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

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

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

INTRODUCTION

Background

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

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

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

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

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

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

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

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

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

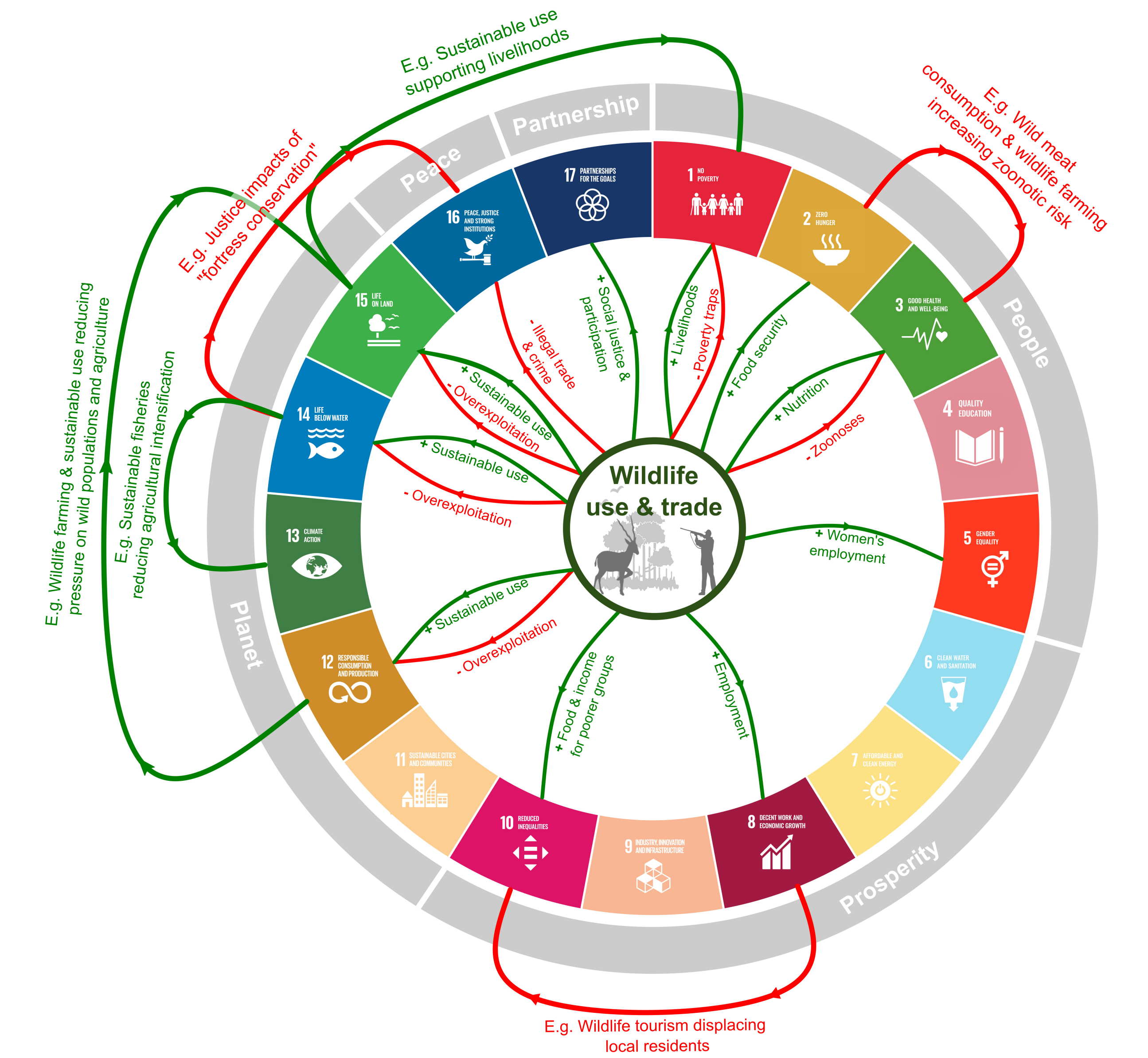

FIGURE 1 | Illustrative examples of some general positive (green) and negative (red) contributions of wildlife trade to the Sustainable Development Goals (SDGs). Direct contributions are denoted by arrows in the center of the diagram, while interactions between the SDGs are denoted by arrows around the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

