pathogens (Hocking and Babbitt, 2014). For instance, many amphibian tadpoles compete with and/or prey on mosquito larvae (Spielman and Sullivan, 1974; Blaustein and Margalit, 1994; Blaustein and Margalit, 1996; Petranka and Kennedy, 1999; Rodríguez and González, 2000; Rubbo et al., 2003; Brodman and Dorton, 2006; DuRant and Hopkins, 2008; Rubbo et al., 2011; Valencia-Aguilar et al., 2013; Cortes-Gomez et al., 2015), an important approach to disease control as more than a million humans die each year because of mosquito-borne diseases (Tolle, 2009). In this regard, the role of amphibians should not be ignored, as a single larval mole salamander (*Ambystoma talpoideum*) can eat up to 900 mosquito larvae a day (DuRant and Hopkins, 2008), and there is now evidence linking the amphibian collapse to malaria outbreaks (Springborn et al., 2020). Furthermore, amphibians prey upon flies associated with human diseases (Peltzer and Lajmanovich, 2002) and deter fly oviposition (Blaustein et al., 2004; Rubbo et al., 2011). Amphibians also have other socioeconomic benefits, such as providing pest control in agricultural landscapes (Lajmanovich et al., 2003; Attademo et al., 2005; Peltzer et al., 2005; Attademo et al., 2007a; Attademo et al., 2007b; Peltzer et al., 2010; Hocking and Babbitt, 2014). For instance, amphibians are especially beneficial to crops such as soy (Attademo et al., 2007b; Valencia-Aguilar et al., 2013) and rice (Teng et al., 2016; Propper et al., 2020) by consuming agricultural pests.

However, the Vietnamese trade ban (Instruction No. 29/CT-TTg, issued on 23 July 2020 by the Prime Minister) is likely to be only temporary and other countries in Asia, with numerous wet markets, have not yet implemented any increased regulation. Moreover, the Chinese trade ban was announced by the Chinese Department of Forestry and does not include species under the jurisdiction of the Department of Agriculture. This distinction has resulted in the continued free trade of most fishes, amphibians and reptiles, even though fish-borne zoonoses have been increasing in number and diversity since the 1950s (Shane, 2011); viral zoonoses have arisen in reptiles (Ariel, 2011); and amphibian-borne fungal panzootics such as those driven by batrachochytrids have contributed to the largest documented extinction of species in modern times (Scheele et al., 2019). Consequently, despite being most welcome, the bans need to be expanded to support the conservation of some of the world's most threatened taxa (Wang et al., 2020) while simultaneously preventing further zoonoses. As we highlight here, the eastern Asian region, geographically defined as bordering the Pacific Ocean and associated countries, is also high in amphibian species richness but lacks comprehensive regulation or restriction of their

exploitation (Krishnasamy and Zavagli, 2020).

We acknowledge the subsistence economy that involves the trade and farming of certain species under the legislation of the Department of Agriculture (Jiangxi Provincial Forestry Department, 2018b) and the importance of the wellbeing of such farmers. One such species is the Critically Endangered, but commercially abundant, Chinese giant salamander, *Andrias davidianus* (Cunningham et al., 2016; Fei et al., 2006; Jiang et al., 2016; Liang et al., 2004; Ye et al., 1993). However, we urge a shift away from farming invasive or non-native species (which are known to carry disease-bearing micro-organisms such as batrachochytrids) for human consumption, such as the American bullfrog (*Lithobates catesbeianus*; Schloegel et al., 2012). In addition, we strongly recommend increased restrictions and regulations on the national and international amphibian pet trade, which involves millions of animals annually (Schlaepfer et al., 2005; Auliya et al., 2016). The trade is the most diverse source of pathogens in terms of species richness, and results in increased physical contact between captive animals and pet owners, as well as pathogen pollution to the wider environment. Regulations and restrictions on the amphibian pet trade would provide safer conditions for both humans and wildlife. These recommendations resonate well with ethics in civil societies around the world (Wilson, 2017). For instance, following the implementation of the wildlife trade ban in China, a questionnaire was developed by Chinese conservation organisations to understand the public's point of view. In urban environments the survey received over 100,000 responses with 96.4% supporting a ban on consumption of all wild animals, and over 90% supporting a ban on all trade in wild animals, including for food or medicinal use (Shan-shui Nature Conservation Center, 2020b). In another survey conducted in March 2020, covering several eastern Asian regions (Hong Kong SAR of China, Japan, Myanmar, Thailand and Vietnam), 93% of the 5000 respondents highlighted the same willingness to eliminate illegal and unregulated markets, with 82% of respondents wishing to do so because of fear of further zoonoses (GlobeScan, 2020).

