The International Alliance against Health Risks in Wildlife Trade
Working Group 'Transformative System Change: The Big Picture'

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Live Wildlife Trade and Markets

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Executive summary

Live wildlife trade and markets create considerable One Health risks across human, animal, and environmental health. These risks arise as a result of the interactions between wildlife, domestic animals, people, pathogens, ecosystems, markets, and governance systems. They are shaped by biological, ecological, commercial, social, and regulatory factors across local, national, and international scales. Live wildlife trade is not confined to illegal activities, a single region, or a particular type of market. Legal and illegal trade both generate and increase zoonotic risk when live wild animals are removed from their natural environments, captured, handled, transported, confined, mixed with animals of the same or different species, sold, slaughtered, or held. These activities can compromise animal health and welfare, disrupt ecological and host–pathogen relationships, and create conditions that are favourable to pathogen exposure, amplification, transmission, recombination, and spillover. The risk factors involved do not act in isolation. Confinement, crowding, species mixing, poor hygiene, transport, inadequate health monitoring, slaughter and handling, international movement, online and informal trade, and repeated close contact between wild animals, people, and domestic animals compound one another throughout the trade chain. In doing so, they raise zoonotic risks for traders, market workers, transporters, veterinarians, enforcement personnel, consumers, agricultural workers, pet owners, and the wider public.

This paper focuses on live wildlife trade involving mammals, birds, and reptiles because of their prevalence in trade and their particular relevance to zoonotic risk. It distinguishes between live wildlife markets, broader live wildlife trade chains, and specific forms of live wildlife trade, including the exotic pet trade. Wider issues such as livelihoods, food security, cultural practices, climate change, and rights-based considerations are recognised as important, but are addressed here only insofar as they directly affect zoonotic risk, prevention at source, and One Health (as defined by the One Health High Level Expert Panel (OHHLEP) responses.

The impacts of zoonotic outbreaks and pandemics extend far beyond immediate public health concerns. COVID-19 resulted in millions of excess human deaths, long-term health burdens, severe economic disruption, and extensive consequences for animal health and welfare. From a fiscal perspective, relying primarily on response after spillover has occurred is both inefficient and prohibitively costly. Prevention at source is likely to be more effective and cost-efficient because it directly targets the ecological, commercial, behavioural, veterinary, socio-economic, and regulatory conditions that enable pathogens to emerge, amplify, spread, and cross species barriers, rather than focussing on their consequences.

Animal health and associated welfare are integral aspects of zoonotic-risk reduction. Compromised welfare is therefore not only an ethical concern but reflects biological stress states that have been shown to affect immunity, pathogen susceptibility, shedding, morbidity, mortality, and transmission dynamics within live animal trade chains.

Live wildlife trade also has important biodiversity and ecological implications. It can drive or exacerbate unsustainable exploitation and biodiversity loss, both directly and indirectly, through direct extraction, bycatch, habitat disturbance, invasive species

introductions, pathogen movement and disruption of ecological interactions. These effects can in turn alter host communities, predator–prey relationships, pathogen dynamics and ecosystem resilience. Biodiversity protection, animal health, ecosystem integrity and zoonotic-risk prevention should therefore be treated as interconnected facets of One Health.

The international exotic pet trade exemplifies many of the above concerns. This global multi-billion-dollar industry affects thousands of species and millions of individual animals from a broad range of taxa. Although some of this trade is subject to CITES reporting and other regulatory controls, monitoring remains partial and uneven, particularly for non-CITES-listed species, domestic trade, online trade, informal or illegal trade, and animals traded under uncertain captive-breeding or sourcing claims. The exotic pet trade involves a host of risk factors, including biodiversity impacts, long and complex supply chains, uncertain origins, inadequate health monitoring, species mixing, high-density holding, international transport, private keeping, online trade, fairs, and demand for novelty, rarity, and status. It therefore has implications for zoonotic disease transmission, antimicrobial resistance, invasive species, animal welfare, and biodiversity conservation.

Legal, regulatory, and enforcement systems generally fall short of operationalising One Health and therefore remain poorly aligned with zoonotic-risk prevention. Relevant frameworks tend to be designed primarily for either conservation, animal health, agriculture, customs, food safety, trade, or animal welfare, rather than for integrated prevention across live wildlife trade chains. Important gaps include inadequate definitions and classifications, limited coverage of non-CITES species, fragmented national implementation, weak traceability, insufficient health screening and quarantine, poor regulation of online and informal trade, weak penalties, corruption risks, poor interagency cooperation and lack of binding obligations in areas currently addressed primarily through voluntary guidance.