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

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

"Safeguarding Nature": Direct Contributions Toward SDGs for Planet

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

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

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

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

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

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

A WAY FORWARD: DATA AND PROCESS FOR HOLISTIC POLICY RESPONSES

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

Case Study Examples

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

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

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

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

(Continued)

TABLE 1 | Continued

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

(Continued)

TABLE 1 | Continued

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

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

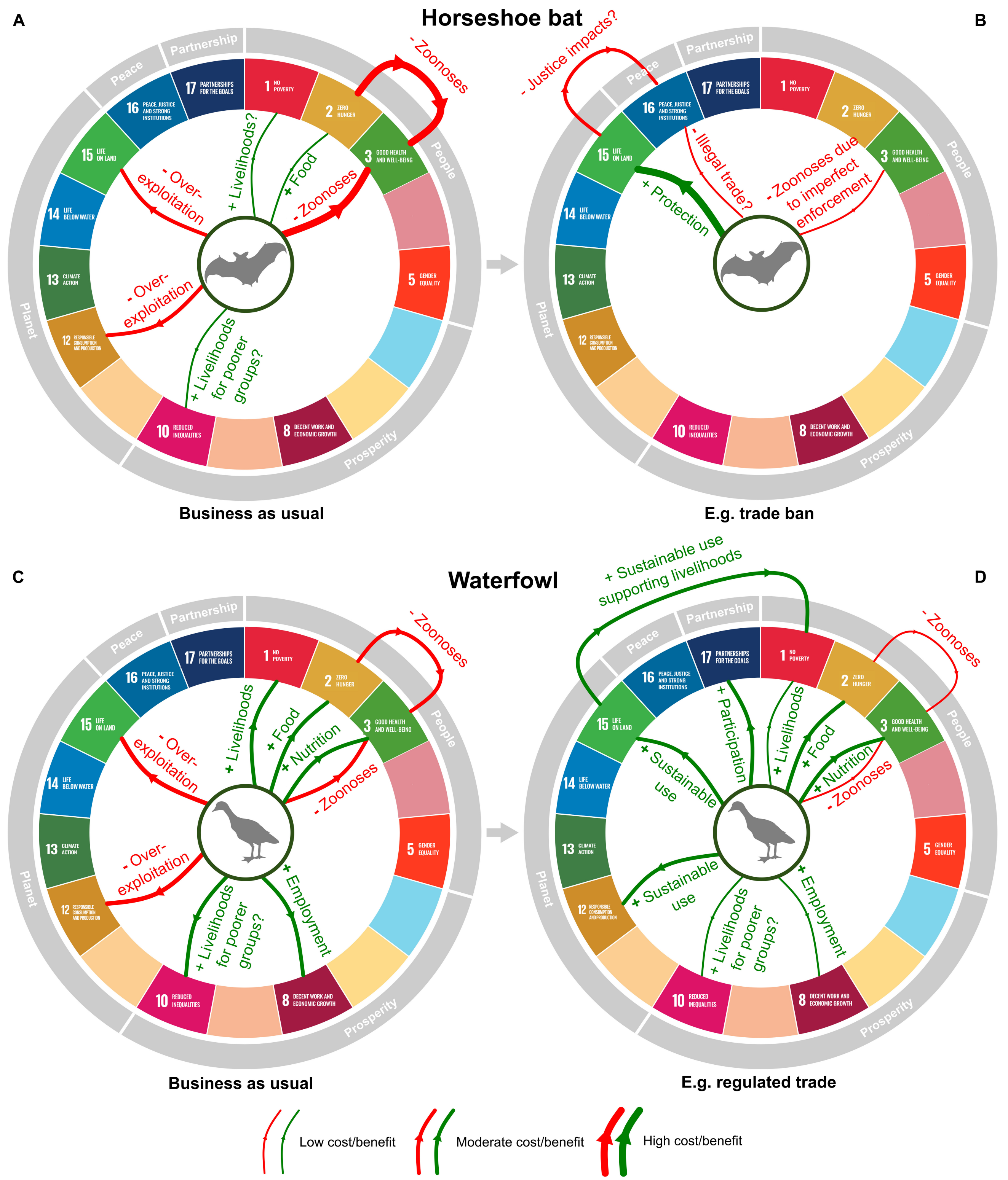

FIGURE 2 | Examples of current positive (green) and negative (red) contributions of horseshoe bat **(A)** and waterfowl **(C)** trade to the SDGs, and how context and species-specific policy responses could improve delivery of SDG outcomes **(B,D)**. Thickness of lines represents the relative size of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