Eastern Asia has therefore shown strong leadership following the current pandemic, the resultant increase in public awareness, and in synergy with the need for quick action to mitigate against further pandemics. However, in this region amphibian trade is not well regulated, amphibian species richness is poorly understood and most species are not nationally protected (Stuart et al., 2008; Rowley et al., 2010; Tapley et al., 2018). For instance, only a small proportion of declining amphibian species are currently listed on CITES (the Convention on International Trade in Endangered Species), yet the amphibian trade is a major cause of population declines in several species (Krishnasamy and Zavagli, 2020; Rowley et al., 2016; Warkentin et al., 2009). In view of the global amphibian decline and the risks of zoonoses, we support the current wildlife trade bans, as well as measures to safeguard wildlife from overexploitation, and propose the following recommendations specifically for amphibians.

2. Restriction to amphibian farming in eastern Asia

Southeast Asia is currently the centre of the amphibian trade as food for human consumption. Historically, much of the internationally traded amphibian meat originated in Bangladesh and India (Altherr et al., 2011; Warkentin et al., 2009), until the Indian bullfrog (*Hoplobatrachus tigerinus*) and the Indian green frog (*Euphlyctis hexadactylus*) were included on Appendix II of CITES, and the trade of the species was banned in both countries due to the illegal and unsustainable capture of wild frogs (Kusrini and Alford, 2006). The amphibian legal trade then shifted, primarily to Indonesia, and resulted in an increase from 180 million to 1 billion individual frogs of several species being traded between 1998 and 2007 (Warkentin et al., 2009; Krishnasamy and Zavagli, 2020). The principal importers for the food industry are the European Union and the United States of America (Carpenter et al., 2007; Altherr et al., 2011), although the trade within the region is not negligible (Kusrini and Alford, 2006).

The domestic harvest of native wild amphibians in the USA (e.g. *Rana aurora draytoni* and *Rana pipiens*; Jennings and Hayes, 1985; Lannoo et al., 1994) and France (e.g. *Rana temporaria* and *Rana esculenta*) has already impacted amphibians through the loss of large populations of some species (Le Serrec, 1988; Neveu, 2004; Ohler and Nicolas, 2017). These countries are now relying on imported frog meat that is generally not traceable (Ohler and Nicolas, 2017; Krishnasamy and Zavagli, 2020). In addition, a significant proportion of the current amphibian trade for food and pets is unsustainable, likely to involve laundering of wild-caught specimens as captive-bred (Krishnasamy and Zavagli, 2020; Warkentin et al., 2009), and likely to spread batrachochytrids (Gratwicke et al., 2010; Kolby et al., 2014) and other pathogens (Gilbert et al., 2013). An example of unsustainable trade is the mismatch between the quota set for the white-lipped treefrog (*Nyctimystes infra-frenatus*, formerly *Litoria*) by the Indonesian Captive Breeding Production Plan and the potential reproduction based on breeding biology of the species (Janssen and Chng, 2017). However, the risks linked to trade need to be mitigated for some species, especially in Indonesia - the primary contributor to the amphibian trade.