Reducing live wildlife trade-related health risks requires prevention-oriented governance. This includes risk-based restrictions or prohibitions for high-risk trade pathways, improved surveillance, quarantine and health screening, clear traceability, hygiene, welfare and biosecurity standards, effective market controls, credible enforcement, strong anti-corruption safeguards and whistleblower protection, targeted public risk communication and demand reduction, and cross-sectoral One Health cooperation. Demand reduction is particularly important where wildlife consumption, ownership, trade, or use is discretionary, commercially amplified, luxury-oriented, status-driven, speculative, novelty-driven, , or occurs at an aggregate scale that exceeds sustainability, animal welfare, or zoonotic-risk limits.

Genuine subsistence dependence and livelihood constraints require careful, equitable, and locally appropriate responses. However, these considerations should not be used to legitimise large scale avoidable, commercial, luxury, status-driven, or speculative wildlife use that exacerbates biodiversity loss, animal suffering, ecosystem degradation, or zoonotic risk. The central policy question is not simply whether wildlife trade is legal or illegal, but whether legal, regulatory, and enforcement frameworks are effective at curbing conditions that allow pathogens to emerge, amplify, spread and spill over.

Where live wildlife trade pathways cannot be robustly regulated, monitored and enforced in ways that reduce risks to precautionary and evidence-based levels, precautionary restrictions or prohibitions are warranted and may be necessary.

The scope of this paper

This paper focuses on the hazards, risks and opportunities related to various aspects of live wild animal trade as they relate to zoonotic diseases and the application of the One Health approach to address these challenges. Given the proportionally higher zoonotic risks associated with mammals, birds and reptiles and the high prevalence in the live wildlife trade chain, this paper concentrates exclusively on these taxonomic groups. Although we recognise issues such as the role of climate change, the problems surrounding livelihoods, and the rights, needs, and cultural aspects of wildlife trade and use as integral aspects of this discourse, their detailed discussion exceeds the scope of this paper.

The International Alliance Against Health Risks in Wildlife Trade collaborates with Indigenous Peoples and local communities around the world to achieve a shared vision for a healthier, more secure, inclusive, just, equitable, peaceful and resilient future, where all forms of wildlife continue to maintain life-sustaining ecological processes as part of culturally valued natural places and communities of organisms.

In line with this scope, this paper distinguishes between live wildlife markets, live wildlife trade chains, and specific forms of live wildlife trade such as the international exotic pet trade. While related issues such as livelihoods, food security, climate change, cultural practices and rights-based considerations are recognised as integral to the wider debate, they are addressed here only insofar as they directly affect zoonotic risk, prevention at source, and One Health responses.

Introduction: live wildlife trade, zoonotic risk, and One Health

Zoonotic outbreaks and pandemics have far-reaching consequences beyond public health. They affect global economies, increase poverty, affect ecosystems and biodiversity, and compromise the health and welfare of wild and domestic animals. COVID-19 claimed millions of human lives, caused substantial animal mortality and welfare impacts, and resulted in trillions of dollars in direct and indirect economic losses. With the pace of newly emerging zoonoses on the rise, COVID-19 was not the first zoonotic pandemic and is unlikely to be the last (IPBES 2020).

Almost 75% of emerging infectious diseases in humans originate from animals, and many originate in wildlife (WOAH 2023). Historical trends show a pattern of increasingly frequent and severe spillover events involving zoonotic viruses with major impacts (Wolfe et al. 2007; Jones et al. 2008; Meadows et al. 2023). In the last century alone, at least six major outbreaks of novel coronaviruses have occurred. Ecosystem disturbance,

urbanisation, climate change, and wildlife exploitation all increase the risk of zoonotic spillover from animals to humans (Gibb et al. 2020; Keesing & Ostfeld 2021; Dubey et al. 2023). Wildlife trade is considered a major driver of pathogen emergence and spillover (Pavlin et al. 2009; Travis et al. 2011; Kolby 2020; Nijman 2021; Shivaprakash et al. 2021), and a report commissioned by the G20 High Level Independent Panel on pandemic prevention, preparedness and response identified better control of the global wildlife trade as an important prevention measure (Shanmugaratnam et al. 2021).

The prevention of pandemics and zoonotic spillovers requires a comprehensive approach that goes beyond traditional health research and outbreak responses. International pandemic reviews following COVID-19 have emphasised that preparedness and response systems need to be complemented by strong prevention measures, including efforts to reduce the risks of zoonotic spillovers before outbreaks occur. This paper therefore underscores the importance of shifting from predominantly response-based approaches towards prevention at source. In the context of live wildlife trade and markets, prevention means reducing the ecological, commercial, behavioural, and regulatory conditions that create high-risk human–animal interfaces. Such approaches are likely to be more effective, equitable, and cost-efficient than primary reliance on outbreak detection, containment, and response after pathogens have already crossed species barriers and are emerging.

