A RAPID REVIEW OF EVIDENCE ON MANAGING THE RISK OF DISEASE EMERGENCE IN THE WILDLIFE TRADE

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Contents

Executive Synthesis

This synthesis integrates the lessons learned from each of the report's chapters and highlights their implications for planning an OIE program on the wildlife trade and emerging infectious diseases. Each chapter includes an executive summary which supports this synthesis.

The wildlife trade involves all OIE Member Countries and all groups of animals the OIE defines as wildlife. The OIE aspires to influence the safety of this trade through multiple means including the creation and sharing of capacity, knowledge, and best practices to safeguard people, domestic animals, and biodiversity through sustainable and responsible practices in legal trade. Managing this risk is, therefore, consistent with the OIE's mandate and strategic goals.

Main conclusions: The nature of future pandemics under global change, and how that might be influenced by alternative decisions, is uncertain. The literature makes it clear that something must be done but is much less clear on how to get it done.

Confronting the threat of emerging infectious diseases in the wildlife trade will require adaptive management that is multifaceted and searches for systemic solutions that reduce the threat of emerging diseases while concurrently improving health, equity, and well-being for all species.

Management approaches will need to be attentive to and adaptable to the socio-ecological determinants that shape this complex trade and drive disease emergence and spread for four main reasons: (i) the wildlife trade is not a homogenous phenomenon; (ii) the origins of pandemic and emerging diseases are deeply rooted in social and ecological interactions and changes; (iii) these changes are happening at an unprecedented rate and scale; and (iv) impediments and enablers of action against pandemic or emerging disease threats are deeply socially embedded.

The extracted literature did not converge to prescribe the most vulnerable points in the supply chain nor effective interventions to predictably reduce the risk of an emerging disease arising in the wildlife trade and threatening public health, conservation, or agriculture. It is a quite different task to accumulate evidence on the presence of emerging pathogens, their locations in the supply chain and their spillover to hosts than it is to accumulate evidence on effective ways to interrupt pathogen spillover or to prevent and mitigate the effects of emerging disease. There are significant and growing amounts of literature on the former, but scant literature on the latter. The absence of systematic evaluations or impact assessments of risk management options precluded identifying policies or practices that are most effective, efficient, acceptable, or sustainable in reducing emerging diseases risks or vulnerabilities of health, social or ecological outcomes. The nature, magnitude, and likelihood of unintended or unanticipated consequences on social and ecological values and functions remains poorly quantified, precluding risk-benefit analyses of options. There is a growing literature on the presence of zoonotic

hazards in parts of the wildlife supply chain that can be used for implication, inference, or analogy but there are few direct measurements of pathogen spillover pathways and the effects of interventions. The bias in the literature to a subset of species and pathogens makes the risk of pathogen spillover within the supply chain unexamined for the bulk of the trade. Tremendous gaps in implementation science prevent comment on the relative feasibility, acceptability, impact, or sustainability of proposed interventions including trade bans, market closures, culling or sanitary regulations. There are many calls for but little validated guidance on how interdisciplinary or systems-based approaches can be operationalized in practice to sustainability reduce risk. There is indirect evidence and opinions that are related to, but outside of or ancillary to the pathogen spillover cascades in the wildlife trade that suggest standard tools used to control domestic animal disease and food safety risks are reasonable to implement but their effectiveness, acceptability, feasibility, sustainability, and unintended consequences cannot be forecasted.

Implications: Uncertainty, interconnectedness, unpredictability, and context-dependence between many different factors in the wildlife trade make this issue a complex and wicked problem. A 20th century 'business-as-usual' approach is, thus, insufficient to confront the complex 21st century challenges of emerging diseases and wildlife trade. Rapid diffusion of evidence-based and adaptable solutions is paramount if the world wants to prevent and mitigate new emerging infectious diseases. Response to this threat must be done collaboratively with other agencies and communities. The scope of possible interventions and partnerships is large but criteria for prioritizing actions and partnerships are lacking and should be developed to fit the mandate of the OIE and its strategic objectives for wildlife trade.

Recommended Actions: Five thematic options were identified to close the knowing-to-doing gap in emerging disease risk management in the face of data deficiencies, debate, and uncertainty: (i) regulatory and governance innovations, (ii) knowledge generation strategies, (iii) knowledge brokering, (iv) implementation support and science, and (v) program evaluation. The relative contribution of each will vary from situation to situation due to the strong context dependency of the origins and management of emerging disease risks. The OIE will need to decide how it wishes to approach its role in emerging disease risk management. It can either (or both) work to ensure trust and confidence in international trade within this era of emerging infections and/or enable and empower efforts to prevent and mitigate emerging diseases and their impacts on domestic animals, people, and wildlife. These are not mutually exclusive approaches, but this decision will influence the resources, skills, and partnerships the OIE will need to implement their wildlife trade programs. This recommendation leads to subsequent general recommendations that the OIE will need to; (i) provide an explicit definition of health to help establish the boundaries of its influence and responsibilities for wildlife health and (ii) determine if

additional investments, personnel, and partnerships are required to provide the technical and contextual knowledge required to implement its wildlife trade programs and plans.

Specific recommended OIE actions:

- develop a theory of change to define the scope and boundaries of its wildlife trade programs.
- implement a multifaceted approach to managing risks within the wildlife trade that includes implementation assessments and program evaluation.
- champion integrated standards and capacity for proactive threat and risk assessments tailored to regionally and locally unique socio-ecological conditions and interactions with wildlife.
- create a collaborative, open access repository of critically assessed research and become the internationally recognized source of high-quality information about the effectiveness, efficiency and sustainability of programs and polices to reduce animal-associated emerging disease risks.
- become a knowledge broker that links knowledge producers and knowledge users and develops international capacity to enable emerging information to be quickly and effectively interpreted, adapted, and applied.
- champion health intelligence to track changes in vulnerabilities that will impact emerging disease threat levels so that nations or regions can proactively tailor their actions to their circumstances.
- adopt a holistic and integrated definition of health that accommodates the need to protect and invest in factors that can prevent emerging diseases and create population resilience against diseases that emerge.
- partner with other organizations and communities to promote an assets-based approach to reduce vulnerability and increase resilience to emerging diseases.
- integrate efforts to reduce emerging disease risks in the wildlife trade with efforts to manage other global risks at the human-animal-environmental interface.
- create a global issue working group that guides innovative and transformative solutions the OIE and national Veterinary Services need to confront the inter-related challenges of emerging diseases, sustainable development, climate change, and biodiversity loss.

Purpose of the Report

The World Animal Health Organization (OIE) is strengthening its wildlife programme to better integrate wildlife health in One Health and animal health strategies. It is planning on developing guidance to address risks of pathogen emergence and spillover through wildlife trade and along the supply chain. The Organization is assembling an ad hoc working group to help in developing that plan.

The purpose of this project was to gather, assess and present evidence from peer-reviewed literature to inform the process for developing guidance to reduce risks of disease emergence through wildlife trade, also considering the impacts on biodiversity. The intent was to complement rather than duplicate previous reports and findings on the contribution of wildlife to emerging zoonotic disease risk. This report focusses on the nature and extent of evidence to help specify effective, efficient, acceptable, feasible and sustainable interventions to reduce the risk of a disease emerging or reduce the impacts of an emerged disease. This project was conducted between December 7, 2020 to February 5, 2021. The timeframe for this project only allowed for a rapid assessment using a desk top exercise that included systematic and semi-systematic literature reviews and key informant interviews and meetings.

Throughout the report prevailing opinions are used to reflect the nature of conversation or opinions uncovered on this topic during this project. These opinions were derived from three sources; (i) comments provided in key informant interviews or in expert group meetings; (ii) comments found on credible websites and (iii) statements or opinions provided in publications that were not explicitly derived from the evidence in the publication, such as general statements used in the introductions to a paper. Opinions were provided because; (i) there are significant gaps in the literature on evaluation and implementation of risk management options for this subject (see chapters two and three) and (ii) tacit knowledge and the opinions of experienced researchers and practitioners make a vital contribution to evidence-based decision making under real-world conditions and in conditions of uncertainty (Hofmeijer 2014, Kothari et al 2012).

The terms of reference for this report were structured around six questions:

- What evidence is there to support the hypothesis that international and domestic wildlife trade (regulated and unregulated) is a risk for disease emergence?
- What are the high-risk practices for infectious disease emergence through wildlife trade, along the supply chain, and at markets?
- What are the socioeconomic drivers for wildlife products and by-products consumption?
- What impacts does wildlife trade have on biodiversity and conservation?
- What risk reduction strategies are currently applied?
- What is the evidence for their impact/effectiveness in addressing disease emergence?

Organization of the report

This document adapts a vulnerability assessment framework to support an appraisal of options to reduce emerging diseases and pandemic threats from the wildlife trade. This assessment has four parts.

1. Chapter 1 Framing the problem.
    a. Goal = Examine the boundaries of the issue and the focus of this report by describing the wildlife trade within the context the OIE's roles and responsibilities for animal health and emerging disease threats.
2. Chapter 2 Vulnerability analysis
    a. Goal = Assess the nature and quantity of peer-reviewed research that could be used to identify critical control points for pathogen spillover between source wildlife within the wildlife trade supply chain and other spillover hosts.
3. Chapter 3 Option identification
    a. Goal = Characterize the evidence of the effects of interventions controlling emerging disease risks within the wildlife trade and document the strength of association and level of confidence in those interventions.
4. Synthesis and recommendations
    a. Goal = Assess the implications of the state of knowledge and use the lessons learned in the literature reviews and interviews to provide opinions and recommendations for OIE.

Chapter 1. Framing the problem

The purpose of this chapter is to examine OIE-related boundaries on the issue by describing the wildlife trade within the context of animal health and emerging disease threats, considering the OIE's roles and responsibilities.

Chapter summary

The Context: Wildlife trade is not a single, homogenous phenomenon. It includes the legal (regulated and unregulated) and illegal, unregulated harvesting, transportation, trade, and end use of wildlife and wildlife products, both at local levels and across jurisdictions along a supply chain involving harvesters, intermediaries, and consumers. The inter-connectedness and inter-dependencies across the various elements of the trade make this a complex supply chain. The OIE aspires to influence the safety of this trade through multiple means including the creation and sharing of capacity, knowledge, and best practices to safeguard people, domestic animals, and biodiversity through sustainable and responsible practices in legal trade.

Scope of the problem: The wildlife trade involves all animal groups defined by the OIE as wildlife and involves all OIE Member Countries.

Size of the problem: Growing scientific evidence and expert opinions combined to allowed us to conclude that urgent risk management actions are required. The wildlife trade has been described both as one of the greatest threats to wildlife species persistence as well as one of the greatest risk factors for emerging infectious diseases (ex. Swift et al 2007, Cunningham et al 2017, 't Sas-Rolfes et al 2019, Fukushima et al 2020) The contribution of the wildlife trade to biodiversity declines varies by species and situations as does the contribution of the wildlife trade to emerging disease risk. The trade impacts positive determinants of human health (ex, income and food security) while at the same time creating conservation, agricultural and public health risks, including but not limited to emerging infections. Data and knowledge limitations combine with the complexity of causal chains and biases in the literature to prevent quantification of the size of these risks and in objective ranking of the wildlife trade as a threat compared to other global threats.

Problem statement: The origins of pandemic and emerging disease risks are deeply rooted in social and ecological interactions and changes. The OIE has a broad vision that could expand their remit to work at root causes, but this would require innovative and collaborative approaches that do not currently exist. The breadth of impacts from the wildlife trade, even if restricted to emerging disease threats, creates several possible trade offs that may influence OIE priorities and resource allocations including managing emerging disease hotspots versus conservation hotspots, reducing zoonotic disease risk versus non-zoonotic emerging diseases and/or preventing new hotspots versus managing existing ones. The scope of OIE's involvement will be determined in part by how it defines animal health. The breath and scope of impacts of the wildlife trade accommodate all aspects of the veterinary domain and fit the OIE's mission and objectives while at the same time creating a complex supply chain that overlaps the interests and mandates of multiple international, national, and local agencies. This breadth creates opportunities, uncertainties, and impediments to selecting and implementing effective actions. Managing the social, ecological, and epidemiological uncertainties or conflicts will require collaborative, adaptive, systems-based risk management. Criteria for prioritizing actions on the wildlife trade from an animal health perspective are lacking and should be developed to fit the mandate of the OIE and its strategic objectives for wildlife trade risk management.

Methods

Step 1: Key informant requests for information

Information on key publications or policies were solicited from members of an International Wildlife Health programs discussion group. This group include representatives from Argentina, Australia, Canada, China, Korea, the Netherlands, New Zealand, Norway, Sweden, Switzerland, Thailand, United Kingdom, and the United States of America. Additional outreach was made to Environment Canada, the Canadian Food Inspection Agency and the Swiss Federal Office of Food Safety and Veterinary Affairs.

Step 2: A semi-systematic literature review

Semi-systematic literature reviews are designed for topics that have been conceptualized and studied differently by various groups of researchers within diverse disciplines and that hinder a full systematic review process. This method is suited to identifying and understanding potentially relevant research traditions that have implications for the studied topic and synthesizing these using meta-narratives instead of by measuring effect size (Snyder 2019).

English language literature was sought from 1995-2020 using the following databases: Google Scholar, Google, the University of British Columbia library general search (which screens multiple databases), the FAO publication search database and the Web of Science. Key words used in different combinations including wildlife, trade, wet market, supply chain, intervention, management, emerging disease, risk, harms, threats, reduction, evaluation, assessment, and policy. All retrieved papers were first screened by reviewing the title for relevance. When relevance was unclear, abstracts were screened and relevant papers selected. References from papers were screened to find additional publications not detected in the database searches. Papers were included at this stage if they contained information to characterize the wildlife trade as to it's possible implications for emerging diseases, pandemics, and wider animal health implications. Relevance screening and reviews were conducted by a single investigator (CS).

GUIDING QUESTIONS

1.1 What is the wildlife trade?

Summary: Wildlife trade includes the legal (regulated and unregulated) and illegal harvesting, transportation, trade (involving money or barter), and end use of wildlife and wildlife products, both at local levels and across jurisdictions along a supply chain involving harvesters, intermediaries, and consumers. There are opportunities for risk management across the entire supply chain that align with the OIE's mission and strategic objectives. The inter-connectedness and inter-dependencies across the various elements of the trade make this a complex supply chain. This implies the need for a systems-based approach to risk management.

Rationale: Wildlife trade involves all legal and illegal sales or exchanges of wild animals (note that other definitions include the sales and exchange of plants as well, but this was not reviewed given the OIE's mandate). This multi-billion-dollar trade involves a diverse range of products including live animals, skins, medicinal ingredients, and food (Broad et al 2003, Rosen and Smith 2010). Participants range from small-scale local harvesters working for their own food or income, to major profit-oriented business, to organized crime. Many people can be involved between harvesters and users in this trade including those arranging storage, handling, transporting, manufacturing, industrial production, marketing, and the export and retail businesses that may operate both domestically and internationally (Nijman 2010). The legal wildlife trade is a large global industry, generating revenue for many national economies, and generating income and providing food for many people worldwide. Although various reports substantiate claims that the quantity and value of the wildlife trade are substantial and increasing (ex. ITC 2015), the size of the trade is difficult to estimate due to data gaps and the role of illegal trade. Based on incomplete data, one report estimated that the global legal trade was valued at ~US$28–92 billion per year and the illegal trade worth ~US$7–23 billion per year (IPBES 2020). The inclusion of fisheries and timber into such calculation led others to estimate that the legal trade was worth US$ 323 billion in 2009 (ITC 2015) and growing in value by 500% between 2005 and 2019 (IPBES 2020). Still others have claimed that the global movement of animals for the pet trade alone is worth approximately US$20 billion per year in 2007 (Karesh et al 2007). "Wildlife is estimated to play a significant and direct part in the livelihoods of up to 150 million people in 2003, much of this from consumption" (Brown and Williams, 2003). "Population growth, increasing buyer power, and globalisation have led to a rise in demand for exotic wildlife (hence international trade) and this has occurred in developed, emerging, and developing nations alike" (Nijman 2010).

The wildlife trade is multidimensional due to the diversity of the species involved, their geographic origins, and the forms in which products are traded (Roberts and Hinsley 2020). Much trade is legal and regulated but there is a growing illegal trade (Phelps et al 2016). The line between legal and illegal trade is not globally consistent: species can move in and out of legal status; their trade in one region may be legal but in another illegal; and the decisions regarding what species will be able to be traded and in what amounts is subject to political influence (Collard 2013). There are multiple types of wildlife trade supply chains. The simplest involve subsistence harvest for personal, shared or very locally traded use. More complicated supply chains involve harvesters having direct

commercial contact with nearby consumers, while others involve harvesters linked through a series of local and national intermediaries to global trading connections (Phelps et al 2016). Some forms of the wildlife trade (such as fisheries) are highly regulated and promoted by governments while other receive little policy attention or enforcement. The balance between import, export and domestic trade varies between countries (IPBES 2020). The routes, volumes and species used in trade, therefore, also vary by country, supply chain, and products.

Wet markets are a portion of the wildlife supply chain receiving most recent attention due to their association with emerging infectious diseases such as highly pathogenic avian influenza, SARS, and COVID-19. Wet markets are where fresh meats, products, and animals, in close contact with other animals and people, are stored to be sold, often in open-air environments. Wet markets sell a range of fresh produce: fruit and vegetables, fish, livestock and, sometimes, but not always, wildlife (Roe et al 2020). Wet markets underpin a food system on which millions of urban and rural people depend. They are a global phenomenon that can allow mixing of multiple species from multiple sources and hence can be locations for pathogen and parasite introduction, amplification, evolution and spread.

Wildlife farming or ranching is an important and growing part of the supply chain. By bringing animals under the direct care and control of people, new opportunities are created to generate local food and income, selectively breed, and preserve animals for re-introduction programs, increase productivity, create opportunities for health management and biosecurity, and reduce the need to capture animals from the wild. At the same time, human interventions can influence the genetic characteristics of populations, create new interfaces for wild/farm interactions, and create conditions conducive to the sharing, spread and evolution of pathogens. There is a long history of wildlife farming and ranching in aquatic species where wild fish are held and reared for population stocking or commercial purposes. Game farming has grown to meet demands for ‘exotic’ proteins. In both cases there are well known risks and conflicts about spillover of pathogens of farmed/ranched stocks to wild conspecifics (ex. chronic wasting disease in cervids and sea lice in farmed salmon). Farms can range in sophistication from local, single operator enterprises to large scale multinational corporate endeavours. The depth and breadth of knowledge on the care and husbandry of farmed/ranched species is generally less than for domestic livestock and highly variable between species, rearing conditions, and countries.

Other aspects of the wildlife trade include capture of live animals for zoos and pets, hunting animals to provide local meat or meat for other market sales, and the use of wildlife parts for clothing, traditional medicines, or ornaments. Despite these differences and variability within the wildlife trade, there are 5 general categories of risk within most supply chains (Christopher and Peck 2004). This framing may help to align a consistent approach to risk management that can be customized to conditions and circumstances of different parts of the trade (table 1.1).