The Ministry of Agriculture and Rural Development of Vietnam ordered a ban on the trade of wildlife in March 2020, implemented in July by the Prime Minister (Instruction No. 29/CT-TTg), stipulating that wild animals and products thereof cannot be traded or consumed even when authorised by CITES permits. In addition, it recommends the closure of illegal wildlife markets, the improvement of wildlife farming management and the development of a database for threatened species currently in captivity (Group IB in the Decree No. 06 and CITES Appendix I). The ban has already resulted in several amphibian species being removed from the trade (ENV, 2020). However, this is a temporary measure with an extension being discussed (ENV, 2020), and specific licences for farmers can still be legally acquired. Nonetheless, this ban means that the sale of wild native East Asian bullfrogs (*Hoplobatrachus rugulosus*) has been discontinued in the country and the bullfrog populations may improve from a break in wild harvests (Warkentin et al., 2009). Furthermore, the environment may benefit from a decreased risk of pathogen transmission (e.g. *Mycobacterium* sp., Suykerbuyk et al., 2007; batrachochytrid, ranavirus and general clinical condition, Gilbert et al., 2013; batrachochytrid, Auliya et al., 2016). If the trade ban is upheld, amphibians currently in captivity would likely need to be either euthanised or released. While culling without financial subsidy is unlikely, these captive populations would probably be illegally sold or released into the wild, as seen in other species in similar situations (Corlett, 2014). Similar to instances of individuals escaping from farms (Garner et al., 2009), the release of farmed amphibians can result in genetic homogenisation and the loss of genetic diversity across wild populations (Kumschick et al., 2017; Turvey et al., 2018), as well as increasing the likelihood of pathogen transmission between released farmed stock and wild amphibians (Jensen and Camp, 2003; Gratwicke et al., 2009; Schloegel et al., 2009). Genetic homogenisation is a particularly salient problem in species complexes where cryptic species await formal description, such as *H. rugulosus* (Yu et al., 2015) and *Andrias* spp. (Turvey et al., 2019; Yan et al., 2018). Fortunately, in the case of *H. rugulosus*, frogs are generally harvested locally for the establishment of farms, therefore escape or release is unlikely to result in the introduction of individuals from segregated or different populations/species that may threaten genetic integrity (Kriger and Hero, 2009).

Other native species have the potential to be locally farmed, such as *Fejervarya cancrivora* and *Limnonectes macrodon* in Southeast Asia (Gilbert et al., 2013; Kusrini, 2005; Kusrini and Alford, 2006), and *Rana* spp. in North East Asia, where amphibian farming relies on species that are better adapted to cooler climates (Park et al., 2014; Ri, 2018). For instance, there were 152 farms breeding *Rana* in northeastern China in 2007 (Liu et al., 2007). In R Korea, farming of three *Rana* species has been permitted since 2005 (R Korea; Ministry of Environment, 2017), and several dozen facilities are now farming *Rana* species (Park et al., 2014). While farming native species can sometimes be benign, the

available numbers of captive-bred *Rana* are not currently satisfying the market (Maslova, 2016). In R Korea, farms can apply for permits to import the same species as the one they breed, mostly from China (R Korea; Ministry of Environment, 2017). In China and Russia, this translates to illegal harvesting from the wild (Maslova, 2002; Maslova, 2016), smuggling (Lyapustin and Fomenko, 2015), unsustainable export (Maslova and Lyapustin, 2005), and species laundering under the cover of farming following the significant depletion of wild populations (Maslova, 2018).