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

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

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

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

Process Considerations

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

Defining the Problem

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

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

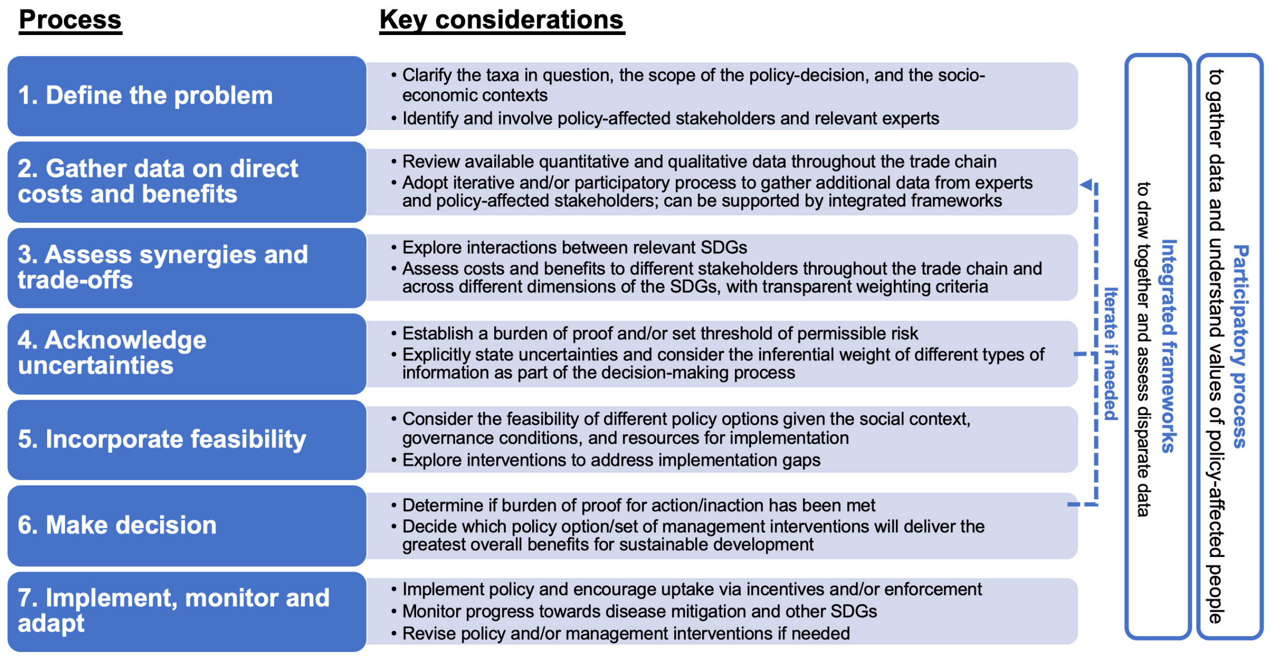

FIGURE 3 | A general process and key considerations for developing risk-based wildlife trade policy for sustainable development outcomes.

Gathering Data

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

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

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

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

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

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

Assessing Synergies and Trade-Offs

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

Acknowledging Uncertainty and Setting Thresholds

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

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

Incorporating Feasibility

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

Making Decisions; Implement, Monitor, Adapt

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

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

Participatory Processes

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

Integrated Frameworks

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

DISCUSSION

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

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

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

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

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

Global Problems Require Global Solutions: The Role of Multilateral Agreements

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

Next Steps for Wildlife Trade and Beyond

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

AUTHOR CONTRIBUTIONS

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

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SUPPLEMENTARY MATERIAL

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