Table 1.1. Generic risk in supply chains with illustrative examples of their possible relevance to risk management of emerging diseases in the wildlife trade

Risk type	Description	Wildlife trade example	Risk management implication
Supply	Factors affecting the flow of products into the market	Declines in preferred species reduce availability of product, shifting supply to another species	Species shifts may introduce new opportunities for novel pathogens to enter the supply chain
Demand	Potential for loss due to mismatch between forecast and actual demands	Local community impoverishment due to lost income from a shrinking wildlife market	Veterinary services can promote domestic animal-based income streams by enhancing remote and rural agriculture which then may reduce pressures to harvest wildlife
Process	Actions taken by suppliers affecting the added value of products	Wild meat butchering at the site of killing	Unregulated butchering may impart animal welfare and food safety harms
Controls	Rules and procedures that govern activities in the supply chain	Diseases status declarations can affect the movement of product	Enhanced transparency and reliability of country wildlife health declarations may make risks detectable and thus manageable
Environmental	Social or ecological actors outside of the supply chain influencing the trade	International support for a new regulatory regime for wildlife trade	Strict sanitary standards customized to the legal wildlife trade may cause unintended advantages for illegal trade

Because the wildlife trade is comprised of interacting, interdependent and changing actors, along with numerous species and regulations that span several scales and change over time and because it is embedded in social-ecological systems, this trade can be consider a complex adaptive supply chain (Surana et al 2005) and risk

management in this supply chain a wicked problem. Uncertainty, interconnectedness, unpredictability, and context-dependence between many different factors are characteristics of complex and wicked problems (Thomas-Walters et al 2020). The parts of complex systems, and the organized structures they create, change dynamically and interdependently over time (Stephen et al 2020b). Complexity in supply chains can result in surprises and mismatches between predicted changes and realized changes. Implementation of policies (decisions) can be defeated by the system's response to the policy, leading to unanticipated, or more modest effects than expected (Agyepong et al 2012). For example, it has been suggested that the European Union's 2007 ban on the import of wild-caught birds to curb the spread of avian influenza was effective in eliminating legal wild bird trade to Europe, but it opened new trade routes that spread disease risk to new world regions (Borsky et al 2020). Systems approaches, rather than crisis-driven, linear decision making is increasingly seen as the necessary approach to complex systems management in health, commercial management, and food production.

Wildlife trade regulations exist at every governance scale, from municipal to international but the trade is a mix of legal, illegal, regulated, and unregulated activities along the path from harvester to consumer. International organizations relevant to or engaged in the wildlife trade include the OIE, the Convention on International Trade in Endangered Species of Wild Flora and Fauna (CITES), Convention on Biological Diversity (CBD) Secretariat, United Nations Environment Program (UNEP), Food and Agriculture Organization (FAO), World Health Organization (WHO), World Trade Organization (WTO), International Union for Conservation of Nature (IUCN) and numerous non-governmental organizations (Cooper and Rooser 2002).

1.2 How does the scope of harms to animal health and welfare and public health align with OIE objectives?

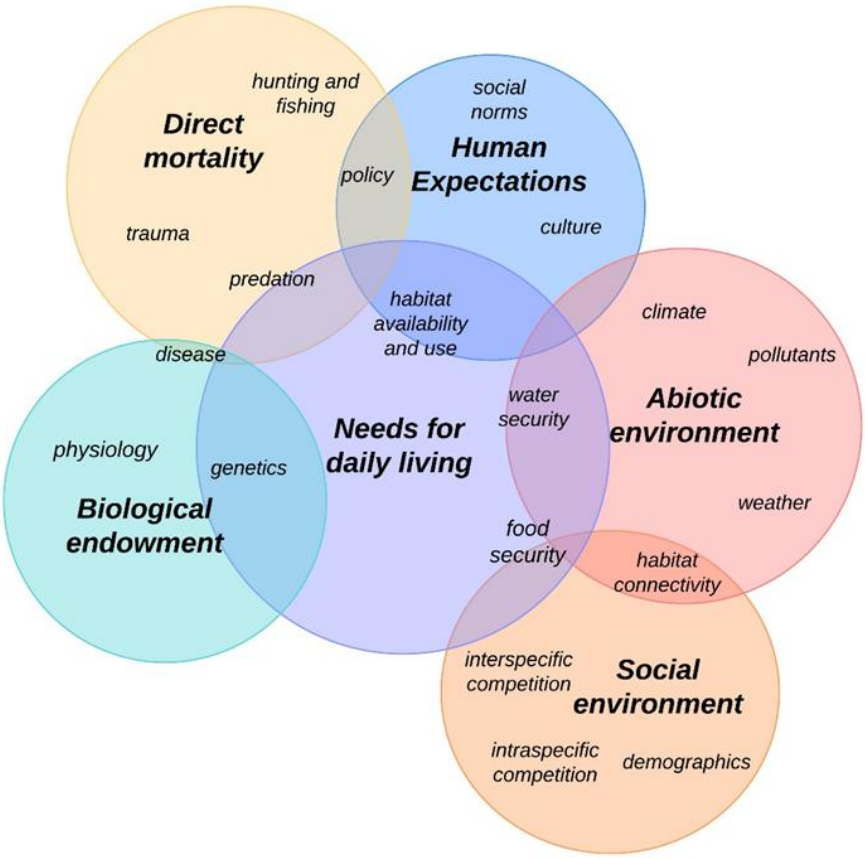
***Summary*:** The wildlife trade poses threats to animal health and welfare and human well-being throughout the veterinary domain. The scope of OIE's involvement in the wildlife trade will be determined in part by how the Organization defines animal health. Health remains explicitly undefined in OIE documents but implicitly remains focussed on disease control. The breadth of adverse impacts on animal and public health associated with the wildlife trade suggest emerging models of wildlife health as a cumulative effect of social, biological, and ecological capacities would accommodate a systems approach to risk management as well as be consistent with the OIE's implicit definition of health and explicit definition of animal welfare.

***Rationale*:** The OIE's 6th and 7th Strategic Plans reaffirm that improving animal health and welfare is the Organization's core mandate. An animal health and welfare focus on wildlife trade would protect the determinants of good health and welfare which, in turn, would reduce the likelihood or impact of a disease emergence and manage factors that increase emerging disease vulnerability and impacts. Such an approach

requires clarity on what constitutes animal health and welfare in order to define the scope of practice for a wildlife trade risk management program. None of the glossaries in the OIE Terrestrial or Aquatic Codes or Manuals define animal health. The definitions of animal health status and animal health management are disease focussed, leaving the absence of disease as a default criterion for health. This perception is re-enforced by pictorial representations of the veterinary domain as per the Terrestrial Animal Health Code which links wildlife only to zoonoses, epizootics and other diseases (WHO-OIE 2014).

The Terrestrial Code recognizes that an animal is experiencing good welfare when it is healthy [undefined], comfortable, well nourished, safe, is not suffering from unpleasant states such as pain, fear, and distress, and is able to express behaviours that are important for its physical and mental state. This is consistent with a definition of wildlife population welfare as coherence between the adapted needs of a species with critical social and environmental resources (Stephen and Wade 2018). Emerging definitions of animal health (fig. 1.1) see health as the cumulative effect of social, physical, and biological influences on the capacity of individuals and populations to; (i) access their needs for daily living; (ii) have capacity to cope with and adapt to stressors and change and (iii) meet ecological and social expectations (Nordenfelt, 2011; Hanish et al; 2012, Stephen, 2014). This perspective accommodates a combined perspective of health and welfare provided in OIE Codes.

Figure 1.1. A proposed determinants of wildlife health model. Categories of determinants are in the circles, with illustrative contributing factors within each circle. The size, shape, interaction, and contributions of each determinant will vary with species, ecosystem, and social context (Stephen 2020)



The veterinary domain includes "all the activities that are directly or indirectly related to animals, their products and by-products, which help to protect, maintain and improve the health and welfare of humans, including by means of the protection of animal health and animal welfare, and food safety" (OIE 2019). The veterinary domain, therefore, implicitly relies on a conception of health as illustrated in figure 1.1.

While current attention has focussed on the role of wildlife trade in emerging zoonotic diseases there are decades old concerns about the impact on other aspects of the veterinary domain including animal welfare, food security, domestic animal diseases and the health and persistence of wildlife populations. The following non-exhaustive description illustrates some wildlife trade impacts throughout the veterinary domain.

Biosecurity and emerging diseases: The wildlife trade has been characterized as the biggest risk factor in the global spread of zoonotic and emerging infectious diseases (Gómez and Aguirre 2008, Swift et al 2007). The importation or movement of invasive species, pathogens, and parasites within, or into the country poses a threat to environmental, social, and economic values (Derraik and Phillips 2010). Emerging infections from wildlife have implications for domestic animal health and for wildlife in addition their zoonotic potential. All species covered by the veterinary domain have been impacted in epidemic form by wildlife infections including people (ex. SARS, HIV, Lyme disease, COVID-19), livestock (ex. African Swine fever, avian influenza) and wildlife (ex. chytridiomycosis, chronic wasting disease). Wildlife is too often considered in this scenario only as sources of risk, however, emerging infections have imperiled wildlife populations already threatened by other risks, driving abundant species to rarity or extinction, and altering the structure of entire communities (Langwig et al, 2015). Most studies of emerging diseases affecting wildlife have been associated with those causing widespread mortalities (ex. amphibian chytridiomycosis, bat white-nosed syndrome), impacting high profile species or species at risk (ex. distemper in big cats) or impacting species of commercial importance (ex. bighorn sheep pneumonia). Details of the association of the wildlife trade and emerging or pandemic diseases are explored in the vulnerability analysis below (Chapter 2). Suffice it to say that growing evidence implicate the global wildlife trade in human disease outbreaks as well as outbreaks impacting livestock, native wildlife, and ecosystems (ex. Karesh et al, 2005, IPBES 2020, Swift et al 2007).

Of relevance to problem framing is the recognition that a diversity of risk factors along the supply chain and the impact of highly variable regulation results in countless opportunities for the generation and transfer of pathogens (Travis et al 2011). Illegal trade multiplies those opportunities by bypassing the usual inspections that serve to protect animal health, food safety, and public health (Wyatt 2013). The release of pathogens and parasites from wildlife involves several co-factors, including anthropogenic or natural ecosystem alteration, climate change, changes in the microbes themselves, and anthropogenic or natural movement of hosts, pathogens, or disease vectors (Travis et al 2011).

Travis et al (2011) concluded that there were 5 major contributors to the spread of pathogens with the wildlife trade: (i) bushmeat trade (ii) invasive species/introduced species; (iii) live animal trade, including pet and research animal trade; (iv) human encroachment or habitat alteration and (v) migration or expansion of habitat.

Beirne (2020) proposed (with some modification) that the causal influence of the wildlife trade on emerging zoonoses is linked to overlapping forms of wildlife-human interaction, highlighting the human dimensions of risks associated with this trade:

1. The shift from indigenous subsistence hunting to professional hunters and organized profit seekers allowed animals and animal parts to be commodified and traded over greater distances and with greater intensity.
2. Degradation of wildlife habitat through rapid human population growth and intrusive activity changed the interactions of wildlife with each other (e.g., increasing the density or types of interactions) and with us.
3. Habitat destruction leading to depopulation, scarcity, or extinction of animals in one area causing wildlife trade to expand into adjacent or more distant regions.
4. Wildlife trade brings together animals of different species, including humans, who would normally not be in contact with each other. This can now occur at unprecedent speed and span greater distances than ever before due to global transportation systems (Karesh et al 2015).
5. Pathogen spillover needs human assistance by creating the four conditions above and failing to marshal the necessary local, national, and international resources to prevent or rapidly respond to risky situations or build resilience in wildlife or human systems to cope with or adapt to an emerging disease.

Both the legal and illegal trade have been linked to the introduction and establishment of invasive species (García-Díaz et al 2017, Souviron-Priego et al 2018). The invasive species may be fellow travelers (ex. pathogen or parasites), stowaways (animals inadvertently shipped with the traded wildlife) or the traded wildlife themselves. Because live animals trade plays a major role in facilitating invasions by non-native species world-wide, the OIE has developed guidelines for assessing the risk of non-native animals becoming invasive (OIE 2011). This tool may be relevant to assessing risks in the wildlife supply chain, but to date, there is no knowledge at the OIE of these guidelines being applied to the wildlife trade (F. Diaz, OIE per com Dec 2020). While there are well defined metrics for assessing invasive species' impacts for agricultural systems and urban and other human-dominated non-agricultural systems (e.g. livestock losses, control costs) there are no commonly agreed-upon metrics with which to evaluate impacts on biodiversity, thus complicating comparable risk assessments (Andersen et al 2004).

Species depletion: The impact of wildlife trade on species conservation is a subject of significant literature, but with seemingly more attention on the impacts of illegal trade or effects on iconic species. Wildlife exploitation is considered one of the most significant drivers of species depletion (Broad et al 2003, Rivalan et al 2007). Unsustainable wildlife trade can not only deplete the target species but can also cause incidental loss of non-target species and deterioration in ecosystem services (Chardonnet et al 2002). While legislation can be in place to maintain trade at sustainable levels, illegal harvest may push the total harvest over sustainable levels (UNEP nd). Unsustainable trade can come from inadequate knowledge to establish sustainable harvest levels, planning

based on human rather than ecological time frames, vested self-interest that value immediate returns over long term assets, species ranges overlapping multiple regulatory and national jurisdictions, and economic and cultural factors (Mace and Reynolds 2001). The long-term viability of a population may be altered or reduced when harvesters target individuals with specific characteristics within a population (Allendorf et al 2009). While a general lack of knowledge of species biology and ecology and of the impacts of harvest practices can complicate assessment and attainment of sustainable wildlife trade, social, political, and economic factor may play a bigger role (Smith et al 2011).

Animal welfare: Impacts on animal welfare are often stated concerns in introductions to this trade but little systematic examination of welfare issues is evident in the peer-reviewed literature ('t Sas-Rolfes et al 2019). Baker et al (2013) analysed 292 peer-reviewed and grey literature publications between 2006-2011 and found welfare concerns clustered in three topics: killing, transport and use. They reported a spectrum of suffering including disease, injury, or functional impairment (25% of screened in articles); environmental challenges such as exposure to hot or cold temperatures or injurious structures (20%); behavioral or interactive restriction (20%); anxiety, fear, pain, or distress (18%); and food deprivation, water deprivation, or malnutrition (13%). Welfare impacts may be underreported in general and the types of welfare harms will vary across the supply chain and with types of animal use. Welfare management is important not only on ethical grounds but also because impaired welfare can lead to stress. Changes in biological function occurring during a stress response may render an animal susceptible to pathogens that may be present in the environment (Etim et al 2014, Moberg 2000). Immunosuppression has been proposed as a contributor to emerging infections such as in amphibians (Carey et al, 1999), some phocine distemper virus outbreaks (Ross et al 2000), disease-linked declines in bees (Mason et al 2013), and Hendra virus shedding in bats (Plowright et al 2008a, Plowright et al 2008b). Welfare standards exist for some forms of legal wildlife trade (as example the Agreement on International Humane Trapping Standards and the Animal Welfare and Safety Act of the Province of Quebec in Canada which applies to wildlife kept for fur, meat, or companion purposes). Current OIE welfare standards deal with many of the domains of harm reported by Baker et al (2013) but are not yet developed for wildlife. International standards in general have little to say about welfare in the wildlife trade and many nations lack wildlife welfare standards (Whitfort 2021).

Food Safety: "A vast proportion of the wildlife trade is for food" (Travis et al 2011). Wild animal meat represents an important source of protein for many people, particularly in rural, indigenous, and vulnerable communities (Wyatt 2013). Consumers are no longer limited to local harvester and traders using wildlife for subsistence. Wild animal derived food is available throughout the world's cities, for private use or sold in restaurants. Although significant attention on wildlife-based foods focusses on terrestrial animals, the wild capture fisheries is an extremely significant producer of wildlife for food. There are many well-documented foodborne zoonotic infections linked to wildlife butchering and consumption (Erickson 2013). For example, the hunting, butchering,

and consumption of bushmeat by humans has been identified as an important human exposure route for the Ebola virus (Alhaji et al 2018). Cantlay et al (2017) concluded that consuming wild meat in Malaysia presented a significant zoonotic risk, based on finding numerous pathogens in wild meats and the cultural preferences for eating raw or undercooked wild meat. The globalization and commercialization of the wildlife trade is creating an expanding exposure network (Cantlay et al 2017) including increased participation of urban residents in this food supply system.

Community well-being: Wildlife trade is not only on the conservation agenda but also on the human development agenda (Cooney et al 2018). It not only provides luxury products for the world's rich, but also essential resources for food and income for the world's most vulnerable people, particularly in developing countries (Roe et al, 2020). People may consider subsistence use of wildlife as legitimate based on longstanding tradition, cultural values or livelihood needs, even if it is illegal. Criminalization of wildlife harvesting and use can disenfranchise communities from their natural resources and foster resentment of conservation efforts (Biggs et al 2017). The IUCN Commission on Environmental, Economic and Social Policy stated that the wildlife trade "can support the survival of traditional knowledge and culture, return equitable benefits from nature conservation to local communities, and help finance basic needs, such as healthcare and education" (Cooney et al 2015.). For communities empowered by effective and equitable governance systems, the benefits derived from trading wildlife products can catalyse community investments in nature conservation, law enforcement and stewardship of wildlife (Cooney et al 2015).

The brief overview above of some of the harms and benefits of the wildlife trade serve as a reminder that this sector is actually or potentially of interest to a wide variety of agencies. The United Nations Development Programme (UNDP), the United Nations Office on Drugs and Crime (UNODC), the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), the World Bank, the International Union for Conservation of Nature (IUCN), the United Nations Environment Programme (UNEP), the World Health Organization (WHO), Global Environmental Facility (GEF) and the OIE have all touched on the need for or have a role in risk managing the wildlife trade. Regional, national, and local regulations further impact aspects of the wildlife trade. The often cited need to deploy a One Health approach to managing pandemic and emerging disease risks from the wildlife trade provides a logical inroad for OIE involvement however what precisely is meant by a One Health approach is variable (Lerner and Berg 2015) and the evidence used to advocate it as an operational framework remains poorly defined (Häsler et al 2014, Baum et al 2017). The OIE, FAO, WHO report 'A Tripartite Guide to Addressing Zoonotic Diseases in Countries', noted that 'most countries have inadequate mechanisms in place for administrative and technical collaboration among the animal health, public health, and environment sectors' (WHO 2019)

1.3 What is the OIE's remit regarding the wildlife trade?

Summary: The OIE aspires to influence the safety of this trade through multiple means. Their interests in January 2021 emphasized the creation and sharing of capacity, knowledge, and best practices to safeguard people, domestic animals, and biodiversity through sustainable and responsible practices in legal trade. The OIE will need health intelligence to support an adaptive management system that tracks the results of its risk management decisions and their unintended consequences on the legal and illegal trade and on emerging disease risk.

***Rationale*:** Recent interest in wildlife trade has been prompted by an apparent surge in East Asian consumer demand, increasingly widespread illegal harvest, unsustainable exploitation of high-profile threatened taxa and emerging and pandemic diseases ('t Sas-Rolfes et al 2019), most acutely COVID-19. This wide scope of concern creates many avenues and needs for intervention to protect and promote the health of animals, people, and ecosystems.

The OIE's mandate is to improve animal health and welfare worldwide, to improve transparency in reporting animal diseases and zoonoses, to contribute to safeguards at the animal/human/ecosystems interface, and to facilitate safe trade in animals and animal products by setting-up sanitary standards. The OIE delivers on its mandate through the establishment for Member Countries of animal health standards, guidelines, and recommendations.

In April 2020, the OIE committed to develop guidelines or standards for trade in wildlife to reduce health risks, and support animal welfare and biodiversity conservation (OIE 2020). Amongst the stated goals are; (i) to support sustainable and responsible practices in legal trade, transportation, capture, farming, marketing, and consumption of wildlife; (ii) create tools for Members to ensure best practices regarding risk assessments and disease management associated with the value chain for the wildlife trade; (iii) strengthen scientific networks to increase sustained Member country capacity for early threat detection, wildlife disease surveillance, information management, risk assessment, prevention of spillover events, and implementation of mitigation measures; (iv) communicate risk and prevention measures to stakeholders to increase knowledge and awareness of Veterinary Services' role in reducing spillover events; and (v) inform at-risk populations of the risks and reduction strategies, to effect appropriate behaviour change.

The OIE currently is still in an 'exploratory phase' regarding the role of Veterinary Services in the illegal wildlife trade. Collaborations have started with INTERPOL on this topic and the OIE is having conversations with the likes of the United Nations Interregional Crime and Justice Research Institute and the United Nations Office on Drugs and Crime. The implications of focussing effort on only the legal trade are unclear. Extreme regulatory risk aversion in the control of legal trade can increase informal or illegal trade, with the unintended consequence of creating additional risks outside regulatory purview (Hueston et al 2011).