The One Health approach is central to this challenge because it recognises the interconnected health of people, animals, plants, and their shared environments. This paper uses the OHHLEP definition of One Health, which frames One Health as an integrated, unifying approach that aims to sustainably balance and optimise the health of people, animals, and ecosystems, recognising their close interdependence. This framework is crucial to address the dynamics of live wildlife trade and live markets, which create hotspots for zoonotic disease transmission while being shaped by psychological, socio-economic, political, cultural, and ecological factors.

Live wildlife markets and trade chains operate within socio-ecological systems that reflect complex relationships between human activities and the natural world. Effective interventions must therefore take account of human and animal health and welfare, biodiversity, and ecosystem integrity as interrelated components of a life-sustaining global health system. They also require an understanding of the underlying drivers of live wildlife trade, including economic incentives, cultural practices, food security considerations, consumer demand, regulatory frameworks and enforcement capacity.

Intact and species-rich ecosystems help to buffer infection risk, whereas the risk of zoonotic spillover increases where ecosystems and biodiversity are damaged or destroyed through human activities such as encroachment, land-use change, and biodiversity extraction (Gibb et al. 2020; Keesing & Ostfeld 2021). These activities are shown to decrease biodiversity, alter ecological niches, increase contact between humans, domestic animals, and wildlife and disturb established host–pathogen dynamics. Habitat destruction and ecological degradation can also favour adaptable species that carry zoonotic pathogens, alter the abundance and diversity of wildlife hosts and diminish the capacity of ecosystems to buffer pathogen transmission and spillover risk. The One Health approach recognises these intrinsic interconnections between

human, animal, and environmental health and is therefore central to understanding and mitigating the effects of human-induced environmental change on zoonotic disease emergence (Plowright et al. 2017; Glidden et al. 2021; Ellwanger et al. 2022).
Human activities, including population growth, intensive agricultural practices, habitat loss and degradation, land conversion, biodiversity decline through use and trade in domestic and wild animals, and climate change, continue to alter ecosystems worldwide (IPBES 2019) and in doing so drive pathogen emergence and spread (Travis et al. 2011; Everard et al. 2020; Gibb et al. 2020; IPBES 2020; Keesing & Ostfeld 2021; Esposito et al. 2023). Our own behaviour, rather than wildlife or nature itself, is therefore what places human health and well-being at risk.
There is much to prevent. In wild mammals and birds alone, the number of undetected viruses has been estimated at 700,000–1.7 million, of which 540,000–850,000 have the potential to infect humans (Carroll et al. 2018; Shivaprakash et al. 2021). SARS-CoV-2 alone has now been reported in at least 35 animal species under field conditions (Nerpel et al. 2022; Nerpel et al. 2023).
Preventing zoonotic spillovers at source can reduce the likelihood of zoonoses while supporting a holistic approach that addresses not only the immediate risks posed by wildlife trade, but also the ecological, economic, behavioural, and regulatory factors that contribute to those risks. In doing so, prevention can generate co-benefits that extend beyond reducing infectious disease emergence, including counteracting biodiversity loss, improving animal welfare, fostering healthier ecosystems, strengthening economies and improving human health and well-being.

Definitions and boundaries

Live animal markets and their supply chains have gained notoriety as potential sources of zoonotic diseases, infections caused by microorganisms that can jump between wild and domestic animals and humans. Live wildlife markets are facilities where animals are kept alive and/or slaughtered to be sold, traded or exchanged alive, dead or as body parts. They supply a wide range of human demands that extends from consumption as food, clothing, medicinal or other purposes to companion animals and high-end luxury items.
Live wild animal trade and markets involve a broad variety of live and killed fauna, their parts and products that may be sourced from the wild or bred in captivity. Live animal markets can be legal or illegal or comprise a blend of both legal and illegal elements at different stages of the supply chain. There are several reasons for the existence of these markets. In warmer climates and areas with limited refrigeration infrastructure, live markets may persist partly because live animals do not spoil before sale. In some contexts, consumers may prefer animals to be sold alive or freshly slaughtered, including for perceived freshness or specific qualities associated with the killing process itself. The exotic pet trade, by its very nature, also relies on live animals. Here, supply chains can be especially long and complex, involving exporters, importers, wholesalers, intermediaries, retailers, online sellers, fairs, and private keepers (Altherr et al. 2020; van Roon et al. 2019; Warwick & Steedman 2021). These trade chains generate frequent

opportunities for contact between wild animals of different species and origins, as well as opportunities for pathogen exposure, amplification, transmission, and spillover (Huong et al. 2020). In addition, demand for new, rare, or unusual species can lead to the establishment of new trade routes and channels and further reduce transparency about the origins of affected animals (Brook & Sodhi 2006; Marshall et al. 2020; Hughes et al. 2023b). These longer and complex trade chains have been shown to increase biological stress in animals, with significant implications for animal welfare, health, and disease risk (Huong et al. 2020).