A complication for the amphibian meat trade arises when a farmed species is non-native, such as the American bullfrog (*Lithobates catesbeianus*; Luque et al., 2014). Multiple escapes and releases have resulted in feral populations of a highly invasive species becoming established in all eastern Asian countries where its ecological requirements are met (Altherr et al., 2011; Groffen et al., 2019; Kusriani, 2005; Mohanty and Measey, 2018; Ri, 2018; Schloegel et al., 2012; Sy, 2014; Wang and Li, 2009). The presence of *L. catesbeianus* has been linked to introduced pathogens and higher pathogen prevalence in native amphibians (Ficetola et al., 2007; Gilbert et al., 2013; Wasserman et al., 2019), as the species is a known reservoir of *Batrachochytrium dendrobatidis* (Bai et al., 2010; Borzée et al., 2017b; Fisher and Garner, 2007; Ribeiro et al., 2019), ranavirus (Gray et al., 2009) and other parasites (Ransangan et al., 2013). The presence of the species outside of its range has been clearly linked to numerous declines in native species (Li and Xie, 2004; Ra et al., 2010; Snow and Witmer, 2010), and negative economic impacts when invasive populations are established (Measey et al., 2016). While upholding the trade ban in Vietnam has a strong conservation benefit for many native species, it may also result in the establishment of farms of invasive species, such as *L. catesbeianus*, and the establishment of invasive populations when farmed individuals release or escape. Similar issues have been expressed about the possibilities of other species becoming invasive. For instance, in the Philippines and in the Malaysian states of Sabah and Sarawak in Borneo, *H. rugulosus* is a non-native species commercially farmed for the food trade as well as for fishing bait and aquaculture feed (Das, 2011; Das et al., 2014; Sy, 2014), despite the climate of the area being adequate for invasions by the species (Mohanty et al., 2020). Additionally, Chinese giant salamanders that were released in Japan after being farmed for food, now hybridise with the native Japanese giant salamanders (*Andrias japonicus*) and threaten their genetic integrity (Fukumoto et al., 2015; Wang, 2015). Consequently, we recommend upholding trade bans, especially for live individuals and threatened species.

While farming of *L. catesbeianus* has not been as successful as expected in some countries, such as Indonesia (Kusriani and Alford, 2006) and the R Korea (Groffen et al., 2019), it is still a widespread practice in some other regions (Kang et al., 2019; Wang et al., 2009), and escapees from farms in all regions continue to threaten the surrounding wildlife. Farming of native frogs has also been developed into a lucrative business (Ding et al., 2015; Zhan and Yang, 2012), with *Hoplobatrachus* spp. individuals reaching marketable size within four months (Fang et al., 2002; Pearson et al., 1997). For comparison, *L. catesbeianus* takes up to three years in natural weather conditions around 40°N, or eight months at 25–30 °C (Lutz and Avery, 1999). Areas with a tropical climate can profitably farm *H. rugulosus* or *Fejervarya* spp., especially given that some of these species are considered to be delicacies in some regions (Truong, 2000). Colder areas can rely on *Rana* spp., where research shows that the farming of *R. chensinensis* and *R. dybowskii* can be profitable (Li et al., 2007; Qian and Chen, 2003; Xu et al., 2018) and where it is now relatively prevalent (Li and Chen, 2005; Liu et al., 2007; Maslova, 2018).

However, the current farming of native species cannot be treated as a net-positive conservation intervention. For instance, harvesters in Indonesia believe that harvested species are declining, although an alternative explanation is competition between harvesters (Kusriani and Alford, 2006). Similarly, populations of the native *H. rugulosus* in China have declined by approximately 30% between the 1980s and 2010s (Xia,

2010), and other large-bodied frog species have declined in Southeast Asia during the last decades (Rowley et al., 2010; Wei et al., 2014). In addition, the genus *Rana* has declined over 60 to 70% of its range despite the active development of amphibian farming in China, resulting in a 21.5% decrease in populations of *Rana* over 15 years (Liu et al., 2014; Liu et al., 2007), on par with the decline in *Rana* populations in Russia (Maslova, 2018). Breeding of these species in farms has not decreased the intensity of harvesting in the wild (Zhan and Yang, 2012), and it is therefore important that the farming of native species starts supporting conservation efforts by relieving pressure on wild populations and that these operations cease the laundering of individuals and contributing to the decline and extirpation of wild populations.