The OIE will require health intelligence to provide the knowledge, partnerships, systems, and process to detect, assess and communicate risks to inform and adapt all their aspirations. Epidemics occur in complex systems involving the interactions between reservoirs and hosts, exposure pathways and transmission rates, and environmental and social factors that are inherently interrelated and unpredictable (Wilcox and Colwell 2005). This suggests that health intelligence for emerging zoonotic diseases will need to be aware of changes in human and animal health indicators. The concept of One Health intelligence is in its infancy, but its operationalization is being examined and advocated (Berezowski et al 2020).

The fact that the number of times the conditions conducive to epidemics exist without an epidemic occurring far outnumber the few occasions when one occurs supports the conclusion that epidemics are emergent phenomena of complex adaptive systems (Stephen et al 2004). Disease (re-)emergence, epidemics and elimination can be conceived as critical transitions in complex systems between conditions when a disease will occur and spread and when it will not (Drake et al 2019). Regulations or standards serve to initiate events that interact with the social context of the system to change the trajectory of a socio-ecological system to a state that is not conducive to a specific rate of an infectious disease occurrence. Risk management in a complex supply chain requires understanding how the social and environmental characteristics and circumstances surrounding proposed interventions interact, influence, modify, facilitate, or constrain the intervention and its implementation (May et al 2016). The assumption that targeting one component of the wildlife supply chain will reduce the likelihood of an emerging disease is intuitively appealing but may not be consistent with complex systems thinking. Consistent high-quality data are crucial to the successful risk management in complex systems (NRC 2001), yet there are significant data gaps on wildlife health, as well as on the legal and illegal wildlife trades.

1.4 Can the OIE limit its wildlife trade strategy to selected species or places?

Summary: Criteria for prioritizing actions on the wildlife trade are lacking and should be developed to fit the mandate of the OIE and its strategic objectives for wildlife health. Many authors or programs recommend focussing on hotspots or 'hot species', but diversity in the methods, data and interests used for hotspot characterization requires the OIE to reflect on criteria for selecting hotspots, including trade offs-between emerging disease hotspots versus conservation hotspots, hotspots for zoonoses versus hotspots for non-zoonotic diseases and the focus on preventing new hotspots versus managing existing ones. These are not mutually exclusive decisions, but the implications of a hotspot focussed approach must be carefully considered in terms of resource use, returns on investments and unintended consequences.

***Rationale*:** There is no single authoritative resource that can be used to characterize the diversity of species and locations involved in the wildlife trade nor to estimate the annual total number of animals involved to find critical control points for the entire trade. Different data sources and methods lead to different estimates. Blundell and Mascia's (2005) comparison of US Customs and CITES estimates of trade volumes, for example, were so

discrepant that they concluded the existing data sources may distort the perceived risk of targeted wildlife exploitation. Market end-point use of molecular methods for species identification can find different species in the supply chain than are reflected in official reports (Baker 2008). Scheffers et al (2020) concluded that "of >31,500 terrestrial bird, mammal, amphibian, and squamate reptile species, ~24% (N = 7638) are traded globally" and "owing to their phylogenetic replacement and trait similarity to currently traded species, future trade will affect up to 4064 additional species" (although this analysis too has been called into question, in Kolby 2019). However, Scheffers et al (2020) did not consider legal and illegal fisheries, or the trade in aquatic and invertebrate species. The World WISE database reported over 6000 species had been seized as part of the illegal

trade between 1999-2018 composed largely of mammals, birds, reptiles, fish, and molluscs but this database does not capture the legal trade (UNODC 2020). Underreporting is likely for species and products that may be easier to conceal or not high-profile ('t Sas-Rolfes et al 2019).

Reporting biases towards larger and charismatic species or species of individual high conservation or economic value, such as elephants and rhinoceros, further skew the publicly available understanding of the breadth of species involved in this trade. Despite the many limitations and biases in data documenting the species involved in the wildlife trade, there is sufficient information to conclude that all animals included in the OIE's definition of wildlife in the Terrestrial and Aquatic Codes are involved in the wildlife trade (this includes mammals, reptiles, birds, bees, fish, amphibians and aquatic molluscs and crustaceans) and that all Member countries are involved.

There is a growing collection of literature attempting to identify high risk species or high-risk locations (hotspots) both for conservation and emerging disease purposes. The intent of finding hotspots or "hot species" is to aid in priority setting and strategic planning. Many hotspots or "hot species" lists are the result of academic exercises. Some have drawn policy maker attention to regions or species of assessed high risk. The concept of hotspots is, however, not consistently used. Infectious disease hotspots have been based on elevated burdens of disease, higher transmission efficiency or risk, or higher probability of disease emergence (Lessler et al 2017). Lessler et al (2017) concluded that emerging disease hotspots have generally been described at broader spatial scales (such as southeast Asia or West Africa) with few attempts to identify hotspots of emergence at finer spatial scales that influence localized disease emergence actions. Morse et al (2012) emphasized regions where human activities take place against a background of high wildlife biodiversity, with concomitant microbial biodiversity as emerging disease hotspots. Allen at al (2017) concluded that "zoonotic EID risk is elevated in forested tropical regions experiencing land-use changes and where wildlife biodiversity (mammal species richness) is high". Wet markets have been described as hotspots where novel zoonotic viruses can jump the species barrier resulting in the emergence of novel pathogens. Brito et al (2012) suggested that geographic hotspots for disease differ for birds versus mammals versus amphibians. Scheffers et al (2020) described wildlife trade hotspots based on the

highest number of traded species (highlighting South America, Central to Southeast Africa, the Himalayas, Southeast Asia, and Australia) but noted that hotspot locations differed by taxa. Selecting what hotspots to use for strategic planning will be affected by the goals of the strategic plan. For example, prioritizing hotspots can allow for efficiencies of action dealing with known threats, but targeting cold spots can allow for pre-emptive action to prevent the emergence of new hotspots (Lessler et al 2017). Prioritized species based on their conservation status may differ from priorities set for emerging disease risk management.

There are ongoing academic and policy discussions about which groups of animals are most likely to carry high risk zoonotic pathogens and parasites, but due to their associations with high profile emerging zoonotic viruses, bats, rodents, invertebrate vectors, and waterfowl have been subject to significant research, and in the case of avian influenza, policies and actions (Chan et al 2013, Cunningham et al 201). Bats have recently been subject of significant interest and investigation, including research on how their immune systems, life histories and ecology influence their role as sources of zoonotic viruses (ex. Luis et al 2013). However, if a risk management focus were on emerging diseases in general rather than just zoonoses, amphibians could be assessed to be the vertebrate group most threatened by disease (Brito et al 2012). The capacity to detect emerging diseases in some wildlife, and therefore assess the relative importance of a species as a source of novel pathogens, is compromised when the emergence involves cryptic species, populations in remote areas or species not under surveillance (Stephen et al 2019). Some authors suggest that assessments of the likelihood that a species will be the source of a zoonotic emerging infection is not a property of the animal group *per se* but rather their species richness and abundance as well detection biases and animals' interactions with people or domestic animals (Johnson et al 2020, Mollentze and Streicker 2020). Minimal pathogen surveillance along the wildlife supply chain has precluded assessment of the health risks posed by this practice (Smith et al 2012). Whether the emerging pathogen in question is a newly evolved virulent strain recently spread into a new geographic area, encountering naive or highly susceptible hosts, or it has been present in the environment but has entered new host species or increased in pathogenicity because of environmental changes will influence which species or circumstances to target for risk management (Rachowicz et al 2005). Priority species selection depends on the assets one is trying to protect, the socio-ecological context of the emerging disease event and the willingness to miss emerging disease circumstances due to a narrowed focus of attention.

Hotspot or "hot species" identification requires high quality data on patterns of diseases, pathogens, and risk factors. Ascertainment biases, differing criteria for declaration of an emerging disease, variations in capacity to detect and investigate emerging diseases, focus almost exclusively on infectious emerging diseases, biased and time-limited investment, emphasis on emerging diseases of public health or economic significance, and the influence of power and privilege on what is reported and examined in epidemics skew the perceptions and estimations of the diversity and priority of species or spaces effecting or being affected by disease emergence (Kapiriri 2020, Oppenheim et al 2019, Woolhouse 2008, Stephens et al 1998). Basing wildlife trade risk management strategies on a sub-set of species or places associated to date with emerging diseases risks being inadequately prepared to detect new or unexpected animal hosts sources of infections. Given that species-based

disease risk management measures are considered by some to be inappropriate to manage alien species unintentionally transported into a jurisdiction (García-Díaz et al 2017), there is reason to believe a species-based approach may be inadvisable for the wildlife trade.

Despite these challenges in evidence-based selection of priority management targets, this literature review revealed that all groups of animals considered wild by the OIE have been or are potentially sources or victims of disease emergence (ex. Tompkins et al 2015, Woolhouse 2007, Williams et al 2002, Daszak et al 2000). Selecting priorities for an OIE wildlife trade risk management program cannot be based on the *a priori* selection based on animal species. Risk management activities will need to involve all Member Countries but will need to be adapted to the unique capacities and socio-ecological circumstances facing each nation.

Chapter 2 Vulnerability Analysis

The purpose of this chapter is to determine the scope of literature that has specifically tried to assess or quantify the cascade of events that lead to spillover of pathogens from wildlife to other hosts within the wildlife trade supply chain. The goals were to identify knowledge gaps, how the spillover cascade has been investigated and if generalizations can be made from the existing literature to identify critical control points in the supply chain.

Chapter summary

The goal of this analysis was to determine the nature and quantity of published peer-reviewed research that could be used to identify vulnerable points for pathogen spillover between source wildlife and non-source hosts within the wildlife trade supply chain.

State of Knowledge: Very few papers specifically looked at events that resulted in the spillover of a pathogen from source wildlife to other hosts within the supply chain using systematic research methods. Those that did used study designs that produce only weak evidence for causal relationships. The literature retrieved using the narrow search strategy for this review revealed that studies tended not to look at exposure across the supply chain (thus looking at the supply chain in parts rather than as a whole), were restricted to a sub-set of places, species, and pathogens (thus excluding much of the wildlife trade from examination) and often failed to provide the necessary contextual information to understand how to orient the findings to the wildlife trade. There was a bias towards detecting zoonotic pathogens or examining human behaviours that were presumed, rather than measured, to influence pathogen spillover based on general principles of hygiene and infection control. The reviewed papers used case reports and case series (which tell us about the possibility of an association between an observed effect and a specific environmental exposure) and cross-sectional study designs (which measures the risk factor and outcome at the same time, but does not tell us about their relationship, especially whether it is a causal one). When articles retrieved in this chapter were combined with literature from chapter 3, it could be concluded that there is evidence that wildlife can be sources of zoonotic pathogens and be co-located in spaces and times with known potential spillover hosts in multiple but variable locations in the supply chain, thereby creating numerous potential points of vulnerability.

Implications: The reliance on circumstantial rather than direct evidence is not uncommon for many animal health risk management scenarios. General sanitary and hygiene principles can reasonably be assumed to affect pathogen traffic but the effectiveness of interventions encouraging or enforcing adherence to these principles will be heavily influenced by social and environmental contexts. While this review was not designed to assemble and assess all of the relevant data outside of the study search strategy, it is reasonable to conclude; (i) short term responses to crisis situation can begin by targeting epidemiologically plausible locations for effective spillover hosts exposures but (ii) the contribution of specific points in the supply chain to emerging disease risk will change between species, trade type and time and, therefore, (iii) a continuum of interventions that are subject to process and program evaluations will be critical to medium-to-long term success.

Methods

A rapid, scoping literature review was used in this chapter. A team of six epidemiologists from the Veterinary Public Health Institute at the University of Bern worked with the lead author between January 7-18, 2021 to search for literature that explicitly examined the cascade of events that would lead to the spillover of emerging pathogens from source wildlife to other hosts within the wildlife supply chain. Papers that were included in the analysis were assessed to determine the circumstances (species, hosts, pathogens) and the methods and types of evidence used to investigate if pathogens could move from source wildlife to spillover hosts in the wildlife trade supply chain.

Papers in English, French, German, Spanish, and Portuguese were sought on from the Web of Science using keywords that:

1. Related to wildlife
    a. wildlife, or wild life, or wild animal or exotic
2. And related to emerging diseases
    a. emerg* disease* or emerg* pathogen or diseas* emerg* or pathogen emerg* or spill over
3. And related to the wildlife trade or activities within the wildlife trade
    a. trade or traffic* or export* or import* or captur* or harvest* or trap* or slaughter* or kill* or butcher* or process* or transport* or hold* or zoo* or wildlife park or sale* or market* or commerc* or consum* or use or own* or pet* or meat* or fur or supply chain" or farm* or ranch* or hunt.

The bolean operator “and” was used to identify the intersection between the three abovementioned groups of terms (i.e., wildlife, emerging diseases, and wildlife trade). The extracted papers were shared between the 6 reviewers. Titles and abstracts were screened to include papers that were from original peer-reviewed research,

mentioned some aspect of the wildlife trade supply chain and were investigating the spillover of a pathogen from a source wildlife host to other spillover hosts. A subset of 114 abstracts were also screened by the lead author to confirm consistency in abstract screening. Screened-in papers were read to confirm that the inclusion criteria were met. The lead author acted as the arbitrator for any papers where the classification was unclear as well as screening all excluded studies. Screened in papers were analysed to determine the context of the study and the types of evidence used to examine spillover using a common rubric of categories of study design and purpose. A search verification process was implemented for reviews and opinion papers identified as relevant. References cited in these papers that were not identified in the search were screened for relevance and added to the list of manuscripts.

GUIDING QUESTIONS

2.1 What conditions must occur to form an effective spillover of an emerging pathogen from a source wildlife host to a spillover host?

Summary: A hierarchy of steps need to be spatially and temporally aligned to result in effective spillover of a wildlife pathogen into another host. These steps are influenced by attributes of the pathogens, the hosts, their shared environments, and prevailing social conditions, the combinations and importance of which will vary from situation to situation. The lack of research that looks across the entire spillover cascade only allows for inference or partial insights into the mechanisms and relative contribution of different parts of the supply chain to emerging pathogen spillover.

***Rationale*:** It can be generally stated that there is a hierarchy of five steps that need to be spatially and temporally aligned to allow spillover to occur; (i) a source (or reservoir) host of the pathogen must be exist; (ii) that host needs to be infected; (iii) the pathogen must be released from the source host into an environment that allows its transmission to a spillover (or recipient) host and be able to survive in that environment to remain viable until the recipient host is exposed; (iv) the spillover host must be exposed to a sufficient quantity of viable pathogen to allow for an effective exposure; and (v) the spillover host must be susceptible to the pathogen (Plowright et al 2015). After this initial sequence, there either needs to be ongoing exposures from the source host to maintain infections in spillover hosts or the pathogen must be able to be maintained in the spillover population without the need for the source hosts contributions. In theory, interrupting one step in this cascade should prevent the spillover of a pathogen from a source wildlife population to other populations, assuming only one spillover cascade is generating the risk.

Spillovers involve complex interactions between multiple species in dynamic environments, making it hard to directly observe and measure the underlying mechanism of spillover and the proportional contribution of each step to the overall likelihood of the event, making empirical studies scarce (Borremans et al 2019). Most empirical evidence for spillover has been the result of "nonmanipulative, observational studies" (Power and Mitchell 2004). "Research on pathogen spillover is often focused on a single component of this process through the lens of a particular discipline", thus failing to account for the "hierarchical and often nonlinear dynamics of the spillover system" (Becker et al 2019). Examination of the cascade of five pre-conditions needs both information on the pathogen and the socio-ecological settings to predict higher risk areas (Becker et al 2019). For example, understanding the process that brings source and spillover hosts together needs more than contact and spatial overlap mapping. It also needs ecological and anthropological studies identifying historical, social, and environmental processes affecting the contact network (Narat et al 2017). Lloyd-Smith et al (2009) noted a lack of data and attention to the dynamics of cross-species transmission in zoonotic disease models. Unfortunately, "systems where data have been collected at all levels in the spillover process are rare, or non-existent, and require investment and sustained effort across disciplines" (Cross et al 2019). Reporting biases can

further complicate efforts to assess various steps in spillover using pre-existing data (Johnson et al 2015). Final impediments to identifying vulnerable points in the spillover cascade is that each cascade can be unique, and the number of known and potential spillover cascades have multiplied tremendously in the past three decades and continues to grow. Pathogen and site-specific ecological knowledge seem essential to unravelling how human and animal behavior lead to infectious disease (ex Judson et al 2016). Categorical and quantifiable statements on the transmission chain leading to spillover of a wildlife pathogen to a recipient/spillover host seem, therefore, to be elusive and not generalizable expect at a conceptual level.

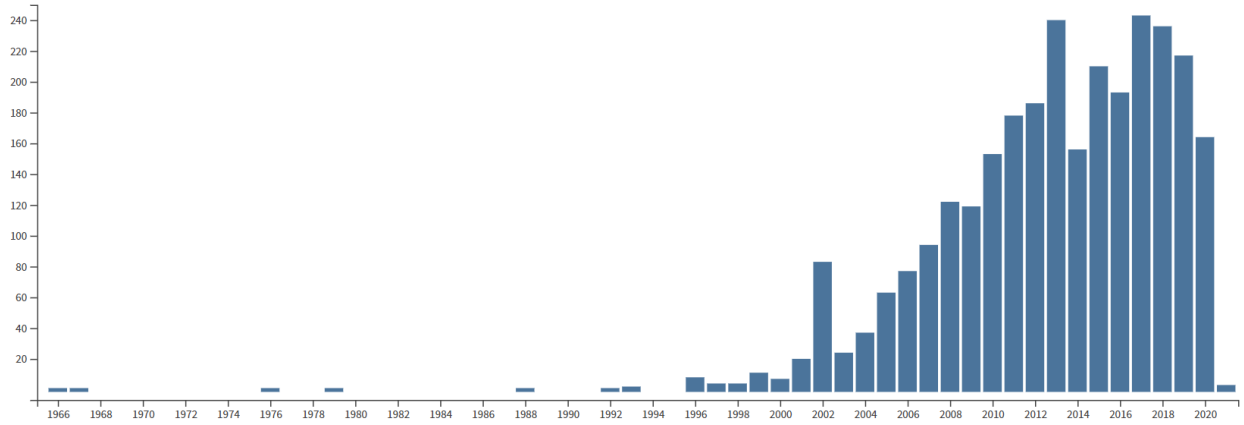
2.2 What were the attributes of papers that considered aspects of the spillover cascade and the wildlife trade?

Summary: Only 1% of the papers found in Web of Science containing our inclusion keywords withheld screening to be included for full analysis (n = 32 papers). Spillover to people was the subject of most interest. Food production and pet trade were aspects of the trade receiving most attention, with a bias towards non-human primates and amphibians as well as to viral pathogens. No studies examined an entire supply chain to trace or compare spillover opportunities for emerging pathogens.

Rationale: The number of papers mentioning wildlife trade and emerging diseases and exposure opportunities within the supply chain have been increasing in number in the past two decades (fig 2.1). Of the 2864 papers including the key words for this review only 1% studied relationships or situations that lead to emerging pathogen spillover within the wildlife trade supply chain. Abstract screening retained 139 papers meeting the initial inclusion criteria. Search verification identified an additional 11 papers, bringing the total to 150 candidate papers (of which 114 randomly selected papers were screened by 2 reviewers with 100% agreement on exclusion). Full manuscript screening left 32 papers included. The excluded papers tended to only mention the key words as background, failed to address the study question or lack details to understand its relationship to the wildlife trade. The remaining 32 were evaluated for evidence documenting or assessing the risk of transmission of emerging pathogens between wildlife source hosts and spillover host within the supply chain.

Non-human primates were the most examined wildlife host (9/32 papers), all from Africa and mostly for viruses related to the HIV pandemic. The chytridiomycosis pandemic resulted in amphibians being the second most frequent host species being studies (7 papers). People were by far the spillover host of most interest (21 papers). Most studies focused on viruses (18 papers), and most of these were zoonotic or potentially zoonotic. Food production and marketing were the most frequently studied components of the supply chain (23 papers). The pet, aquarium and laboratories sectors were the second most frequently studied (6 papers) and mostly involved amphibians. No studies obtained through our search examined an entire supply chain to trace or compare spillover opportunities for emerging pathogens.

Figure 2.1 Number of citations initially extracted using the key words described in the methods section for this chapter on emerging diseases, the wildlife trade, and aspects of the supply chain (n=2864)



The review team encountered some challenges when classifying papers because of lack of description about the wildlife hosts source and the context of the study or lack of definitions. For example, in some cases it was difficult to decide how many generations post-introduction a wildlife host could be considered wild when held in zoos, game farms or the pet trade. As another example, it was sometimes unclear if the bushmeat trade being studied was supply meat for personal use, local trade or distant markets. These deficits could be explained in some paper where the interest was focused on the pathogen rather than the population or the socio-ecologic context of the study.

2.3 How did the extracted literature explore the spillover cascade in the wildlife trade?

Summary: The included papers produced weak evidence of causal relationships between a source wildlife hosts and successful spillover of an emerging pathogen to another host. Papers used cross-sectional or case series designs which are best used for hypothesis generation. There was a bias towards studies that focussed on finding pathogens. Those papers measuring exposure risks used indirect means to assess transmission and rarely accounted for exposure routes other than the wildlife hosts of interest.

Rationale: Included papers were categorized based on the types of evidence they produced and their study designs. Half of the papers (15/32) produced evidence of a pathogen in a source host or a spillover host or in an environment shared by both hosts but did not show pathogen movement between hosts or show both types of hosts concurrently infected. One paper showed the pathogen in both types of hosts but without documented contact or co-occurrence of the wildlife host and spillover host at the same point in the supply chain. Ten papers isolated the pathogen from both the wildlife and spillover host(s) with documented contact or co-occurrence of the wildlife host and spillover host at a point in the supply chain. Only two papers isolated the pathogen from

both the wildlife and spillover host(s) with documented contact of co-occurrence of the wildlife host and spillover host at a point in the supply chain and had molecular evidence implicating that the same strain of pathogen was in all hosts. Three studies were described with inadequate detail or were insufficiently designed to categorize the types of evidence they produced.

Cross sectional study design was the most common (20 of 32 papers) followed by case reports or case series (9 papers). Eleven of the cross-sectional studies were surveys to find evidence of a pathogen mostly in wildlife source hosts. Papers showing co-occurrence and co-infection of source and spillover hosts used both case series and cross sectional (n = 6) study designs.

Case studies provide evidence that something can occur, but they provide no information about how important the risk is, since they provide no information about how frequent exposure opportunities occur, or the prevalence of the pathogen in the wildlife host, or the mechanism of transmission, or the breadth of circumstances that facilitate transmission. An example is an outbreak of Psittacosis in customs officers in the Netherland (De Schrijver 1995). Following dealing with illegally imported parakeets, six of the customs officers developed pneumonia which was confirmed to be Psittacosis and on postmortem examination one of the parakeets was found to have pericardial lesions typical of Psittacosis. Another example is the Monkeypox outbreak in the USA (Reed et al 2004). Monkey pox was identified in people and their recently acquired prairie dog pets, which had been exposed to rodents imported from Africa.

Cross-sectional studies of wildlife hosts often relied on a convenience sample (hunted animals, animals/products sold at markets, live animals sampled after being assembled for transport, after transport or during customs examination). Transmission of the pathogen to the spillover host was usually assessed by collecting samples from spillover hosts usually in a region where infected wildlife hosts were suspected or known to reside. In people, samples were most often blood. Amphibian spillover hosts were often captured, euthanized, and then sampled. Testing for the presence of the pathogen could include detecting the presence of antibodies in the spillover host, or detecting the pathogen (PCR, culture, histology etc.). Evidence of wildlife exposure in people was mostly obtained by administering questionnaires to the study subjects who were asked questions to determine if they hunted, butchered, processed, cooked, ate, or purchased wildlife products from markets. Associations between these activities and previous infection with the pathogen (sero-positivity) were considered evidence that the exposure activities reported in the questionnaire successfully transmitted the pathogen from the wildlife host to spillover host. Cross-sectional studies provide weak evidence of causality and at best should be used to develop hypothesis to be tested in future studies. The reason for this is they cannot be used to establish the time sequence of the occurrence of events. For example, a cross sectional study cannot provide any evidence that the exposures of subjects (hunting, slaughtering, processing, eating wildlife) occurred before the subjects developed antibodies to the pathogens being studied.

Clinical trials are the types of epidemiological studies that provide the strongest evidence for causality. We were only able to find one clinical trial in our list of included papers. This was a laboratory study that demonstrated that bullfrogs could transmit *Batrachochytrium dendrobatidis* to uninfected frogs through shared water sources. This clearly established the high risk of transmission of the pathogen from infected to uninfected frogs. There was controversy as to whether or not this paper was relevant to the wildlife trade as the research question was related to the trade in frogs, but spillover was not studied within the supply chain.

2.4 What are the implications of using a narrow and specific guiding question for this review?

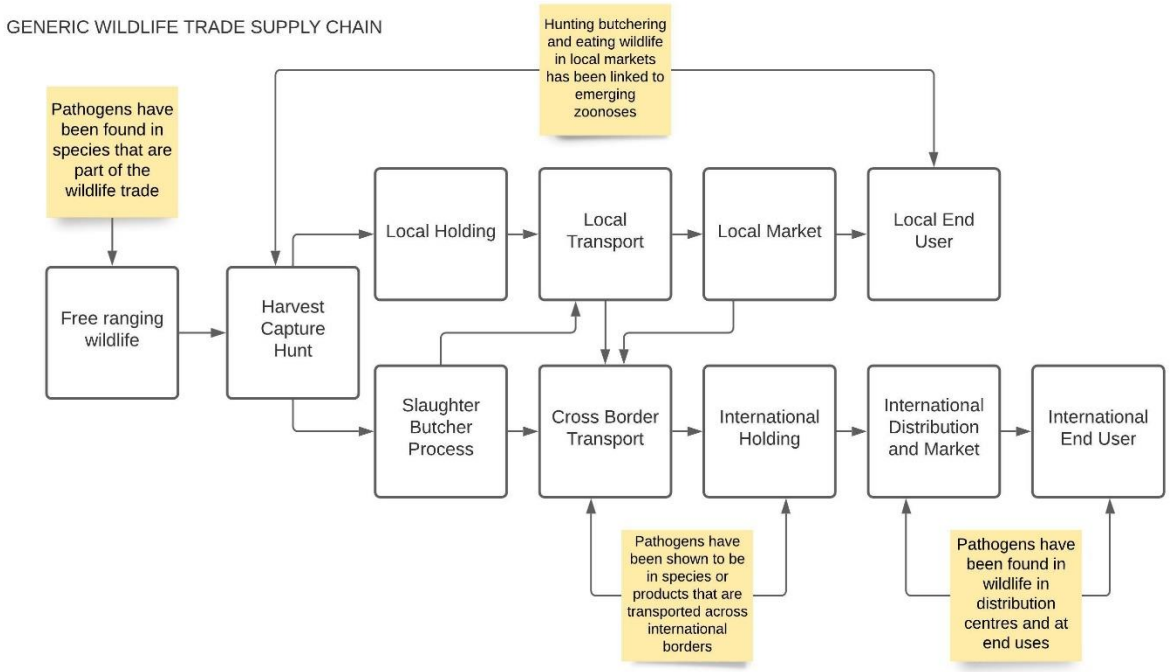
Summary: The restricted nature of the study question allowed the review to seek evidence specifically and explicitly in the context of pathogen spillover in the wildlife supply chain, but it prevented assessment of papers that generated evidence outside of the wildlife supply chain, did not directly explore the possibility of spillover or failed to use the key words selected for the literature extraction. The strong influence of social and ecological context on the origins and spread of emerging pathogens creates concerns about the external validity of data collected outside of the supply chain to draw conclusions on the spillover cascade within the supply chain. Data collected outside of the supply chain and studies undertaken for reasons other than to assess the spillover cascade can, however, produce useful facts, assumptions, and inferences about where exposures may take place in the supply chain. The OIE will need to rely heavily on these types of information to triangulate their evidence base for decision making. Care is advised to ensure those data are assessed for; (i) their coherence with the decision-making context, (ii) their relevance to understanding how the social and ecological context will affect their validity, (iii) the possible ripple effects of interventions at one point in the supply chain and (iv) how well they meet accepted criteria for causation before they are used for decision making. The context dependency of future interventions will necessitate careful postintervention monitoring and evaluation to adapt interventions to changing circumstances. The breadth of evidence the OIE must gather and assess will depend on the Organization's desired scope of practice.

Rationale: We set out to ask two main questions of the extracted papers (i) did they produce rigorous evidence to support a decision on whether a point in the supply chain was vulnerable to pathogen spillover and (ii) could the findings be useful outside the context of the specific study? To be included in this review, papers needed to address wildlife and their trade or traffic, including some descriptor of a plausible activity that occurs in the supply chain and state they were looking at an emerging pathogen. This search strategy excluded evidence relevant to the wildlife trade but generated outside of the trade. For example, prevailing opinion is that subsistence use of wildlife is not part of the trade and therefore, studies of hunted animals for personal use were not be included even though capture, killing and butchering animals for personal use may be analogous to activities in commercial or trade uses. There are many peer-reviewed and grey literature publications that examine portions of a spillover cascade or actions/activities that were examined outside of the wildlife trade

supply chain but are relevant to the supply chain (ex. pathogen surveys of free-ranging animals, evaluating human sanitary behaviours in markets, disease assessments in conservation programs). Papers focussed on endemic rather than emerging infections can also give insight into pathogen spillover to and from wildlife. Excluding these types of papers from this systematic literature review does not mean their contributions were not considered in this report, but rather they did not directly address the study question. Review and research articles excluded for this chapter and literature used in other parts of this project were examined and allowed us to conclude evidence exists for the presence of zoonotic pathogens in many points in the supply chain and that spillover hosts can co-occur spatially and temporally with the source hosts, creating multiple potentials for exposure pathways (fig 2.2).

The restrictive search terms were imposed on this literature review because context should be considered throughout the process of developing and evaluating population health interventions (Craig et al 2018). A population health intervention results in and occurs as a series of inter-related and interacting events within a broader system. Intervention effects are thus modulated by the context in which it is implemented. Care must, therefore, be taken in adapting and transferring evidence generated in one context to another (Minary et al 2018). For example, the microbiological profile of meat collected from wild animals will be affected by the care and attention paid to slaughter hygiene, which in turn can be affected by the outcomes of the meat being contaminated. People hunting for their own food will have different motivations for hygienic practices than hunters who export their food through illegal means to consumers in distant countries. Given that interventions to reduce emerging disease risks will principally be targeting human behaviours, it is important to account for how characteristics of people's social groups and context affect their individual behaviours (as per Diez-Roux 1998).

Figure 2.2. A generic wildlife trade supply chain with notes on where evidence was found detecting pathogens in wildlife or their products.



The OIE asked that this report did not repeat a review of literature on emerging diseases and wildlife trade but rather to build on those previously conducted, hence the focus on examining evidence to support interventions. Suffice it to say that a continuum of interventions will be required because the risks affecting the wildlife trade supply chains will need to be managed at different points and by different players. It further implies that interventions targeting specific locations in the supply chain will need to be attentive to the well-known phenomenon of supply chain ripple effects. These are created when a disruption in one part of the supply chain cannot be restricted to that single part and cascades to impact other points in the supply chain. Ripple effects can be affected by a supply chain's robustness and resilience which are created by redundancies in the chain such as flexible and diverse options for sales or by back-up suppliers and flexible inventory (Mishra et al 2019). For example, alternatives to wet markets as points of sale could allow suppliers to market products elsewhere if wet markets are banned.

Based on this review and expert interviews, the OIE can expect to have access to four types of information for intervention decision making; (i) limited information explicitly examining spillover risks within recognized parts of the supply chain, (ii) a large amount of information generated outside of the supply chain or inside the chain but ancillary to spillover questions, (iii) information generated by studies conducted outside of the supply chain, not explicitly examining spillover, but providing analogy or inference and (iv) expertise of personnel with firsthand observational information. This has two implications. First, critical review of the quality, diversity, and implications of the data available beyond this review's search terms is warranted before triangulating available information for international or local decision making. Even if available data are not specific to a decision-making context, they can be useful to produce hypotheses, inference, and assumptions for action, as is commonly practiced in uncertain decision situations. Such evaluations will benefit from reviews undertaken by people with knowledge of the challenges of studying wildlife diseases and challenges in casual studies involving wildlife and the wildlife trade. Second, the OIE will require access to tacit knowledge. Tacit knowledge can help in identifying hazard sources, in the management of emergency situations and the development of preventive solutions (Boiral 2002). It has been proposed that using people's gained knowledge and experience in strategic decision making can lead to better decisions (Brockmann and Anthony 2002). The OIE will, therefore, need to review the nature and availability of professional experiences and expertise available to them to help interpret and make sense of the varying types of evidence to which it will have access.

An OIE wildlife trade program will undoubtedly require multiple interacting components involving several organisational levels and an evolving yet incomplete knowledge base. The OIE will, therefore, need post-intervention monitoring and evaluation to determine if an intervention is achieving what it set out to do, is making a difference, and is not causing adverse unanticipated effects. The OIE will not be able to pick the 'right" answer using the currently available evidence. Monitoring and evaluation will help reduce uncertainty about which interventions are most promising or effective and ensure ongoing learning for program improvement.

Explicitly stating causal assumptions about how an intervention will work will allow external scrutiny of its plausibility and help evaluators decide which aspects of the intervention or its context to prioritise for monitoring, investigation, or investment (Moore et al 2015). Process evaluation will help identify implementation problems while an assessment of how well a plan is adapted to local conditions will help identify critical knowledge gaps (Craig et al 2019).

Spillover events are rare. There are many more opportunities for spillovers to occur compared to the number of spillover events that occur and lead to disease outcomes. This means that it will be hard to measure the effectiveness of interventions. Lack of impact of an intervention may reflect the lack of contextual relevance of the evidence used or it could reflect implementation failure rather than genuine ineffectiveness. Alternatively, the lack of an outbreak in response to an intervention may be due to an effective intervention or because the conditions were not right for a spillover event to occur. This will create serious challenges for finding concrete evidence that identifies the most important risk factors or assesses interventions. The OIE will need to encourage and enable innovative methods for identifying the most effective mitigation strategies and measuring their effectiveness.

Figure 2.2 serves as a reminder that there are many parts of the wildlife trade that are currently not subject to OIE standards and guidelines. Most of the reports we uncovered dealt with two means for wildlife disease emergence; (i) pathogens being transmitted around the world by movement of live animals (e.g. monkey pox in the USA, squirrel pox in the UK and *B. dendrobatidis* globally) and (ii) pathogens transmitted to people by activities aimed at getting food from wildlife (some of these resulted in small scale, even individual infections, while others have been linked to pandemics such as HIV, SARS and COVID-19). This dichotomy suggests that a focus only on international trade will fail to address the entire spillover cascade, leaving significant holes in emerging disease prevention and control. The OIE has a strong mandate and history of success in influencing standards related to live animal trade. Their influences on local trade, especially for countries lacking a large wildlife trade, and on local food safety standards were not reviewed for this project. The prevailing literature implies that the OIE will need to work with partner agencies and communities to influence the events that transition a spillover event to a pandemic because that transition has little to do with wildlife trade and more to do with human behaviours.

Chapter 3 Options Identification and Screening

The purpose of this portion of the report is to characterize the experience and success in controlling emerging disease risks associated with the wildlife trade and document the strength of association and level of confidence in evidence-based identification of interventions.

Chapter summary

The goal of this chapter was to characterize the experience and success in controlling emerging disease risks associated with the wildlife trade and document the strength of association and level of confidence in evidence-based identification of viable and effective interventions. To address this goal, a semi-systematic, narrative scoping literature review was conducted.

State of Knowledge: The absence of systematic evaluations or impact assessments precluded identification of polices or practices that are most effective, efficient, or sustainable in reducing emerging diseases risks or vulnerabilities for health, social or ecological outcomes. Different experiences and opinions prevented the selection of a single best approach or combinations of approaches to use. The nature, magnitude, and likelihood of unintended or unanticipated consequences on social and ecological values and functions remains poorly quantified, prohibiting risk-benefit analyses of options.

Options screening: Six options most mentioned in the literature were, closing or managing wildlife or wet markets, trade bans, sanitary regulations and biosecurity, reducing demand, culling, farming, and socio-ecological interventions. Evidence and opinion argued for and against each of these options. The tremendous gap in implementation science prevents comment on the feasibility, acceptability, impact, or sustainability of these and other options. Principles of supply chain management demand a multi-faceted approach rather than targeting only one place in the supply chain. Despite the many impassionate arguments for why we need to manage emerging disease risks by addressing its socio-ecological drivers, there is little validated guidance on how this can be done in practice.

Acting in the face of uncertainty: Despite the many uncertainties, there is an expectation of a response to this threat. There is no one-size fits all approach that could manage all emerging disease risks in all settings. Successful interventions will undoubtedly need to be adaptable and multifaceted. Increased capacity and tools to promote transparent and consistent assessments of intervention acceptability, feasibility, adaptability, effectiveness, and sustainability are critically needed. By applying a knowledge-to-action pathway framework, five thematic options for action were identified: regulatory and governance innovations, knowledge generation strategies, knowledge brokering, implementation support and science, and program evaluation. The relative contribution of each of these themes and their associated actions will vary from situation to situation due to the strong context dependency of the origins and management of emerging disease risks.

Methods

Step 1: A semi-systematic search of the same databases used for framing (Chp 1) as well as a search of the evidence hub of the International Initiative for Impact Evaluation (https://www.3ieimpact.org/about-us) were used to find English language literature published between 2000-2020. The latter funds or assesses other projects producing and synthesising evidence in support of evidence-informed equitable, inclusive, and sustainable development. Its database was searched using key world terms, emerging disease, wildlife trade and wildlife disease. Key terms used to search Google Scholar, Google, the University of British Columbia library general search (which screens multiple databases) and the Web of Science included: evaluation wildlife disease prevention control; wildlife emerging disease program or intervention or control; effective wildlife zoonosis program or intervention or control; wildlife trade emerging disease risk management; wildlife trade or wildlife traffic, emerging disease risk evaluation; emerging disease risk effect or effectiveness; avian influenza wild bird risk evaluation; effect* wildlife trade practices and policies emerging disease; wet market effectiveness emerging zoonoses. The titles of the first 250 returns from each search were scanned for relevance, and where not clear, abstracts were reviewed.

Step 2: The key informants as in chapter 1 were supplemented with 10 additional subject matter experts to seek examples of studies which systematically assessed policies or practices to risk manage the wildlife trade from an emerging disease perspective.

Guiding Questions

3.1 Are peer reviewed, evidence-based interventions for managing emerging disease risks in the wildlife trade available?

***Summary**:* The dearth of systematic evaluations or impact assessments precluded identification of polices or practices that are most effective, efficient, or sustainable in reducing emerging diseases risks or vulnerabilities for health, social or ecological outcomes. Different experiences and opinions prevented the selection of a single best approach or combinations of approaches to use. The nature, magnitude, and likelihood of unintended or unanticipated consequences on social and ecological values and functions remain poorly quantified, preventing risk-benefit analyses of options. Prevailing experience and opinion indicate that interventions need to be context specific in terms of the locations, species and form of wildlife trade and their effectiveness and sustainability will be highly influenced by local social conditions and norms. There is no one-size fits all approach that could manage all emerging disease risks in all settings. Successful interventions will undoubtedly need to be adaptable and multifaceted. Increased capacity and tools to promote transparent and consistent assessments of intervention acceptability, feasibility, adaptability, effectiveness, and sustainability are critically needed.

***Rationale*:** There are four main approaches to evaluating health interventions (Spiegelman 2016):

1. Implementation science to assesses the extent to which efficacious interventions can be effectively integrated within real-world systems.
2. Impact evaluation to assesses the efficacy and effectiveness of an intervention in terms of intended and unintended outcomes, involving the explicit statement of a counterfactual.
3. Program evaluation to assesses the processes and outcomes of a program with the intent of furthering its improvement.
4. Comparative effectiveness research to assesses which interventions works best for whom, and under what circumstances in terms of health, economic and (in this case) conservation outcomes.