Therefore, we recommend a complete ban on the farming of non-native amphibian species, especially when there is a high potential for feral populations of such species to become established in the environment surrounding the farm, i.e. non-native species to become naturalised. In the absence of alternatives, and when possible and ecologically sustainable, non-native species should be replaced by local native species. A certification system to trace the provenance and source of animals by both sellers and buyers, as used in fisheries, could help identify and curb illegal wild harvests; however, clear mechanisms to prevent fraud are also needed (Veith et al., 2000). Alternatively, regulated harvest of wild populations could still be allowed at specific times of the year and in specific contexts, such as rice fields, as these are the primary habitat of numerous common and non-threatened Asian anuran species (Borzée et al., 2017a; Holzer et al., 2017; Kusriani and Alford, 2006; Naito et al., 2013). Considering this, rice fields would require protection, as an increasingly high number of rice fields are being developed for non-agricultural uses, especially in northern Asia (Fujioka and Lane, 1997; Yan et al., 2015; Borzée et al., 2017a; Deng et al., 2019; NBSC, 2019; Wang et al., 2019).

Finally, it would be important to give consideration to rectifying the negative impact of farming non-native species, such as the local eradication of feral populations of *L. catesbeianus*, already planned by some nations (Democratic People's Republic of Korea, National Biodiversity Strategy and Action Plan, 2017), following precedents set elsewhere (Kamoroff et al., 2020).

3. Regulation of the amphibian pet trade

Amphibian pathogens are spread and introduced through the wild-life trade (Fisher and Garner, 2007; Gilbert et al., 2013; O'Hanlon et al., 2018), and the pet trade is known to be a significant pathway for the spread of amphibian pathogens (Nguyen et al., 2017; Rowley et al., 2016). In addition, the pet trade threaten species (Choquette et al., 2020) and may result in the introduction of feral populations, and while no such species has been reported in Asia, to our knowledge, potentially invasive species have been found in the wild, such as *Xenopus laevis* in R Korea following release or escape (iNaturalist, 2020). Another amphibian invasion related to the trade is *Polypedates megacephalus*, which was introduced at several localities with horticultural plants, and the populations have been increasing ever since (Lee et al., 2019). However, international trade is not the only problem, and trade of species between provinces of a country with different species assemblages results in the same loss. Southeast Asia is a hub for international amphibian trade, and this has a critical impact on threatened species (Nijman, 2010; Sodhi et al., 2004; Krishnasamy and Zavagli, 2020). As a result, several species in the region have exhibited declines in population sizes and have been locally extirpated (Duckworth et al., 2012; Phimmachak et al., 2012; Rowley et al., 2016; Stuart et al., 2006). Specifically, the pet trade is now the primary threat to some Southeast Asian newts, with the USA the largest importer until recently (Krishnasamy and Zavagli, 2020). An example is the Lao warty newt (*Laotriton laevis*) in Lao People's Democratic Republic, where collection for the pet trade is a principal driver for the species' decline (Rowley et al., 2016). Villagers relied on the sale of 100 individuals to European,

Japanese, and Chinese collectors in 2008 and 2009, an unsustainable number for the species (Krishnasamy and Zavagli, 2020). The situation is additionally worrying in view of the spreading pathogen *Batrachochytrium salamandrivorans* that originated from the region and has an impact on other amphibian species, particularly on Palearctic and Nearctic Caudata (Krishnasamy and Zavagli, 2020; Laking et al., 2017; Martel et al., 2014) and anurans (Nguyen et al., 2017), with potentially catastrophic implications (Martel et al., 2013; Stegen et al., 2017). Therefore, it is important to regulate movement of species that can spread pathogens through the pet trade, such as *Laotriton laoensis* (Rowley et al., 2016), but also species such as the European *Salamandra salamandra* (Sabino-Pinto et al., 2015) that can carry pathogens to countries in East Asia (Beukema et al., 2018; Koo et al., 2020). In addition, amphibians in Southeast Asia are also potentially threatened by emerging diseases from other parts of the globe. While the legal trade may be regulated, the illegal trade results in the movement of numerous individuals, such as dendrobatid frogs, through Lebanon and Kazakhstan, before being sold in Thailand (Krishnasamy and Zavagli, 2020; Nijman and Shepherd, 2009), and these individuals are potential vectors of emerging diseases (Woeltjes et al., 2011). The amphibian trade also results in the death of numerous individuals while they are shipped, an exacerbated problem in the case of the illegal trade.