We failed to find papers that were explicitly designed to undertake any of these forms of evaluation in a systematic and well controlled manner. These findings are consistent with what was found in recent reviews of policy and program actions for the wildlife trade in general. Both Cheng et al (2017) and UNEP (2019) concluded that there is surprisingly limited empirical evaluation of the effectiveness of wildlife trade policy or practices. Cheng's et al (2017), while not in the peer-reviewed literature, provided sufficient methodological details to give confidence in their results. UNEP (2020) concluded that, "a stronger evidence base and greater capacity-building is needed to understand complex risk profiles and to assess the costs, benefits, acceptability and scalability of {such} intervention." They also noted a problem of sustainability of promising prevention efforts that fail to be taken up after time-limited projects end. None of the experts interviewed for this project could provide peer-reviewed or grey literature examples of evaluations of wildlife trade interventions for emerging disease prevention or control.

No definitive statements could be made about cause-effect relationships between interventions and wildlife trade outcomes for several reasons including lack of evaluation of the impacts of interventions, study design limitations (ex. researchers used no control, used historical controls, relied on ecological design {in the epidemiological sense}), assumptions that lack of negative events is proof of effectiveness, lack of sufficient time to follow-up to establish medium-to-long term benefits, and/or unaccounted confounding variables. Some paper contradicted others' or relied on surrogates of risk rather than measuring the impacts on health outcomes or transmission dynamics. These deficits are not surprising because; (i) there was a bias in emerging disease research on hazard detection and pathogen ecology and on describing mechanisms of harm rather than on evaluating interventions and (ii) it is exceedingly challenging to assess the effects of an intervention on outcomes that do not regularly or predictably occur (ex. pandemics) or when the circumstances of their occurrence can vary between incident and situations (e.g., emerging diseases).

A wide variety of interventions were proposed in the grey and peer reviewed literature (see table 3.1 for examples). Many papers identified or postulated points within the wildlife supply chain that could allow for transmission, amplification, evolution, or spread of pathogens (with a bias towards viruses) (See chapter 2).

Table 3.1 Illustrative summary of some options encountered in the peer-reviewed and grey literature to reduce the pandemic and emerging disease risk from the wildlife trade.

Risk type	Description	Example options
Supply	Factors affecting the flow of products into the market	Responding to the illegal trafficking of wildlife through crime prevention, community engagement and enforcement. Banning the trade of wildlife for food and medicines outside of local subsistence needs. Banning high-risk species from inclusion in the trade. Sanitary and biosecurity training and enforcement for wildlife market merchants and along the supply chain. Support sustainable wildlife use systems. Risk assessment methods adapted to the wildlife trade, including the use of HACCP and decision analysis methods.

Demand	Potential for loss due to mismatch between forecast and actual demands	Supporting alternative wildlife-based revenue streams for local communities. Demand management to incentivise use of alternative sources to wildlife. Supporting and incentivizing viable and sustainable food supplies to reduce reliance on wildlife as protein and income sources.
Process	Actions taken by suppliers affecting the added value of products	Sanitary and biosecurity training for harvesters and sellers. Sanitary inspections of markets. Traceability systems for wildlife and wildlife products. Eco-labelling or other marketing tools to place higher value on safer product.
Controls	Rules and procedures that govern activities in the supply chain	Sanitary regulations for wildlife markets. Facilitate safe international movement of animals including compartmentalization and zoning. Engage rural communities that neighbor or live with wildlife as key partners in risk management.
Environmental	Social or ecological actors outside of the supply chain influencing the trade	Enhanced capacity for wildlife disease surveillance, investigation, response, and reporting. Manage environmental and social drivers of emerging wildlife disease inside and outside of the supply chain. Increased investment in interdisciplinary approaches to understanding and regulating the trade. Increased investment in research to support evidence-based regulatory responses and identify critical control points adaptable to local circumstances. Management of the livestock-wildlife interface.

Themes of discussions about some proposed options

This section provides a thematic assessment of trends in discussions seen in the extracted literature for some of the management options most frequently encountered in this review. The following is not a systematic review nor can it be considered a complete review. Time precluded an in-depth assessment of each option for all relevant circumstances. For example, experience in managing endemic zoonoses of wildlife origin was not reviewed nor was the experience in emerging zoonotic disease control for domestic species. Publications dealing with conservations harm from the wildlife trade were touched on only as they related to emerging disease risk management. The purpose of this section is not to endorse or refute the effectiveness of any of the options presented, but rather to provide some high-level insights into issues that will need to be considered when contemplating options for emerging diseases risks management in the wildlife trade.

REGULATIONS

"Regulation of the wildlife trade is challenging due to its breadth, scale and the myriad species and products involved" (IPBES 2020). Wildlife trade regulations exist at every governance scale, from municipal to international. The regulatory framework is, therefore, extremely diverse (Cooper and Rosser 2002). There are multiple laws and other international measures that intend to reduce the over-exploitation of wildlife, the movement of pathogens and parasites with wildlife, and animal welfare impacts of the trade (Cooper and Rosser 2002). The regulatory framework needed to manage zoonotic disease emergence, however, extends well beyond sanitary regulations related to animal trade, transportation, and use. It is difficult to draw distinct lines to categorize regulations as relevant or not for managing emerging disease risks. For example, forest fragmentation has been characterized as a risk factor for wildlife disease emergence (Wolfe et al 2005), therefore, forestry regulations could be considered one of the regulatory tools available for risk reduction in some settings. Global transportation of animals and animal products is another risk factor that is governed by agencies outside of the animal health milieu such as International Air Transport Association Regulations (Cooper and Rosser 2002). Policies for human development will impact the need for people to exploit wildlife for food and income (Ament et al 2019). The regulations and agreements addressing the multiple drivers of emerging disease risks are fragmented across multiple agencies at the international, national, and local level. For example, CITES regulates the legal trade in wildlife but does not deal with zoonotic disease emergence; the OIE safeguards trade, animal health and public health but does not deal with the environmental drivers of risk, the WHO deals with the public health implications of outbreaks but does not work at the root causes found in wildlife health, and INTERPOL pays attention to the illegal trade but not the legal trade. This fragmentation can be mirrored at a national level. For example, a 2017 review of Canadian legislation to control a wildlife disease (Segers et al 2017) found that the national and sub-national specific acts and regulations that apply to wildlife disease control interventions depend on the nature of the intervention, the protected status of the species involved, and the

land management jurisdiction. A single intervention type could be regulated under multiple laws and by multiple agencies, with no coordination across laws or agencies. There was no set process, single entry point, nor single contact to guide one through the process of understanding the regulatory pathways, identifying the regulatory agencies involved, or acquiring permits. Anon (2020) described highly variable regulatory regimens amongst the 28 counties in their review of wet market regulation, noting a significant challenge in enforcing regulations, variability in how protected vs non-protected species are regulated and which agencies are responsible for legislation. Magouras et al (2020), concluded that the legal framework for wildlife farming is often poor.

As illustrated below, there are several calls for changing regulations covering different parts of the supply chain including trade bans and wet market controls. Borsky et al's (2020) model suggested that making wildlife trade requirements that restrict trade of animals with a high risk of passing disease to humans could lead to a decrease in the number of animals traded and coincidentally the number of potential zoonotic diseases that are traded (his model relied on CITES data which does not cover domestic trade or fisheries). However, the follow discussion on options shows that the differing experiences and opinions on the effectiveness of regulatory interventions prevents a conclusive assessment of the impacts of regulations on emerging disease risk in the wildlife trade.

CLOSING OR MANAGING LIVE MARKETS

Many non-governmental and governmental organizations have proposed temporary or permanent closure of markets selling wildlife or wildlife products for food or medicines. Examples include the UN Convention on Biological Diversity Secretariat, the proposed US. Preventing Future Pandemics Act, and the China Biodiversity Conservation and Green Development Foundation (Greenfield 2020). Others have noted that millions of low-income households rely heavily on wet markets for affordable fresh food and advocate for a targeted approach to market hygiene and sanitation infrastructure upgrades rather than closures (ex. Nadimpalli and Pickering 2020).

Evidence in support of closures was largely found in avian influenza risk management literature. Papers most often dealt with commercial or domestic poultry rather than wild birds. Both Offendu et al's (2016) systematic review and Shi et al's (2020) meta-analysis of interventions in live poultry markets concluded that evidence exists to conclude that market closures can reduce avian influenza virus circulation in market environments (based on review of 16 and 19 papers respectively). They concluded that market closures are a viable strategy to reduce the zoonotic risk of avian influenza but that economic and socio-political implications favour less drastic interventions. Caution was advised on using their findings due to some of their included studies being ecologic in nature or designed such that considerable confounding and bias were possible. Fournié et al (2014) similarly documented risk reduction effects during market closures but noted that human infections were also interrupted in cities where this measure was not implemented, suggesting that market closures might not have

been the most important driver of reduced incidence. Wang et al's (2020) review of experience with closures in China supported the idea of closures for risk reduction but concluded that effectiveness was influenced by the type of intervention, seasonality, or other confounders. Support for permanent closure of markets can be affected by the frequency of disease outbreaks and risk habituation of market users as familiarity with the disease reduces risk perceptions (Liao et al 2016). Nguyen et al (2017) recognized how market interventions in some situations might shift rather than eliminate risk. They found that trading outside formal markets was highly likely to occur when live markets were closed because the supply chain remained highly flexible in their study location, with traders willing and able to trade in many possible locations. Notwithstanding their centrality in recent discussions on this trade, targeting only wet markets for risk management would be inconsistent with modern food supply chain risk management which acts at all stages of the supply chain, from producer to consumers (Aruoma 2006).

SANITARY REGULATIONS AND BIOSECURITY

Sanitary regulations targeting handling of animals and meat at different points in the supply chain and sanitation requirements imposed on food businesses were emphasized in some documents, especially in response to COVID-19. The director general of the WHO, for example, stated in April 2020 that "WHO's position is that when [wet] markets are allowed to reopen it should only be on the condition that they conform to stringent food safety and hygiene standards" (Briggs 2020). Karesh et al (2007) suggested sanitary conditions be implemented for major wildlife trading hubs to shift disease risk management from the public to vendors and traders, recognizing that the effectiveness or feasibility of such an approach was untested. The regulatory landscape is highly variable in that some countries do not have wet markets, some have but do not regulate them and some jurisdictions have sanitary regulations tailored to wet markets (Anon 2020). The mixture of responsibilities of public health versus animal health agencies for these regulations varies between countries. Prevailing capacity will constrain how a supply chain can respond to new or changed food safety regulations (Henson and Mitullah 2004).

No assessments of the effectiveness of sanitary standards on direct measures of emerging disease risk along the wildlife supply chain were found. Some authors have proposed the need for international food safety agreements (for foods in general) rather than international trade agreements on food safety, arguing that the WTO's Agreement of Sanitary and Phytosanitary Measures are intended to facilitate trade and does not raise public health standards (or in this case, conservation standards) (Silvergrade 2000). Others see a need for commodity-based approaches to international sanitary regulations because of the differences in risks between commodities (Thomson et al 2004). This raises the question about the need (or not) to modify existing agreements to accommodate unique aspects of the wildlife trade.

Biosecurity regulations separating infected and unaffected populations through mechanisms such as health certificates, border inspections, zoning and compartmentalization and practices at production sites are frequently used to reduce disease risks linked to trade in livestock. Pre-movement screening and treatment are

increasingly expected and required for wildlife translocations and re-introductions (see for example the IUCN Guidelines for Re-introductions). The impacts of border and post-border biosecurity activities to act as emerging disease barriers has, however, seldom been investigated but frequently are assumed to be adequate (García-Díaz et al 2017). In 2015, CITES and the OIE agreed to work together to strengthen science-based standards, guidelines, and recommendations as well as measures for safe trade related to disease risk management at the interface between wildlife, domestic animals, and humans (see cites.org/eng/node/18857). A superficial overview of the basic requirements for biosecurity reveals several questions that need to be addressed to successfully design wildlife trade biosecurity measures (table 3.2)

Table 3.2. Three tiers of questions that will influence the design of wildlife trade biosecurity efforts.

Tier 1 questions	Tier 2 questions	Tier 3 questions
Can a biosecurity threat be detected?	Can risky settings be accessed for sample and observation collection?	Can legal and illegal supply chains be accessed? Are there critical risk nodes in the supply chain that are accessible? Can animals be accessed prior to entering the supply chain? Can resources be deployed in remote areas where animals are harvested? Is there the regulatory and resource support to access sufficient samples frequently enough to characterize the risk?
	Can hazards be detected?	Is there adequate laboratory support for timely detection? Are diagnostic tests validated for wildlife? Do case definitions exits?
Will risks be consistently and accurately recognized?	Is there a harmonized risk assessment method adapted to the uncertainties and challenges of risk assessment in wildlife??	Is there a risk assessment framework to assess and weigh conservation, public health and agriculture concerns consistently and transparently in an equitable manner? How will the many uncertainties and unknowns about wildlife trade and emerging disease risks be accounted for in risk analysis? How will trade-offs be made between different concerns (ex. public health vs conservation; food security and human autonomy vs government disease risk management)?

Can risks be managed?	Do validated and accepted methods for risk reduction exist?	Is there a system to identify, validate and adapt methods that are effective in different settings? Which biosecurity measures most effectively separate infected and uninfected wildlife or separate wildlife from non-wildlife? Can Hazard Analysis at Critical Control Points be undertaken in the supply chain?
	Can control points be managed and can management methods be adapted to different socio-ecological settings, different wildlife species or different pathogens?	Can animals be traced in the supply chain? Where in the supply chain can infected and uninfected populations be separated through biosecurity measures? Is there the authority, resources, and expertise to intervene in the supply chain to reduce risk by creating biosecurity barriers? Are international emerging disease biosecurity standards in place? Can interventions shown to be effective in one setting or circumstance be generalized to other settings and circumstances? Is there adequate enforcement capacity?

TRADE BANS

Many organizations, papers, or reports, such as Aguirre et al (2020) and Borzée et al (2020), call for bans on all or parts of the wildlife trade. Some governments have supported or expressed support for restrictions or bans on parts of the wildlife trade in response to the COVID-19 pandemic. Prior to associations of wildlife with pandemic infections, trade ban discussion often focussed on decreasing the commercial use of particular species

to safeguard their populations. International agreements such as CITES and national or regional agreements, such as the US Wild Bird Conservation Act, can lead to bans. Some bans have been proclaimed a success, such as bans on Neotropical parrot trade, while in other cases, such as South African rhinos, animals continue to be killed despite the bans (Santos et al 2001). The effectiveness of trade bans on reducing conservation and public health threats and the unintended social and ecological consequences continue to be debated.

Roe et al (2020), Rivalan et al (2007) and Santos et al (2011) advised cautious and careful approaches to bans to avoid inadvertent conservation and social impacts which may result in undesired non-targeted effects such as increased illegal trade or reduced social benefits from wildlife in vulnerable communities. They noted that complex and context specific social factors will play a large role in impacting the effectiveness of bans. Challender et al (2019) concluded that trade prohibitions have been linked to reduced trade volumes for some species but difficulties in predicting the circumstances of their effectiveness complicate their general application. Baker et al (2013) found in their literature review of 292 publications that past interventions to influence or limit trade were generally reported not to have achieved their goal (58%), whereas positive impacts were reported in 24% and mixed results in 18%.

Experience with Ebola virus showed that social issues such as the mismatch between public health risk messaging and lived experiences of local community members, food security and trust of government can all undercut the effectiveness of bans (Dindé et al 2017, Bonwitt et al 2018). Bans may also transfer risk from one location to another. For example, because the European Union's 2007 ban on the import of wild-caught birds was associated with new trade routes that spread disease risk to new regions, Reino et al (2017) concluded that bans need to be global to avoid rerouting risks. Bans may not only impact livelihood but also can reduce local community engagement in conservation programs, as was seen in the northern Canadian polar bear trade (Weber et al 2015). Concerns have been raised that more restrictive trade could make banned species more valuable and increase illegal trade. Rivalan et al (2007) found that trade volumes can increase in years where species are being transitioned to a more restrictive trade status. Discussions on changing cultural beliefs and practices to reduce consumer demand after bans are controversial in the literature, with tensions between the need to curtail globally risky activities and suggestions of neo-colonialism, stereotyping peoples' beliefs, and xenophobia. Some authors worried that over-emphasizing wildlife trade bans as a panacea for pandemic prevention will distract attention and effort to look at the wider social and ecological factors driving the emergence and spread of infectious diseases (ex. Eskew and Carlson 2020).

Three proposed preconditions for long term success of wildlife trade bans are: (i) they must be coupled with a reduction in demand for the banned products; (ii) they must not undermine incentives to conserve endangered

species in the wild and (iii) they must be supported by governments and citizens in the countries where these species live (Anon, 2008). Regulations and enforcement in the exporting countries, capacity to regulate legal trade and control illegal trade, clear property rights, and the availability of substitute products have also been proposed as determinants of success for trade bans (Santos et al 2011).

DEMAND REDUCTION

"Demand reduction has now been recognised at both national and international levels as essential if the illegal trade in wildlife it is to be effectively combated" (Ayling 2015). Veríssimo and Wan (2019) reviewed 236 campaigns to reduce consumer demand and concluded that "information on outcomes and impacts was largely anecdotal or based on research designs that are at a high risk of bias, such as pre- and post-campaign comparisons. It was unclear whether demand-reduction campaigns had direct behavioral or biological impacts". They also noted that campaigns most often focused on a single species of mammal (except for sharks) and many focused on broad themes, such as the wildlife trade in general. Thomas-Walters et al (2020) similarly concluded that the breadth of evidence needed to understand and predict the potential outcomes of demand reduction interventions is lacking. These authors were concerned that "the conservation community are advocating a shift from one reductionist approach based on limiting supply, to another based on limiting demand", and argue that "conservationists should learn from the public health and international development projects that have integrated systems thinking." Recommendations that cultural sensitivity must underpin demand reduction strategies because they may lead to more effective efforts and move recommendations beyond cultural misrepresentation and racism are noteworthy (ex. Margulies et al, 2019). Bergin et al (2020) noted, but did not specify, growing research into more nuances and effective behaviour change campaigns to effect wildlife demand. Others noted that elements of social marketing are widely used and a platform exists from which to build more comprehensive behavioral influence campaigns, but there remain substantial gaps between best practice in social marketing and current practices in the design of demand reduction campaigns (Greenfield and Veríssimo 2019).

CULLING

Culling remains one of the few feasible tools for wildlife disease management drawn from the options used in livestock. Rarely is mass vaccination, mass treatment, isolation, or quarantine feasible or affordable in free-moving wild animals. Exceptions do exist such as wildlife fences and rabies immunization. Culling is used to reduce the likelihood of transmission of a pathogen or parasite between populations by reducing the density of the infected population below a specific threshold. Several nations are currently using culling or selective culling to control wildlife diseases such as chronic wasting disease and African Swine fever in Europe. In other countries, the negative impact on wildlife conservation and increasing public concerns regarding the ethics of culling challenge or limit its use. Culling can have the undesirable effect of increasing or shifting, rather than reducing, disease risks. For example, culling rats in Canada for pest control led to a significant increase in the odds that surviving rats carry *Leptospira interrogans*. (Lee et al 2018); culling badgers in the United Kingdom to control bovine tuberculosis led to an increased potential for the geographic spread of the disease owing to the disruption

of the social structure of badgers (Donnelly et al 2005/06) and selective culling of Tasmanian devils to control infectious facial tumors had no effect on slowing the progress of the disease (Lachish et al 2010). Harrison et al (2010) recommended that culling should only be considered when (i) the pathogen transmission cycle, including the involvement of all hosts and vectors, is known; (ii) the response of the wildlife population to culling is known and (iii) the benefits outweigh the costs of sustaining a culling program (especially as cost escalate as the last remaining wild animals are sought for killing). None of these conditions are likely to be met when first confronting an emerging pathogen or parasite. The effects of culling for emerging diseases are, therefore, difficult to anticipate due to the complex relationships between host density and contact rates, and disease incidence and because of the likelihood of undesired impacts on diseases dynamics and host conservation. Miguel et al's (2020) literature review concluded that decreased disease risk is far from being guaranteed by culling and that culling can lead to counterintuitive and detrimental outcomes.

WILDLIFE FARMING

Wildlife farming has been proposed as a means of reducing pressure on free-ranging wildlife while fulfilling consumer demands for wildlife products. Having animals under human care and control in farming or ranching settings offers opportunities for diseases surveillance and control, and opportunities to implement hygienic and sanitary standards in raising and butchering animals (Carruthers, 2008). Some organizations have advocated for captive rearing of wild species used in the pet trade as a public health and conservation endeavour (Conniff 2016). Wildlife farming or ranching makes a substantial contribution to the production of wildlife for meat, fur, or pets and is a major economic contributor to many nations. Some countries have regulatory frameworks that subject farmed or ranched wild animals to disease regulations equivalent to livestock, thus enabling traceability, quarantine, surveillance, and disease control efforts. Magouras et al (2020), however, concluded that the legal and technical framework for wildlife farming is often poor, health-monitoring programs are seldom implemented in many countries and published information on production and health is scarce. Occurrences of diseases such as chronic wasting diseases in farmed cervids, COVID-19 in farmed mink, and challenges with disease control in salmonid aquaculture have led to concerns that intensive wildlife farming could create circumstances conducive to pathogen spread, amplification, and maintenance in wildlife farms. Escapes or intentional releases of farmed wildlife or the unintentional translocation of exotic pathogens with the transnational movement of wildlife for farming purposes have also been proposed as threats for disease spread to livestock and other wildlife from wildlife framing (Butler et al 2005).

Tensen (2016) proposed that five conditions need to be met for wildlife farming to be an effective conservation tool: "(i) the legal products will form a substitute, and consumers show no preference for wild-caught animals; (ii) a substantial part of the demand is met, and the demand does not increase due to the legalized market; (iii) the legal products will be more cost-efficient, in order to combat the black market prices; (iv) wildlife farming does not rely on wild populations for re-stocking; and (v) laundering of illegal products into the commercial trade

is absent". Tensen (2016), however, concluded that these criteria are unlikely to be met for most species encountered in the wildlife trade.

SOCIO-ECOLOGICAL INTERVENTIONS

There is a quickly growing literature pointing to systems level changes, such as how we manage our landscapes and relationships with nature, as the drivers of disease emergence. This literature was not reviewed for this project for three reasons:

1. The tools and techniques for modifying emerging disease risks through environmental and social policies and practices falls outside of the current scope of practice of the OIE.
2. There are yet to be universal laws of disease emergence, like there are laws of physics. The complex relationship between socio-ecological system changes and emerging disease risks is still being studied. This makes associations between interventions and outcomes time, location, and circumstance specific.
3. There remains ongoing debate about how changes in landscapes and biodiversity affect risks. Some of that debate comes from trying to compare associations between different host-pathogen relationships.

Complexity is a key characteristic of a 21st-century health and health risks. Transformative changes are needed to manage disease emergence as a complex system outcome. Systemic risks require whole-of-government and whole-of-society approaches (Kickbush and Gliecher 2012), yet an ongoing systematic review of One Health literature is finding that this form of thinking and research is rare in One Health (C. Gallagher pers com Dec 21, 2020). Despite the many impassionate arguments for why we need to manage emerging disease risks by addressing its socio-ecological drivers, there is little validated guidance on how this can be done in practice. Drawing lessons from the application of systems thinking to whole of government and whole of society governance for other health issues could support expanding emerging disease risk management to a systems rather than pathogen perspective.

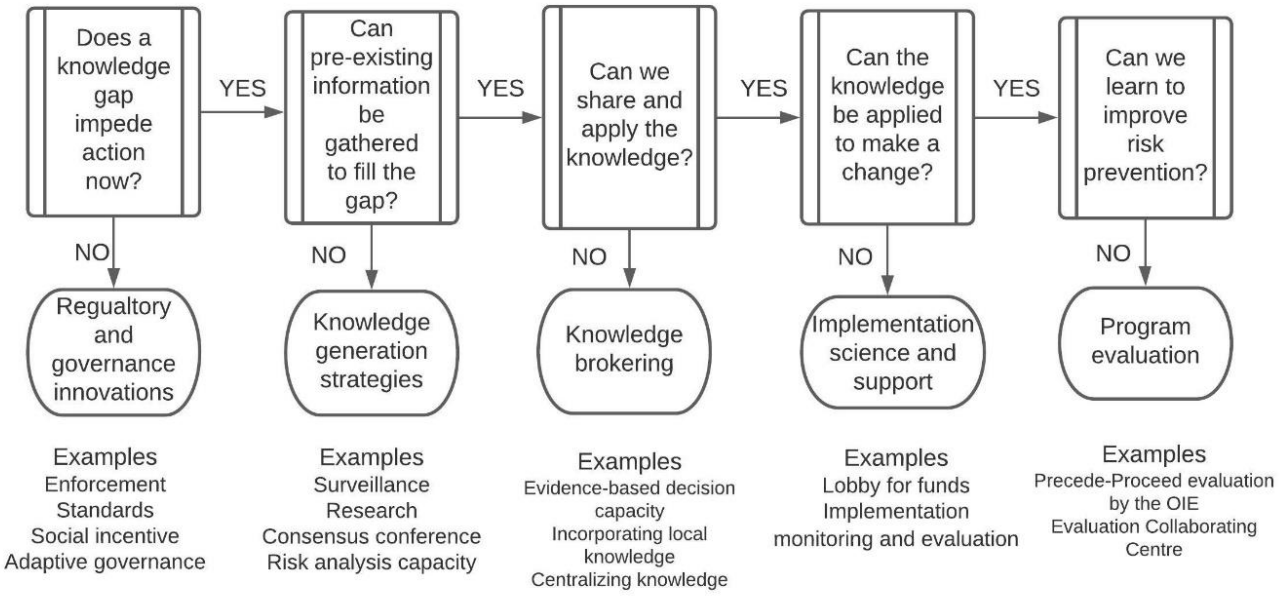
Options Guidance

There were many types of uncertainty and knowledge gaps plaguing the selection of risk management options. The wealth of literature on disease risk management outside of the wildlife trade supply chain (such as in domestic animal supply chains), on the ecology of infectious and parasitic diseases in wildlife and on the management of endemic wildlife diseases provides a rich source of information from which to propose critical control points in the supply chain. The OIE could adopt triangulation methods from public health which synthesizes data from multiple, diverse sources of evidence, including stakeholder input, to inform actions. "Triangulation can be limited by the quality of the original data, the potentials for ecological fallacy and "data dredging and reproducibility of results" (Rutherford et al 2010), therefore, the quality, validity, and comparability of these diverse studies will need to be understood before data and information are combined. Agreements on how to interpret and combine data and to deal with data gaps and uncertainties would also need to be established. Moreover, there will be challenges to generalizing such data to the socio-economic, political, and

environmental differences between the wildlife trade and non-trade settings in terms of determining if an intervention would be effective, affordable, acceptable, or sustainable. Given the tremendous gaps in evidence on risk management throughout the wildlife trade supply chain, significant time and effort may be needed to understand how to combine the pre-existing data reliably and convincingly for decision support.

In the absence of time and resources to launch the requisite consensus processed to develop triangulation governance, we turned to the uncertainties and their associated impediments to action we found in this review to identify options for OIE action (fig. 3.1). Figure 3.1 was informed by literature on closing the knowing-to-doing gap (also known as the implementation gap). The diversity and significance of uncertainties will vary from region-to-region, pathogen-to-pathogen, and species-to-species. Therefore, different elements of figure 3.1 will need to be emphasized for different situations, pointing to the need for an adaptive management approach.

Figure 3.1. This figure identifies themes of actions to remove impediments to implementing interventions in the wildlife trade to reduce emerging disease risks. It uses knowledge mobilization questions (rectangles) to identify themes for action (ovals) intended to address its associated question. Example actions are provided under each theme.



Chapter 4 Synthesis and Recommendations

The purpose of this chapter is to assess the implications of the state of knowledge for the OIE and use the lessons learned in the literature reviews and interviews to provide opinions and recommendations for OIE actions.

Chapter Summary

Key Conclusions: Existing evidence did not converge to prescribe the most vulnerable points or effective interventions to predictably reduce the risk of an emerging disease arising in the wildlife trade and threatening public health, conservation, or agriculture. There is complementary evidence to suggest that the typical tools used to control international animal disease risks can apply in this case, but their effectiveness, acceptability, feasibility, sustainability, and unintended consequences cannot currently be estimated. The presence of divergent or contradictory findings and conclusions further impeded the nomination of the 'best' options for OIE action. Emerging disease actions need to address risks that change over time, locations, species, and pathogens, with high degrees of uncertainty as to the rate and magnitude of changes in response to interventions. Responses to these challenges demand transformative changes in how we approach human-animal-environmental relationships and their co-dependence for health. The OIE's approach to managing emerging disease risks in the wildlife trade must, therefore, be adaptive, multi-faceted, and multi-solving. The OIE will need to align its vision for animal health and its resources and expertise with the information and intelligence demands required to manage this problem in order to define its scope of practice in the wildlife trade.

Specific Recommendations:

1 The OIE develops a theory of change to define the scope and boundaries of its wildlife trade programs.

2 The OIE implements a multifaceted approach to managing risks within the wildlife trade that includes implementation assessments and program evaluation.

3 The OIE champions integrated standards and capacity for proactive threat and risk assessments tailored to regionally and locally unique socio-ecological conditions and interactions with wildlife.

4 The OIE creates a collaborative, open access repository of critically assessed research. It becomes the internationally recognized source of high-quality information about the effectiveness, efficiency and sustainability of programs and polices to reduce animal-associated emerging zoonotic disease risks.

5 The OIE becomes a knowledge broker that links knowledge producers and knowledge users and develops international capacity to enable emerging information to be effectively interpreted, adapted, and applied.

6 The OIE champions health intelligence to track changes in vulnerabilities that will impact emerging disease threat levels, so that nations or regions can tailor their actions to their circumstances.

7 The OIE adopts a holistic and integrated definition of health that accommodates the need to protect and invest in factors that can prevent emerging diseases and create population resilience against those diseases that emerge.

8 The OIE partners with other organizations to promote an assets-based approach to reduce vulnerability and increase resilience to emerging diseases.

9 The OIE's efforts to reduce emerging disease risks in the wildlife trade are integrated with efforts to manage other global risks at the human-animal-environmental interface, such as climate change.

10 The OIE creates a new global issues working group.

Synthesis of findings to guide recommendations

The nature of future pandemics under global change, and how that might be influenced by alternative decisions, is uncertain. The primary conclusion of this report is that the existing evidence did not converge to prescribe the most critical control points or effective interventions to predictably reduce the risk of an emerging disease arising in the wildlife trade and threatening public health, conservation, or agriculture. The magnitude of pandemic or emerging disease risk reduction from actions implemented in the wildlife trade could not be estimated due to complex and multiple ways new infections can emerge and spread and to the lack of specificity on the magnitude or contribution of different points within the supply chain to the risk. The bias in the literature to a sub-set of high-profile species and pathogens leaves most of the wildlife trade supply chain unexamined.

There is complementary evidence to suggest that the typical tools used to control international animal disease risks can apply in this case (such as zoning, sanitary regulations, and surveillance), but their effectiveness, acceptability, feasibility, sustainability, and unintended consequences cannot currently be estimated. It also suggests that some of the standard tools for risk management in an animal supply chain, such as Good Agricultural Practices, Good Manufacturing Practices and traceability are less likely to be effective due to the sizable contribution of the illegal trade to the supply chain and the reliance on field capture, killing and processing for many products. The presence of divergent or contradictory findings and conclusions further impeded the nomination of the 'right' options for OIE action. This is not a surprising conclusion given well known challenges in understanding the status of infection in free-ranging wildlife and in deploying study designs that would allow for confidence in casual associations made between changes in the wildlife supply chain and emerging disease outcomes.

Evidence-based decision making is not merely using formal research findings and quantitative data to support your position. It is about weighing various types of evidence, facilitating appropriate use of evidence, combining various sources of evidence, and providing supplementary evidence appropriate to the local context (Bowen et al, 2009). Evidence-based decisions, therefore, need three types of evidence; (1) evidence specific to the decision-making social and ecological context; (2) evidence extracted from other settings or situations and (3) evidence pertaining to the values and expectations of the decision makers and those affected by the decision. This review found that studies of emerging diseases are highly contextual, thus complicating generalizations of type 1 evidence on interventions. Studies on the human dimensions of the origins and control of emerging zoonotic infections are only recently being published and lack sufficient replication to draw broad conclusions on the relationships between societies, communities, and risks (type 3 evidence). The OIE will, therefore, remain, in the short-medium term, heavily dependent on type 2 evidence from other settings or situations to formulate a strategic approach to diseases risks emerging in the wildlife supply chain.

Managing complex system risk in the wildlife trade

The wildlife trade is a complex dynamic supply chain. The problem of emerging diseases in the wildlife trade has characteristics of a wicked problem including; each occurrence of an emerging disease is unique in its own respect, the range of causal factors can be uncertain and can be very wide as can the suite of possible solutions, many people and organizations are involved or affected, problems are multi-faceted, it takes time and resources to get to root issues driving the problem, and fixing one aspect of the problem can create new problems. In complex wicked problems, there is no single, elegant, rational, scientific finding that will point to the right decision to fix the problem. Wicked policy situations arise when each problem in the system is unique and tailor-made solutions are needed and when multiple stakeholders diverge in their perceptions about what are the problems and their causes (Hamm, 2009). These features of wicked problems were commonplace in the wildlife trade and emerging disease literature we found and interviews we conducted.

Progress can be made on wicked problems when organizations switch from being the one to provide the solution, to helping develop a collective view of the questions that need to be asked to allow for incremental improvements on aspects of the problem for which there is agreement and to promote a collective responsibility to act before we have perfect knowledge of the situation (Grint, 2010). Organizations working on wicked problems need the ability to cooperatively work across agency boundaries, debate the appropriate accountability framework, engage stakeholders and citizens in understanding the problem and identifying solutions, engage in big picture thinking, better understand behavioural change, have a comprehensive focus and/or strategy, and accept uncertainty (Thormann 2018).

The challenges that face the OIE today differ from the past because as the scale of human influence has increased, the most significant threats are global in nature, and problems are aggregating and compounding with each other. The rate and nature of new infectious disease emergence is expected to increase in unexpected ways as climate change interacts with other global and local forces (Zell 2004). Responses to 21st century health threats will be unpredictable and emergent rather than predictable and planned because of the unprecedented rate of social and environmental change and the complexity of interactions between co-occurring global threats (Hanlon and Carlisle 2008). Actions to reduce emerging disease risks from the wildlife trade need to address risks that change over time, locations, species, and pathogens, with high degrees of uncertainty as to the rate and magnitude of changes in response to interventions. Responses to these challenges demand transformative changes in how we approach human-animal-environmental relationships and their co-dependence for health. The OIE's approach to managing emerging disease risks in the wildlife trade must, therefore, be adaptive, multi-faceted, and multi-solving.

The OIE will need to select high-impact actions within each of the themes of adaptive, multi-faceted, and multi-solving interventions. Reiman et al's (2014) proposed principles for adaptive management in organizations where failures can result in significant negative effects merge with many of the themes encountered in this review and may provide some guiding principles to operationalize an adaptive, multi-faceted, and multi-solving approach (table 4.1).

Adaptive management "is intended to increase the ability to fashion timely responses in the face of new information and in a setting of varied stakeholder objectives and preferences" (NRC 2004). Adaptive management requires collaborations to characterize the full extent of a problem, anticipate the possible consequences of responses throughout the system being managed, evaluate impacts of interventions, and incorporate lessons learned into future decisions (Ebi 2011). Without this approach, the OIE may find itself implementing policies and programs that are less than effective, inefficient, and potentially harmful.

Table 4.1 Principles for managing safety in complex adaptive systems used as guidance for the OIE's task to respond to emerging infectious diseases in the wildlife trade (after Reiman et al, 2014)

Principle	Guidance for OIE emerging disease risk management in the wildlife trade
Set boundaries, objectives, and priorities	The OIE must set explicit boundaries for its activities since there are no natural all-inclusive boundaries between the various overlapping components of the wildlife trade. This will help the Organization focus its unique skills and knowledge, select metrics and means to monitor progress, and develop needed partnerships.
Promote prevention as a guiding principle	The OIE must work with partners (local to international) to develop a shared value of prevention that will encourage actions in advance of harms.
Create standards and processes	The OIE should review if or how its existing trade and sanitary standards can be directly applied to wildlife or if evidence suggests they must modify or develop standards and guidance to assess risks and to assess and apply evidence for action in the unique context of the wildlife trade.
Monitor the system	Monitoring and surveillance systems must be adapted to the objectives and goals of future OIE wildlife trade programs. To evaluate and assess a full spectrum of risk factors and impacts of wildlife trade risk management interventions, monitoring and surveillance may need to consider a wide suite of variables such as tracking adverse outcome factors (such as diseases and outbreaks), risk factors (such as pathogen traffic or changes in human uses of wildlife), vulnerability determinants (such as changes in human-wildlife interaction in critical areas), and program outcomes (such as changes in sanitary actions in the supply chain).

Create capacity for situational self-organization	The OIE must adjust and interpret rules and standard operating practices according to situational requirements. This will require risk managers to have sufficient understanding of the possible risk impacts of their actions building from a good understanding of the core tasks, populations, threats, and hazards that need to be managed within a wildlife health context.
Optimize local efficiency	Emerging diseases cannot be managed in isolation from other OIE processes and strategies. They must be managed considering other threats (such as climate change and biodiversity loss) and account for differences in local capacities and risk circumstances. OIE actions to control emerging disease risks must avoid creating new or additional threats and conservation or social harms
Facilitate novelty and diversity	Our understanding of the genesis, prevention and response to emerging infections is changing and can be expected to keep changing under current conditions of social and environmental change. The OIE must assess, clarify, reinforce, and amplify locally developed innovations and facilitate their diffusion and adaption to other settings in a timely fashion.
Facilitate connections, interactions, and collaborations	Interactions in which people trust each other, know and respect each other's competences, and are willing to share information, and learn from each other are needed to foster collaborative interventions and remain innovative. The OIE must pay particular attention to human dimensions of the wildlife trade that impede or enable effective risk management.

There is growing recognition and advocacy for transformative changes in how we address mega-threats like emerging diseases and climate change. The recommendations below strive to provide the OIE with tangible actions it can take to transform towards a systems-based and evidence-based adaptive management approach considering its current governance and decision-making structure. The recommendations have been developed with due consideration to the OIE's 7th Strategic Plan and its historic scope of practice, including its significant roles in capacity development, harmonization and creating equitable access to knowledge and decision support tools.

Aligning the report with OIE priorities

Summary: The wildlife trade should be managed as part of a comprehensive strategy to combat the spectre of emerging disease, synergising investments in livestock, human health, and ecosystem interventions. It is not possible but is inappropriate to attempt to quantify the attributable risk of the wildlife trade for the purposes of

arguing if investment in risk management is or is not required. There is an international gap in coordinated leadership to address wildlife contributions to this global risk. Action on the wildlife trade is consistent with the OIE"s 7th Strategic Plan. The findings and recommendations from this report align well with that plan as well as ongoing OIE actions.

Rationale: The evidence provided in the report can substantiate the need for OIE action for two reasons; (i) there is evidence from past emerging disease (ex. avian influenza, SARS and COVID-19, Ranaviruses) that wildlife trade associated emerging diseases can have highly significant social, economic, agriculture, conservation and animal welfare impacts and (ii) in response to a high social risk perception, coordinated efforts are needed to amass the necessary information for ongoing risk assessments to align investment in wildlife trade risk management with evolving insights into its contribution to local and global emerging disease risks. Sections 1.2-1.4 provide additional justification for OIE involvement in this issue.