The current wildlife trade ban implemented by countries such as Vietnam resulted in some threatened species that were legally collected for the pet trade now being protected from harvesting, such as *Theloderma palliatum* (IUCN Species Survival Commission (SSC) Amphibian Specialist Group, 2017) and *Theloderma bambusicolum* (IUCN SSC Amphibian Specialist Group, 2015), both under Governmental Decree No. 06/2019/NC-CP of Vietnam (2019). From the point of view of a recipient country of the trade such as the R Korea, where more than 85 anuran and 37 caudate species are imported in the pet trade (Koo et al., 2020), 28 species such as *Rana lessonae* and *Rana pipiens* have been recently listed as “inflow-cautious organisms” (illustrating their potential as invasive species; R Korea; Ministry of Environment, 2020b) and with efforts made to further limit the trade, now require special importation documentation (Heo, 2008a; Heo, 2008b; Borzée et al., 2020a). It is, however, necessary to acknowledge the benefit of amphibian farming locally for the pet trade in specific circumstances and under appropriate biosecurity measures (Mattioli et al., 2006; Tensen, 2016). In addition, an acceleration of the CITES process regulating trade to better match, and catch-up with the IUCN assessments identifying trade as a risk for a particular species could help improve the situation (Frank and Wilcove, 2019). As an example, if species such as *T. palliatum* were included to CITES Appendix II (and Governmental Decree No. 06/2019 of Vietnam, 2019), the trade of these species would halt, similarly to that of *Hoplobatrachus tigrinus* and *Euphyctis hexadactylus* (Kusrini and Alford, 2006). Finally, investing in amphibian conservation in the wild in the form of habitat protection, and not their trade would be a valuable second step (Liu et al., 2019).

Therefore, following in the path of other governments regulating pet trade to prevent the spread of zoonotic and panzootic diseases (Gray et al., 2015; Sullivan, 2018), we call for a stricter regulation in the amphibian pet trade. It would be beneficial that local and international trade accessibility be aligned with species extinction risk and specific trade threats highlighted by The IUCN Red list of Threatened Species, National Red Lists or other more recent and authoritative work. Additionally, quotas should be set and national regulations and CITES procedures should be enforced, along with the improvement of reporting and training of the national bodies responsible for enforcement.

4. Expansion of the wildlife trade ban

Species under the jurisdiction of the Department of Agriculture were excluded from the wildlife trade ban in China. This means that aquatic wildlife, with the exception of species explicitly banned by the Wildlife Protection Law (2018) or in protected areas, can be freely harvested and

consumed (Feng et al., 2018). The reason for this is that the National People’s Congress qualifies aquatic species as a “natural resource and an important agricultural product, as well as a common international practice” (Xinhua News Agency, 2020b). As a result, farmed amphibians on the List of National Key Protected Aquatic Wild Animals for Farming and the List of National Key Protected Economic Aquatic Animals and Plants Resources (Xinhua News Agency, 2020a) can be bred for consumption, or other consumables, and will remain so until further consideration from the Ministry of Agriculture and Rural Affairs from China (Xinhua News Agency, 2020a).

Notable species omitted from the wildlife trade ban include newly described and recently discovered, but undescribed, species of Chinese giant salamanders (*Andrias* spp.) and crocodile newts (*Tylostotriton* spp.). While giant salamanders were formerly widely distributed across much of South and Central China, recent phylogenetic developments have split the clade into distinct species: *A. davidianus*, *A. sligoi*, and an undescribed species, known only from farms (Turvey et al., 2019; Yan et al., 2018). Human-mediated translocations, trade, and release for commercial farming have also led to hybridisation and genetic homogenisation, blurring range delineations through population admixture. Wild Chinese giant salamander populations are now critically depleted or extirpated over much of their range (Turvey et al., 2019; Yan et al., 2018), and extinction risk did not improve following the release of hundreds of thousands of farmed individuals into the wild (Lu et al., 2020; Yan et al., 2018). The genus *Tylostotriton* contains morphologically similar species (AmphibiaWeb, 2020), several of which are listed as threatened (Endangered and Vulnerable) on The IUCN Red list of Threatened Species and Chinese Red Lists (Jiang et al., 2016). Some of these species are continually threatened by the intense harvesting pressure for the international pet trade and habitat destruction (Hernandez and Hou, 2018). Others, such as *T. yangi*, which is Endangered on The IUCN Red list of Threatened Species (IUCN SSC Amphibian Specialist Group, 2020), are harvested to be dried, sold, and used for traditional medicine (Wang et al., 2017).