Emerging diseases have created severe risks for agriculture, public health, and conservation. Their origins reside not only in the wildlife trade but also in livestock management, technological changes, landscape management, climate change and more (IOM 2009). Governments may want or need to prioritise resource allocation to the sector(s) providing the biggest attributable risk for emerging diseases. We did not encounter any documents that could allow us to rank the wildlife trade as a contributor to emerging disease risks in comparison to other animal sectors. The real importance of the wildlife trade is still under debate and detailed evidence about its effects is often lacking (CITES 2012). Assessing and comparing attributable risk represents a significant challenge as disease emergence is a complex, dynamic, and geographically diverse process. The different methods, scales, evidence bases, and interdependencies make it hard to compare risk assessments across the wildlife, poultry, and livestock sectors. The different capacities and policies for launching and sustaining interventions makes it hard to assess how interventions will modify risks differently across sectors. Our findings suggest that a global statement on relative risk could not be made due to the context specificity of emerging disease events. Given the interdependencies and complexities highlighted in this report, it seems a false choice to ask if the OIE should or should not have a role in managing this risk or that risk management can be done in isolation from other animal and human health sectors. The complex, interdependent, and emergent challenges of emerging diseases require transformative, collaborative leaders who can effectively manage the risk as a system rather than trading off or managing one risk contributor over another.

A 2012 World Bank report noted that government investment in wildlife services is minimal and the interaction between the wildlife department and veterinary and human health services are either absent or mostly informal and predominantly at the research level (World Bank 2012). The report further went on to state that "current budgets for wildlife health surveillance and control are extremely low, in spite of wildlife being the principal source of zoonotic diseases rather than livestock." An open letter to members of the IUCN stated that "there is no intergovernmental agency with the mandate to oversee wildlife health, and fragmented responsibility at country level means that this task typically falls between environment and veterinary services" (https://www.iucn.org/crossroads-blog/202009/it-time-a-global-wildlife-health-authority). This suggests there is both a measured and perceived international gap in leadership in wildlife health. The OIE's 7th Strategic Plan

commits the Organization to broadening its approach to animal health systems, including wildlife, and to tackle complex intersectoral issues including the "role of wildlife and associated value chains in disease emergence and spread". This suggests an important opportunity for the OIE to address a pressing international gap in animal health leadership.

Table 4.2 illustrated how the findings and recommendations of this report align with the OIE's 7th Strategic Plan. The OIE has committed to communicate risk and prevention measures to stakeholders to increase knowledge and awareness of Veterinary Services' role in reducing spillover events, and to inform at-risk populations of the risks and reduction strategies to effect appropriate behaviour change. This is consistent with many of the recommendations and findings of this report. An April 2020 Statement of the OIE Wildlife Working Group reported that the OIE has initiated several steps including developing guidelines or standards for trade in wildlife, the creation of a set of tools for Members to ensure best practices regarding risk assessments and disease management associated with the value chain for the wildlife trade, strengthening scientific networks to increase sustained Member country capacity for early threat detection, wildlife disease surveillance, information management, risk assessment, prevention of spill over events, and implementation of mitigation measures (https://www.oie.int/fileadmin/Home/eng/Our_scientific_expertise/docs/pdf/COV-19/A_OIEWildlifeTradeStatement_April2020.pdf) . This further aligns this report's conclusions with the ongoing and proposed OIE activities.

Table 4.2 Summary of the relationships between central elements of the OIE's 7th Strategic Plan and the findings and recommendations of this report.

Elements of the OIE 7th Strategic Plan		**Alignments with this report**
ALIGNMENT WITH FINDINGS IN THIS REPORT		
Vision	Safe and fair trade	Wildlife trade is a multiple billion-dollar activity (IPBES 2020) that deserves equivalent standards for safe and fair trade to those for domestic species. Current standards should be tailored to the unique needs of the wildlife trade, the lesser capacity for wildlife health management globally, and the large role of the illegal trade.
	Public health	Wildlife trade has been associated with negative public health outcomes in the form of emerging diseases and positive determinants of health such as food security and income. Animal health, trade and use are drivers of these negative and positive public health impacts.

	Global food security and safety	Millions of people remain dependent on wildlife as sources of protein and critical nutrients (Brown and Williams 2003).
	Sustainable socioeconomic development	Millions of impoverished people depend on wildlife for income and a growing commercial sector contributes to many nations economies (IPBES 2020), but these are imperiled by biodiversity loss and concerns about the safety of the trade.
ALIGNMENT WITH RECOMMENDATIONS IN THE REPORT		
Mission	Promoting coordination of animal health and welfare management	Addressed in general recommendation 2, and specific recommendations 1 and 2. Recent calls for a Global Wildlife Health Authority reveal a gap in coordinating wildlife health management.
	Fostering transparency in the animal disease situation worldwide	Specific recommendations 1,2,4 and 5 enhance the transparency of program planning and the information upon which decisions are based. Actions linked to recommendation 6 focus on building wildlife health surveillance and intelligence capacity.
	Supporting Veterinary Services to strengthen the governance of animal health systems	Specific recommendations 7 and 8 create new opportunities for governance innovations that support One Health approaches to this issue.
Actions	Standard setting	Addressed in specific recommendation 3
	Coordination of global frameworks	Specific recommendations 7, 8 and 9 build partnerships and conceptual frameworks for integrated planning and action while specific recommendation 5 establishes a global framework for sharing information and innovations.
	Information management	Specific recommendations 4 and 5 present actions to close the knowledge mobilization gaps in information management for this topic
	Sustainable capacity development	General recommendation 2 focus on building OIE capacity. Specific recommendations 5 and 6 call for actions on capacity development in Member Countries, 8 and 9 provide frameworks to develop One Health capacities and 10 provides foresight on new areas for capacity development.

	Facilitating international collaboration	Specific recommendations 8 and 9 offer ways to develop interagency cooperation at the international and national level while recommendations 3-6 must be developed with and for all Member Countries.

Recommendations

Focus of the Recommendations.

The following recommendations focus on enabling evidence-based selection of risk management interventions based on principles for managing safety in complex adaptive systems (Table 4.1). Strategic selection of actions first requires one to specify goals, develop a theory of action, select the targets for intervention and decide on the level of prevention desired (Keller et al, 2002). Specifying wildlife health interventions would be premature in the absence of the OIE completing these steps.

There are four essential questions to answer when planning interventions (Glascow et al, 2019).

1. Who is willing to participate in an initiative, intervention, or program, and reasons why or why not?
2. What is the impact or effectiveness of an intervention on important outcomes and variability across subgroups?
3. Can an intervention be effectively implemented under the prevailing conditions?
4. Can the program or policy become institutionalized or part of the routine practices and policies?

We found insufficient information to answer these questions for specific wildlife health interventions intended to reduce emerging diseases risks associated with the wildlife trade. This does not mean that wildlife health practices and policies affecting this trade should not be targeted, but rather that OIE programs will need to first be developed using expert consensus processes and then modified through adaptive management as more knowledge and experience is gained.

The following recommendations strive to place the OIE as a leader in the process of empowering Member Countries to take reasonable steps that can make incremental improvements in the safety situation by focusing on ways of thinking about and doing risk management that appreciate and effectively apply the distributed, uncertain, and collaborative nature of information, as is recommended for coping with wicked problems (Head and Alford 2015).

Goals of the Recommendations

1. Provide the foundation from which the OIE can build an adaptive risk management program for a situation of high urgency but high uncertainty.
2. Support adaptive management of emerging disease risk in the complex and uncertain wildlife trade supply chain in the face of concurrent threats to health, equity, and conservation by being multi-faceted and multi-solving.

General Recommendations

General Recommendation 1: All zoonotic disease risk management interventions must respect the social and ecological integrity of local communities.

Purpose: Emerging disease risk management is highly context specific and highly interconnected. Gaining acceptance of new regulations or standard must respect other goals to secure the necessary collaboration for sustainable change.

Actions: Because of the public good aspects and indigenous legacy of nature, all the recommendations should be developed respecting the rights of people to own, manage and use their traditional lands and natural resources, and to participate in political and policy processes that affect their rights, as reflected in the 2007 UN Declaration on the Rights of Indigenous Peoples and the 2018 UN Declaration on the Rights of Peasants and Other People Living in Rural Areas. Recommendations should also not impede reaching conservation goals or impinge on the integrity of ecosystems in accordance with international conservation agreements such as CITES and the Convention on Biological Diversity.

General Recommendation 2: The OIE should review its existing capacities and expertise and determine if additional investments, personnel, and partnerships are required to provide the technical and contextual knowledge required to implement its wildlife trade and emerging disease programs and plans.

Purpose: The wildlife trade and wildlife disease risk management have features unlike those in domestic animal trade that will need to be understood and incorporated into risk management interventions to increase the likelihood of their effectiveness.

Rationale: Wildlife cannot be considered a single commodity. The large diversity of species and uses, the large gaps in knowledge and the need for a trans-disciplinary approach for assessing and managing emerging disease risk necessitate specialized perspectives, experience, and expertise to implement the recommendations in this report and to meet the expectations for evidence-based risk management. Each successful spill-over event is complex and unique and, since it is a singularity, it is a local event needing local solutions. There is a strong argument that local solutions, and community-based research to find them, are essential to progress on wicked problem.

Actions: Upon defining is scope of activities, the OIE must reflect on the adequacy of wildlife health and program evaluation expertise and experience it can access to ensure contextually and scientifically appropriate programs.

The OIE must consider how it will access and use local community and Indigenous knowledge and its role in enabling the development of risk mitigation strategies at a local level as part of this process.

Specific Recommendations

THEME 1 – MULTI-FACETED ACTIONS

Recommendation 1: The OIE develops a theory of change to define the scope and boundaries of its wildlife trade programs.

Purpose: *To allow the OIE to transparently identify the necessary resources, enterprise and partnerships needed to meet its risk management goals and communicate its success to stakeholders and Member countries.*

Rationale: The complexity of the problem of wildlife trade and emerging diseases will create significant challenges for the OIE to create clear links between their programs and the impact on risk status. A theory of change helps to see the connections between short term action and long-term goals, making explicit what we know, what we assume, what we can feasibly do and how multiple actions contribute to a program's goals and objectives. It helps communicate the program and rationale and can be used to find small wins that contribute to evaluating progress in a way that energizes stakeholders instead of paralyzing them in the face of a wicked problem (Termeer and DeWulf 2019). Past reviews have shown the frequent absence of performance standards for wildlife health programs, limiting capacity to assess their reliability and utility for risk analysis and management (Stephen et al 2019).

Actions: A change theory requires the involvement of knowledge creators, planners, beneficiaries, and stakeholders at the start to develop consensus on the shared goals by explicitly documenting different views and assumptions and by helping people see how sharing their knowledge contributes to long-term positive impacts (Stephen 2020b). Two essential steps in developing this theory of change include (i) determining which risk management changes are within the span of control of the OIE, require partnerships, or require advocacy for others to implement, and (ii) the degree of desired safety. Given that emerging infectious diseases are caused by factors other than the wildlife trade, and the causal contributions of elements within the wildlife trade to emerging disease risk are variable, unquantified, complex, or uncertain, the OIE will need to define a non-zero tolerable risk and will need to decide if their interventions are focussed on changes in disease outcomes, vulnerabilities, capacities, and/or other attributes. The OIE will need to decide if it serves to prevent emerging diseases or mitigate their impacts, build resilience against their inevitable occurrence and/or adapt trade to continue despite emerging diseases. The theory of change should include performance standards that allow the OIE to assess the capacity of its program to perform its essential services, identify critical gaps in performance, inform partners of the program's role, track and measure accomplishment, and justify continued or expanded service.

Recommendation 2: The OIE implements a multifaceted approach to managing risks within the wildlife trade that includes implementation assessment and program evaluation.

Purpose: *To align the OIE programs with the principles of complex supply chain safety management and promote learning-by-doing that can be adapted to different situations.*

Rationale: There will always be inherent uncertainty and unpredictability in the dynamics and behavior of emerging diseases, but management decisions must still be made. Supply chain risk management requires multiple tools, techniques, strategies and external coordination and collaboration to reduce vulnerability and ensure ongoing positive outcomes (Fan and Stevenson 2018). A suite of interventions that have been collaboratively designed, implemented, and evaluated with stakeholders is usually required to achieve sustainable change in a health policy outcome and avoid unintended policy consequences (Oliver et al 2019). It is, therefore, reasonable to conclude that the OIE will require a collaborative and multifaceted approach to risk management.

Actions: Although existing science cannot prescribe which of the current OIE standards or guidelines can be adapted with effectiveness to the wildlife trade, in general a wildlife trade emerging disease strategy requires actions in: (i) identifying and addressing pre-existing socio-economic, ecological, and health inequities that are conducive to disease emergence and increases vulnerability to their effects; (ii) proactively building capacity for individuals and populations to cope with multiple interacting threats and stressors to build resilience against the additional pressure of an emerging disease; (iii) developing capacity to adaptively respond to surges in unexpected diseases or disease outbreaks; (iv) integrating emerging disease activities into animal health, public health and ecosystem management; (iv) investigating and communicating the implications of emerging disease for animal health, conservation, , food security, public health, and community resilience to encourage political and multi-sectoral collaboration; and (vi) innovative leadership, partnerships, and governance that support cross-sectoral, collaborative actions.

There are many barriers believed to hinder uptake of potential risk reduction measures, but these barriers are poorly studied. Despite multiple calls to apply a One Health approach, there is scant evidence that interdisciplinary approaches result in more effective or efficient responses. The lack of evidence can be traced to the preponderance of evaluations that focus on single diseases or outcomes rather than focussing more holistically on settings and systems. The OIE can advocate for a balance between discovery science and implementation research in forthcoming calls for funding, capacity development or research.

Information remains limited on the factors affecting implementation and effectiveness of interventions. The deployment of any of the OIE's existing tools (e.g., zoning, health certification, surveillance and reporting) must, therefore, be accompanied with ongoing program evaluation. The OIE may wish to develop new capacity in program evaluation that it can use internally or support an international resource, (such as seeking a

Collaborating Centre on Intervention Evaluation). The OIE could champion innovations that look at program impacts and outcomes to produce an ongoing source of intelligence data to assess the impacts of its programs. The OIE may also provide leadership in developing protocols and building capacity to undertake program evaluations and use its knowledge brokering assets to disseminate these evaluations to speed the spread of innovations and avoidance of failures.

THEME 2: EQUITABLE ACCESS TO KNOWLEDGE AND INFORMATION TO ASSESS RISK AND SUPPORT LOCALLY ADAPTABLE EVIDENCE-BASED INTERVENTIONS TO NARROW THE KNOWING-TO-DOING GAP.

Recommendation 3: The OIE champions integrated standards and capacity for proactive threat and risk assessments tailored to regionally and locally unique socio-ecological conditions and interactions with wildlife.

Purpose: *To enable the OIE to provide advice, standards, and assistance that help Member Countries accommodate the successive, incremental, and combined impacts of socio-ecological change on the likelihood, impact, and management of emerging disease risks in their own settings.*

Rationale: Risk to a system, including emerging disease risk, is "inherently and fundamentally a function of the states of the system and of its environment" (Haimes 2009). Answering the 3 usual risk assessment questions, what can go wrong, what is the likelihood and what are the emerging disease consequences of the wildlife trade, is inherently complex, and fraught with unknowns and uncertainties. Each question touches on public health, human well-being and equity, ecosystem integrity, species conservation and more. Pro-active risk management must identify the factors and processes that determine whether ecological, social, and integrated socio-ecological systems are conducive to disease emergence and anticipate how they will experience harm due to exposure to an emerged pathogen. To be efficient, these responses should be coordinated across the various agencies and organizations tasked with managing the plethora of risks and opportunities produced by the wildlife trade.

Actions: The OIE supports expert working groups or consensus processes to develop systems-based and harmonized approaches that incorporate the states of the socio-ecological system into a multi-dimensional risk analysis framework. This undertaking should be made in coordination with other agencies to avoid conflicting or redundant risk assessments and management recommendations. Draft system-based risk assessment methods may first be rolled out as part of OIE workshops for wildlife health focal points to assess their feasibility and to 'jump-start' systems thinking for managing the wildlife trade.

Recommendation 4: The OIE creates a collaborative, open access repository of critically assessed research. It becomes the internationally recognized source of high-quality information about the effectiveness, efficiency and sustainability of programs and polices to reduce animal-associated emerging disease risks.

Purpose: *To provide an accessible source of high-quality, relevant, up-to-date, and synthesized research evidence from around the world to ensure no Member Country is limited by insufficient knowledge to undertake risk management actions rapidly, reasonably and transparently.*

Rationale: It is an indictment of the animal health and human health sectors that we were unable to find studies that systematically assessed interventions for their effectiveness, efficiency, or sustainability. A similar situation was found in a recent review on the veterinary response to climate change, wherein more scholarly attention is placed on identifying hazards and describing harms than developing and assessing adaptation interventions. (Stephen and Wade 2020).

Actions: The OIE may wish to model the Cochrane Collaboration, the International Initiative for Impact Evaluation, or similar organizations which serve as a home of evidence to inform health decision making. The OIE should collaborate with existing academic organizations with experience in evidence-based decision making, with the possibility of creating a new Collaborating Centre of Evidence-based Animal Health Policy as an international resource to complement and help implement OIE guidance provided to Member Countries.

The OIE can drive research agendas to fill critical knowledge gaps in two ways. It can work with funders and governments to develop a long-term research strategy intended to close critical knowledge gaps on the genesis, spread and control of emerging diseases, with a focus on a complex systems science and implementation research. It can also facilitate and enable a set of regionally distributed multi-sectoral groups of researcher producers and research users (governments, NGOs, communities, businesses) to assemble available data, information, and knowledge to identify short term strategies to manage and prevent high risk activities and develop feasible methods to deal with them. The importance of being locally contextually relevant will necessitate the inclusion of tacit knowledge, local knowledge, and indigenous perspectives in this exercise. This group could review and update its findings on a periodic and regular basis to adaptively develop consensus on the best steps forward in the face of scientific uncertainty. A secondary benefit would be the development of international networks of people dealing with these problems and in doing so support relationships, trust, and communications channels to rapidly share ideas and lessons learned.

Recommendation 5: The OIE becomes a knowledge broker that links knowledge producers and knowledge users and develops international capacity to enable emerging information to be swiftly and effectively interpreted, adapted, and applied.

Purpose: *To bridge different types of knowledge and decision makers, thus speeding the diffusion of innovations and solutions.*

Rationale: Delays in information flows about corrective actions reduce controllability in dynamic systems (Bradley et al 2020). Rapid diffusion of solutions is paramount if the world wants to prevent and mitigate new emerging infectious diseases. Knowledge brokers play a key role in facilitating and supporting evidence-based decisions not only by building knowledge and skills, but also shifting the culture to evidence-based decision making and developing infrastructure and mechanisms that support it (Dobbins et al 2018).

The gaps between knowing what to do to reduce risks and doing it can be wide and difficult to breach. Lack of experience being impacted by a hazard, lack of trust in authorities and exposure to false alarms reduce willingness to act (Stephen, 2020). A particular challenge in emerging disease risk management is that a realized

danger produces far more emotional impact on the population than the averted risk (Arias-Maldonado 2020), thus, differently impacting motivation to be proactive. Potential sources of failure to act on warnings that are relevant to pandemic preparedness are (i) cross-sectoral communication break down, and bureaucratic conflicts and inadequate protocols make organization unreceptive to warning signals outside of their usual scope of practice; (ii) priorities and overcrowded agendas discourage collaborative actions that extent beyond immediate interests and (iii) insensitivity to new information, perceived power dynamics, cognitive overload and wishful thinking can lead to failure to recognize and act on very early warning signals (Stephen 2020).

Actions: The OIE should build links between knowledge users and knowledge producers and empower Member Countries to incorporate emerging information to their policies and programs. The OIE should facilitate solutions to overcome the three barriers to action mentioned by Stephen (2020) to successfully broker knowledge into adaptive change. The shift to a prevention, rather than reaction management culture could benefit significantly by incorporating social science and human health promotion literature into OIE program planning and implementation. The OIE may benefit from literature on best practices for promoting collaborative, cross-sectoral knowledge brokering functions.

Recommendation 6: The OIE champions the development of health intelligence to track changes in vulnerabilities that impact emerging disease threat levels so that nations or regions can proactively tailor their actions to their circumstances.

Purpose: *To broaden the scope of information available to signal changes in emerging disease vulnerability and therefore enable prevention of emerging disease as a risk management strategy.*

Rationale: Warning occurs when a change in vulnerability status is revealed and that change is rapidly communicated to those able to respond (Yamin et al. 2005). Vulnerability describes the characteristics and circumstances that make a population or system more likely or prone to be harmed by a hazard. The COVID-19 pandemic showed how the velocity of social and ecological change can lead to swift spread of emerging diseases resulting in governments scrambling to keep pace with unanticipated threats. Governments can not rely only on early signals of morbidity and mortality to make strategic decisions on the allocation of surveillance or management resources and expect to be “ahead of the curve”. A hazard-by-hazard approach to risk management is insufficient to ensure pandemic preparedness when the next hazard cannot reliably be predicted (Stephen 2020). Landscape changes, climate change, invasive species, urbanization, globalization, and pollution are all affecting the occurrence of wildlife diseases and their impacts on socially valued outcomes (Bradley and Altlzer 2007, Brearley et al 2013, Daszak et al 2001, Gallana et al 2013, Gibbons et al 2000). The COVID-19 crisis revealed the need for proactive analysis tools for pre-crisis threat assessment and management leading to efficient deployment of surveillance and response resources.

Pandemic warning needs a connected system of human intelligence distributed throughout the causal chain of a pandemic that can combine hazard surveillance with population reconnaissance that identifies socio-ecological system changes in vulnerability (Stephen, 2020). Pandemic planners need to reconceive early warning

surveillance as a system made up of a chain of subsystems each with their own knowledge of an aspect of the social and ecological drivers of pandemics.

The goal of health intelligence is to protect and promote health by early actions in advance of harm. This contrasts with the usual wildlife surveillance goal of early detection of harms to quickly minimize their effects. Health intelligence provides information, knowledge, and wisdom to (i) prioritize problems and needs, (ii) track progress to evaluate the impact of interventions, and (iii) make evidence-based decisions on policy, program design and resource allocation (Regmi et al, 2016). Health intelligence results when collecting and analyzing data in a way to make them understandable and usable for future decision-making *(*Jamot 2013*).* Decision support arises when the intelligence outputs account for real-world opportunities, constraints, perspectives, and priorities (Berezowski et al 2020). Intelligence, therefore, relies on information from multiple sources to provide a stream of information that can be inspected to support decisions about prevention, surveillance, or responses (Han and Drake 2016).

Actions: The OIE and national Veterinary Services should create ongoing collaborations with health, social development, and natural resource management agencies to secure the necessary insights into changing emerging disease vulnerabilities throughout the wildlife trade. The OIE will need to invest in processes to assemble these various inputs into warning outputs that can inform resource allocation in advance of a pandemic.

Vulnerability intelligence in wildlife is a new concept. The OIE should advocate for research and development of vulnerability assessments and look to innovations in climate change vulnerability assessments that might be rapidly adapted for use in emerging diseases.

Effective vulnerability intelligence will require that the current deficits in wildlife surveillance are remedied. Methodological, practical, financial, and regulatory challenges all preclude a direct extrapolation of domestic animal surveillance methods to wildlife (Stephen and Zimmer 2019). Continued low investment in wildlife surveillance creates the likelihood that the next wildlife borne emerging disease will not be recognized until people or domestic animals are affected. Encouraging countries to invest in harmonized wildlife health programs that allow for regular detection and tracking of wildlife diseases and risk factors for wildlife diseases underlies many of the actions needed to make evidence-based risk management decisions. Output-based approaches to surveillance should be explored as a wildlife health standard. Output-based standards prescribe what the surveillance must achieve in contrast to what surveillance activities must be performed. This would allow details of surveillance activities undertaken be adapted to Member Country capacities and circumstances if the quality of the result meets the required standard.

THEME 3 MULTI-SOLVING

Recommendation 7: The OIE adopts a holistic and integrated definition of animal health that accommodates the need to protect and invest in factors that can prevent emerging diseases and create population resilience and resistance against those diseases that emerge.

Purpose*: To align the OIE's perspectives on health and its determinants with the expectations for systems-based approaches to safety management in complex systems risk management.*

Rationale: Emerging and pandemic disease research has made great strides in discovering threats, mapping their consequences, and mounting responses when the threat is known. It has been much less successful in ''getting ahead of the curve'' to inspire action in the advance of human or domestic animal health impacts or to prepare for multiple, uncertain, or unknown threats. Given that (1) emerging infections result from interacting biological, social, and environmental determinants, (2) there is ambiguity and uncertainty at the human–animal–environment interfaces where diseases originate and (3) emergent behaviour is a defining feature of complex, ambiguous systems, predicting the next emerging disease with sufficient precision to inspire proactive changes seems unlikely in the short term (Stephen et al 2015). The ability to anticipate risks in time to act in a complex global society is not in harmony with the ability to minimize the likeliness of the realization of those risks, in part because "risks abound, and resources, including public attention and political decisiveness, are scarce" (Arias-Maldonado 2020). Investment in creating populations that are less vulnerable to emerging diseases and better able to recover seems, therefore, a logical component of an emerging disease risk reduction strategy. This strategy demands a balance between efforts to predict and detect emerging diseases with efforts to build resilience against the next inevitable surprise.

Pandemic plans usually focus on reducing the harm by reducing exposure to pandemic agents. A health-oriented approach would also address the total impact of a harm by promoting populations' capacity to cope with an emerging disease and by managing how other social and ecological outcomes influence pandemic vulnerability. Although there is general agreement about the co-dependent interplay among individual, environmental, ecological, and social factors influencing emerging disease risk management, there is a disconnection between the multiple policies, practices and perspectives influencing this issue.

Action: The OIE should manage the wildlife trade as part of a comprehensive strategy to combat the spectre of emerging disease, synergising investments in livestock, human health, and ecosystem interventions. The OIE must formally defines health in a manner that links animal health protection and promotion with the needs for systems-based risk management. The OIE can champion the creation of more unified set of guidelines to comprehensively promote pandemic resilience by concurrently and collaboratively tending to the determinants of health and resilience, for animals, our communities, and the natural environment.

Recommendation 8: The OIE partners with other organizations to promote an assets-based approach to reduce vulnerability and increase resilience to emerging diseases.

Purpose*: To facilitate a risk prevention and resilience agenda for wildlife trade and emerging disease programs.*

Rationale: The traditional approach to managing health at the human-nature interface has presumed that health is protected by solving problems and by removing deficits and obstacles. A deficits approach focuses on problems, needs and deficiencies (such as disease, food insecurity or lack of resources). It has historically emphasized the role for professionals to act on behalf of communities. Disaster management, climate change preparation and pandemics planning are increasingly recognizing that, to deal with a surprising and unpredictable future, communities, populations, and ecosystems need to be able to cope with what may come (Stephen 2020). While there is an urgent need to deal with deficits and depletion driving disease emergence, there is also a need to promote resilience, adaptability, and well-being (as per DiFabio 2017). An assets-based approach is concerned with identifying and sustaining the shared protective factors that support health.

An assets-based approach would encompass the biomedical and socio-ecological circumstances of a particular place that affect health capacity and vulnerability. It would emphasize community action, leading to a path that strengthens the ability of local individuals and communities to co-produce healthy conditions for themselves, their animals, and their supporting ecosystems. An assets approach to reciprocal care of society and nature should lead to conditions where people work together to protect and preserve the health promoting assets of their relationship with animals by having more power and influence over what happens. It should promote both resistance (the ability to withstand the initial impacts of an emerging disease) and resilience (the capacity to recovery from, adapt to or cope with longer term effects of the emerged disease) in wildlife, domestic animal, and human communities. There is evidence that sustainable behaviour changes come from assets rather than deficits approaches (Harrison et al 2019).

Actions: An assets-based approach will require steps that make it easier for people to make good choices that lead to healthier conditions by equipping them with the knowledge, skills, attitudes, and circumstances to make healthy choices easier. The OIE can adapt human health promotion methods to develop strategies that assist citizens and regulators to adopt a health-first, assets-based approach to emerging disease risk management. The OIE can empower Veterinary Services to collaborate with agencies responsible for protecting assets that lead to health and resilience against emerging diseases by increasing awareness of the value of a health and assets-based approach, facilitating strategic partnerships at the national and regional level, and incorporating human health promotion concepts in its cumulative risk analysis and program evaluation tools. This could be a valuable contribution of OIE training for wildlife health focal points.

Recommendation 9: OIE efforts to reduce emerging disease risks in the wildlife trade must be integrated with efforts to manage other global risks at the human-animal-environmental interface.

Purpose*: To increase efficiency of programs and to manage emerging disease risk as a complex problem by addressing shared causes of concurrent threats and increasing the collateral benefits of a wildlife and emerging disease program.*

Rationale: Individuals and populations are confronted by many interacting determinants of health and threats (i.e., emerging diseases, food insecurity, low income, habitat degradation, and social conflict) that do not exist in isolation. It seems reasonable to ask whether a wildlife trade risk management program needs to evolve from interdisciplinary teams tackling single issues (ex. emerging diseases) to 'interprobleminary' teams that examine the interactions and implications of multiple problems occurring simultaneously in a place or population.

Because the drivers of vulnerability and resilience against multiple global threats overlap, directing actions at shared drivers not only better prepares populations for surprising emerging diseases but also for other threats. This approach would align the OIE emerging disease strategy with the 2015 UN Sustainable Development Goals that link human development and well-being with healthy animals, ecosystems, and environments.

Actions: The OIE can champion a perspective of animal health as the cumulative effect of social, biological, and environmental assets and work with other agencies to identify and foster the shared determinants of health and resilience for domestic animals, wildlife and the communities that depend upon them. A multi-solving approach has the potential to produce win-win-win situations that improve the well-being of participants in the wildlife trade and protect animal and public health by aligning constituencies that might not otherwise see their common interests.

Recommendation 10: The OIE creates a global issue working group that guides transformative solutions the OIE and national Veterinary Services must use to confront the inter-related challenges of emerging diseases, sustainable development, climate change, and biodiversity loss.

Purpose*: To help the OIE adapt to the rapidly changing risk situation through foresight on governance, priorities, and science.*

Rationale: Global social and ecological changes are the most pressing factors shaping health threats across the veterinary domain. Business-as-usual will exacerbate these global threats, while also exacerbating pre-existing global inequalities. Veterinary Services will not be able to confront future pandemic and emerging disease threats without strengthening links between animal health practice, policy, and research, with social, ecological, economic, and human health sectors in concert with communities to build locally relevant actions. Transformative solutions are needed for the OIE and national Veterinary Services to come to grasp with confronting the inter-related challenges of emerging diseases, sustainable development, climate change, and biodiversity loss. OIE permanent Working Groups are responsible for continuingly reviewing developments in their fields, and for keeping OIE Members informed of current issues.

Action: An OIE Working Group on Global Threats could not only provide guidance on innovative governance models and integrated risk analysis and management methods targeting shared drivers of global threats but also could provide foresight that can help prioritize actions and find efficiencies in collaborations that will allow the OIE and society to ‘get ahead of the curve’ rather than remain in a reactive mode.

Reflecting on the six guiding questions

This report was launched by six initial questions. These questions shaped the evidence-gathering strategy. The answers to these questions and their supporting literature are dispersed throughout the report. The key elements of the answers to these questions are summarized below.

Question 1: What evidence is there to support the hypothesis that international and domestic wildlife trade (regulated and unregulated) is a risk for disease emergence?

This report intentionally did not replicate past reports or papers that have concluded that the wildlife trade is a risk for emerging infections (such as IPBES 2020, Pavlin et al 2009, Swift et al 2007). Rather it set out to examine this question by thinking about risk in two ways. The first is a regulatory approach to risk which has four components; (i) the likelihood of a hazard being introduced in a particular setting or situation, (ii) the likelihood of susceptible individuals, populations or ecosystems being exposed to the hazard, (iii) the consequences of the release and exposure to the hazard, and (iv) the uncertainty associated with the first three components (Dufour et al 2011). Many papers cited in preceding sections of the report show that emerging pathogens can found in wildlife in many countries and settings, infected wildlife can be co-location with people in plausible exposure settings, spillover human, domestic animal and wildlife hosts can develop clinical illness and, in some cases, significant economic or ecological harms can occur. The reviewed papers did not allow for quantification of likelihoods and provided a limited view of consequences (with a bias to human clinical effects). We found no papers that attempted to integrate all consequences (e.g., economic, impacts on biodiversity, social impacts, health outcomes) into a single measure. The many data gaps, lack of assessment of most of the supply chain and emerging surprises due to the complex dynamic nature of the trade made this a high uncertainty situation. The precautionary principle enables decision-makers to adopt precautionary measures when scientific evidence about a health hazard is uncertain and the stakes are high. A precautionary approach would argue that this is a high-risk trade requiring actions due to the high consequences of wildlife trade associated emerging diseases and the uncertainties in predicting which new emerging event will be serious. There is, however, no universally accepted definition of the precautionary principle. As per specific recommendation 1, the OIE will need to not only define its targeted levels of safety, but also will need to clarify how its definition of the precautionary approach applies to this trade.

The second dimension of risk is the social perception of risk. The goal of risk management is to “reduce risks (either the hazard itself or its consequences) to a level deemed tolerable by society and to assure control, monitoring, and public communication” (Rohrmann 2008). Risk perception and risk attitudes steer people’s concern about and willingness to act on a threat. Many international institutions, including the WHO, IUCN, CBD, UNEP, World Bank, and OECD have identified the wildlife trade as a high-risk situation for emerging diseases. Some countries have integrated biodiversity measures in their COVID-19 policy response including changes to regulation on wildlife trade to protect human health (Anon b 2020). Other countries such as the USA and China

and the regional blocs such as the European Union and the Comprehensive and Progressive Agreement for Trans-Pacific Partnership have introduced, explored, or advocated for new or enhanced legislation concerning wildlife health and/or wildlife trade and pandemic prevention. Although not a stance shared by all countries, there is a large public and political perception that this is a high-risk trade requiring management.

Based on these two concepts of risk, one can conclude that wildlife trade is a high-risk for emerging diseases.

Question 2: What are the high-risk practices for infectious disease emergence through wildlife trade, along the supply chain, and at markets?

The reader is referred to chapter 2 which highlights the available evidence on risk reduction targets. In summary, the practices and places that allow for the spillover of a pathogen from wildlife to become a high impact emerging disease have not be studied in a manner that confidently establish causal links between practices and emerging disease outcomes. Wildlife butchering, consumption, handling, aggregation, and transportation have all been proposed as risk factors for pathogen spillover from wildlife to people (ex. Keusch et al 2009, Monagin et al 2018) but relationships vary substantially based on the species, pathogens, and circumstances. Ecological, landscape and climatic factors have been linked to the likelihood of pathogen emergence, but these relationships also vary with locations, species, pathogens, and circumstances involved (ex. Alexander et al 2018). These are all plausible risk factors based on the evidence to date and experience in other sectors or trades. But as shown in chapter two, study design limitations create the need for caution on assuming the magnitude of cause-effects relationships between practices and disease emergence. Caution is also needed when extrapolating cause-effect studies in one setting, for one pathogen-host system to another setting and system. The available evidence has not been produced in a manner that allows one to identify the highest ranked risks, to compare the risks across supply chains, pathogens, or situations, or to compare wildlife trade risks with other sources of emerging disease risk.

Question 3: What are the socioeconomic drivers for wildlife products and by-products consumption?

As outlines through the report above, there are many diverse reasons humanity consumes wildlife. They can be roughly placed into seven categories.

1. Providing the needs for daily living
    a. Wildlife are a critical source of nutrition and income for numerous people, many of them the most vulnerable members of society.
2. Providing preferred food items
    a. Terrestrial, aquatic, and marine animals of many taxa are captured and killed for food that meets preferred rather than subsistence needs. Preferences may be cultural, nutritional, economic, or gastronomic.

3. Providing companionship, prestige, or esthetical value.
    a. The pet trade writ large supplies animals for individual use or display. Animals products such as trophies, furs and skins are used as luxury items.
4. Supporting research and education.
    a. Wildlife is used for research purposes and for education through hands on experience or through display (such as in zoos)
5. Providing traditional or alternative medicines
    a. Whole animals, animal parts or animal products have and continue to be a source of materials believed to have medicinal properties.
6. Supporting cultural or religious practices
    a. Animals may be killed, released, or otherwise used in some traditional practices.
7. Supporting political perspectives or perceived injustices
    a. This can include retaliation targeting individual animals, species or areas that are perceived to affect people's access to resources or expression of rights.

Culture, economics, regulatory environments, greed, peer pressures, inequity and entitlement are, therefore, among the drivers of wildlife use. Chapter 3 briefly reviewed efforts to modify demand and concluded that there is an absence of generalized approaches to demand reduction and efforts need to be tailored to local circumstances, respectful of the rights of Indigenous and rural people and attentive to cultural changes.

Question 4: What impacts does wildlife trade have on biodiversity and conservation?

Prior to COVID-19, there was substantial scientific and regulatory attention on the impacts of the wildlife trade on biodiversity and conservation. Ecosystem conversion and degradation, exploitation, pollution, climate change and alien species are all individually and collectively threatening biodiversity (CBD 2010). Despite international, regional, and national regulations and agreements to protect biodiversity, there is growing recognition that global biodiversity loss continues at a rapid pace (Butchart et al. 2010). Wildlife trade regulation has been recognized for decades as an important component of biodiversity protection. Some feel that the policies and practices to regulate the wildlife trade has not kept up with increasing demand for wildlife products or the unprecedented rate of social and ecological changes that exacerbate and accelerate the impacts of biodiversity loss due to wildlife trade (as per multiple authors in Oldfield 2003). Whether or not the wildlife trade was identified as the most important threat to wildlife in the literature reviewed for this project seemed, in part, to depend on the experience and disciplinary lens of authors and investigators. The attributable risk from wildlife trade for biodiversity loss also varied by species and location.

Like many other aspects of this report, quantifying the impact of the wildlife trade is constrained by the lack of data and the large role of the illegal trade. For this report, the main messages are (i) there are numerous existing agreements and regulations about the wildlife trade, with seemingly more on the horizon, (ii) there is a ground swell of non-governmental and governmental support for action on the trade in many counties and, thus, (iii) this provides an opportunity for OIE multi-solving as action on the trade will also be actions on emerging disease risks. Addressing the trade separately from address emerging disease risks would go against much of the logic of this report.

Question 5: What risk reduction strategies are currently applied?

The reader is referred to chapters 2 and 3 which highlight evidence on risk reduction targets and strategies. In summary, we tended to find authors focussing on one action as opposed to taking a systems approach to manage risk throughout this complex supply chain. Actions such as trade bans, demand reduction, sanitary reforms and regulations, and wildlife farming were among options explored or discussed in the literature (see table 3.1). The assumption that targeting one component of the wildlife supply chain will reduce the likelihood of an emerging disease is intuitively appealing but may not be consistent with complex systems thinking. Modern supply chain risk management acts at all stages of the supply chain, from producer to consumers (Aruoma 2006). Short term crisis responses can begin by targeting epidemiologically plausible locations for effective spillover host exposure but the contribution of specific points in the supply chain to emerging disease risk will change between species, trade type and time and, therefore, a continuum of interventions that are subject to process and program evaluations will be critical to medium-to-long term success.

Question 6: What is the evidence for their impact/effectiveness in addressing disease emergence?

The reader is referred to chapter 3. In summary, the lack of impact assessments or follow-ups to interventions of appropriate length greatly limit any assessment of impact or effectiveness of interventions for reducing the risk of disease emergence. Most studies focussed on actions post-emergence. Most of the supply chain is unexamined. Designing studies to show interventions prevented disease emergence is methodologically challenging. The fact that the number of times the conditions conducive to epidemics exist without an epidemic occurring far outnumber the few occasions when one occurs (Stephen et al 2004) makes it exceedingly difficult to design a study that shows an intervention changed the likelihood of emergence. Studies examining the effects of post-emergence outcomes either failed to be designed to assess impact, were variable and contradictory, or were not suitable to meta-analyses to identify interventions that could work across settings, species, supply chains and pathogens.

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