The farming of *Andrias* spp. can be used to support ex-situ conservation breeding and has the potential to relieve harvest pressure on wild populations. However, while *Andrias* spp. have now been bred for several generations in commercial breeding farms, there are currently no existing *Andrias* spp. captive breeding programs that can produce offspring suitable for subsequent release into the wild. The often unknown provenance of founding stock, presence of multiple pathogens (and the inability to reliably screen for some of these pathogens), and sometimes sub-optimal biosecurity make current farming and breeding facilities inappropriate for conservation breeding. Furthermore, there is evidence that the exploitation of wild *Andrias* spp. is ongoing despite the existence of the farming industry (Tapley et al., 2020; Turvey et al., 2018). Improved supervision and monitoring by authorities is required to address this situation and it would be beneficial to set trade regulations with regard to genetic screening, provenance and pathogen surveillance in collaboration with scientific institutions. There is a need for co-ordinated monitoring and protection of *Andrias* spp., as well as strengthening of legislation and enforcement to protect any surviving wild populations (Turvey et al., 2018). Thus, termination of commercial farming in or near reserves because of the difficulty in regulating poaching, genetic testing for origin of clade before reintroduction, and the development of ecotourism to raise awareness has been recommended (Lu et al., 2020). While the original intention was likely to use ex situ breeding of *Andrias* spp. to alleviate poverty and protect wild populations through “sustainable” farming practices, farming and conservation are clearly different endeavours. Sustainable farming practices can support community development and relieve the pressure on wild populations; however, for the strengthening of in situ protection to safeguard wild *Andrias* spp., any conservation breeding and release would require strict monitoring. Similarly, several species of *Tylostotriton* are now listed as Class II on the List of Endangered Species of China and law enforcement was reinforced during the breeding season of the

species, with habitat restoration and captive breeding programs implemented, with support from local communities (Wang et al., 2017).

It is important to ensure that the sustainable farming practices for these species do not result in an increased risk of zoonoses through pathogens such as *Mycobacterium*, a common bacteria in captive settings (Densmore and Green, 2007). Farms rearing *Andrias* spp. are currently permitted to release untreated effluent from indoor holding tanks directly into streams and rivers, leading to a risk of pathogen transmission (Cunningham et al., 2016). Similarly, consumption of *Tylototriton* spp. as traditional medicine or in food markets can also result in cross-species pathogen transmission through human consumption as food or traditional medicine (Fig. 1). A complete ban on amphibian farming is likely to be harmful to both the environment because of the resulting illegal and non-regulated harvests, and to the human communities who depend economically on the trade. A ban would also likely drive the market underground in addition to the unresolved question regarding either releasing or euthanising the millions of animals now in captivity. The wildlife farming industry is estimated to have employed more than 14 million people and to have generated over £56 billion in China, with food consumption involving species such as the Giant salamander, frogs, and peacocks representing 24% of the total profit (Shuhui, 2008). Therefore, we recommend a gradual shift away from non-sustainable farming practices to alleviate pressure on people affected by an edict (Jiangxi Provincial Forestry Department, 2018a), and with consideration given to the strengthening of wild amphibian populations, to ensure that unintended negative consequences to threatened species can be managed adequately.

5. Conclusion

We recommend that wild individuals of species listed as threatened on The IUCN Red List of Threatened Species (i.e., Vulnerable, Endangered, and Critically Endangered; IUCN, 2020), as well as species listed as Data Deficient and Not Evaluated, should not be legally traded or used without approval from relevant institutions, and never in breach of conservation requirements for the species. Specifically, for species not yet commercially used, or used on a small scale, it would be beneficial to issue and enforce a strict ban. For species that have already been legally commercially farmed and traded at large scales, an impact evaluation on how best to shift to sustainable farming should be conducted including evidence-based recommendations for levels of sustainable use, e.g. through population modelling. A conservation plan with a standardised and regulated methodology should be incorporated into breeding programs for each species. In addition, we recommend that only local native species be farmed to mitigate the risk of introduction and pathogen



Fig. 1. *Tylototriton shanjing* being traded at a market in Hainan in August 2019. This is one of the 40 bags available for sale despite being a nationally protected species in the People's Republic of China (photograph by Benjamin Tapley).

pollution, while maintaining a distinction between farm- and conservation-orientated breeding, but only if this results in sustainable replacement from wild populations. Ultimately, all amphibian farming needs to be sustainable and contributing to the conservation of the species that are farmed independently of the threat level to the species, and must in no case be detrimental to wild populations.

National legislation, such as the Catalogue of National Key Protected Wild Animals for Artificial Breeding in China or catalogues with a similar function in other regions would benefit from re-examination to list amphibian species according to the points developed above. Ideally, any species not present on a national list of species for which trade is legal would not be sold domestically or internationally under any circumstances, and it would be best that permits allowing additional domestication and wild capture of species for commercial or consumption purposes not be issued (Shucong, 2015). However, in the case of species that are abundant in the wild, “laundering [through farms may] not pose a conservation risk; it is a compliance issue” (Natusch, 2018). While the harvest of threatened species must be controlled and stringently limited, harvest of species with population sizes similar or higher than that prior to human activities can be of conservation benefit providing incentives for the protection of wild populations and their ecosystems, through benefits accrued by communities conducting the harvests (Hutton and Leader-Williams, 2003). While this system may be difficult to implement, it is not impossible if this measure is adapted contemporarily and examples where villagers actively protect natural habitats from conversion to agriculture exist (Natusch, 2018), and their example should be emulated.

We also suggest discouraging the consumption of threatened and non-native amphibian species and alternatives should be sought, including the resurgence of regional dishes and food varieties that do not include wild or invasive species, or plant-based alternatives (da Fonte and Marin, 2020; D’Cruze et al., 2020). As an example in China, few species other than commonly farmed species were eaten during celebrations before the Song Dynasty (Hughes, 2020). In addition, we recommend a transition to sustainable farming certification schemes for threatened species. However, the current inability to permanently mark amphibians in a way that is tamper-proof makes certification difficult, and we call for research to test marking systems. For instance, trials with microchips to track the *Andrias* spp. trade were attempted in China, but the project was terminated following concerns over consumers biting into the microchips (B. Tapley, pers. comm). Other methods relying on natural colour patterns for individual identification could also be trialled, such as seen on *Bombina* species (Gollmann and Gollmann, 2011) and Hylidae (Kim et al., 2017).

Emerging infectious diseases are linked to the current extinction crisis affecting amphibians (Bishop et al., 2012; Pimm et al., 2014; Stuart et al., 2004), and to cross-region contamination via international trade. We recommend measures that tailor regulations in such a way as to stem future risks. An example of such regulations would be those in the USA to prevent the introduction of *Batrachochytrium salamandrivorans* (Gray et al., 2015). Finally, we recommend the development of amphibian trade bans in all countries and regions following the examples of China and Vietnam, ensuring that amphibians receive the same degree of consideration as other vertebrates while maintaining a clear distinction between sustainable farming of threatened species and conservation programs, which may include a certain level of regulated harvest. This recommendation applies to native species that are not harvested for subsistence or food production, and under stringent control following the recommendations or trade-regulating organisations such as CITES for species that are traded for purposes other than consumption. Strict enforcement should also be conducted to prevent the legal trade from moving underground. This is the ideal time to be taking these steps, in the light of increased global awareness of the potential impacts of wildlife trade.

CRedit authorship contribution statement

Members of the IUCN SSC Amphibian Specialist Group developed the original idea and drafted the first file, and all authors provided critical feedback, writing and review.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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