Zoonotic Diseases and Live Wildlife Trade Chains

Live wildlife markets exist on every continent. They vary in size and scope from small local markets to large-scale international supply chains and are particularly diverse in the tropics (Scheffers et al. 2019). Live wildlife trade and related markets are not confined to one region. They involve local, national, regional, and international supply chains, with different taxa, commodities and consumer markets involved in different parts of the world. These supply chains may be legal, illegal, or combine legal and illegal elements at different stages. Available evidence indicates that trade intensity, species diversity, and associated risks vary geographically, but the underlying One Health concern is global: live animals, pathogens, people, and commercial networks are connected across long distances. Regulatory gaps are also not confined to countries commonly associated with live wildlife markets; for example, a review of animal markets and zoonotic disease in the United States identified multiple consumer-facing animal markets and supply chains relevant to zoonotic spillover risk (Linder et al. 2023).

Wildlife trade provides a variety of live animals, body parts, and derivatives for local and international use. According to the CITES Secretariat (2022), revenue from legal trade in wild animals and plants is estimated at around USD 220 billion per year, including both CITES and non-CITES listed species. More than 7,600 terrestrial vertebrate species — nearly a quarter of all described terrestrial vertebrates — are subject to trade (Scheffers et al. 2019). Wildlife trade across most sectors has expanded in terms of both the number of species and the quantities of animals in trade. Legal trade is substantially larger than illegal trade and, like illegal trade, has been shown to contribute to overexploitation (Hughes et al. 2023a; Wyatt et al. 2022). Higher volumes of traded wildlife have been associated with a greater recorded diversity of zoonotic diseases linked to traded species (Borsky et al. 2020).

Legal trade reported under CITES has grown substantially, rising from fewer than 5,000 annual transactions in 1977 to a peak of more than 1.3 million in 2015, with shipment size broadly following similar trends (Hughes 2021). The CITES World Wildlife Trade Report further indicates that, between 2011 and 2020, approximately 3.5 million CITES shipments were reported in direct trade by exporters, involving more than 1.3 billion individual organisms, including 1.26 billion plants and 82 million animals, as well as 279 million kg of products reported by weight (CITES Secretariat 2022). In addition, legal trade flows are

known to correlate with and provide cover for illegally traded wildlife (Bager Olsen et al. 2021; Tittensor et al. 2020; UNODC 2020).

CITES trade data indicate that legally reported international trade includes substantial numbers of live animals from taxa associated with pathogens of zoonotic concern. The WHO R&D Blueprint identifies priority diseases and pathogens with epidemic or pandemic potential for which research and development is especially urgent. A UNEP-WCMC/JNCC analysis of CITES-listed taxa associated with these priority diseases found that, between 2011 and 2020, more than 575,000 live individuals from 49 CITES-listed species directly associated with priority diseases were reported in legal international trade. A broader analysis found that live trade in CITES-listed species from families associated with at least one WHO R&D Blueprint priority disease involved more than 1.12 million individuals over the same period. This distinction is important: the smaller figure refers to species with direct documented associations with priority diseases, while the larger figure captures a broader taxonomic risk category. These findings illustrate that zoonotic risk is relevant to legally reported live wildlife trade, rather than only illegal or informal trade. These findings also underline the limitations of current monitoring systems, especially for non-CITES-listed species and for illegal, informal, or domestic trade.

Studies into illegal wildlife trade also illustrate that disease-relevant trade pathways are geographically widespread and include the pet trade, bushmeat, so-called wet markets, and others. A review of published literature and conference proceedings from 1990 to 2020 identified 240 pathogens reported in the context of illegal wildlife trade, while noting that testing and surveillance of illegal shipments remain sparse and geographically uneven (Rush et al. 2021).

Live wildlife trade and markets, and their underlying supply chains, are associated with significant and multi-layered risks in the context of zoonotic disease transmission, emergence, and prevention (Nijman 2021). In the wake of high-impact zoonotic disease outbreaks, including the SARS-CoV-2 pandemic, scientific, political, and public attention has been drawn to the risks associated with wildlife trade and markets that involve live animals. Foremost among these are contact and close proximity between humans and wild animal species, the mixing of species that would not normally mix in nature, cramped and unhygienic conditions and repeated forms of contact throughout the supply chain, including in high-density mixed-species captive populations close to human populations.

Live wildlife markets and trade can involve zoonotic risks across the entire trade chain, from extraction or breeding to transport, housing, handling, slaughter, processing, display, sale, and consumption. They can serve as amplifying environments for pathogens, allowing them to replicate and mutate in diverse host populations and increasing the risk of novel zoonotic events (Naguib et al. 2021; Magouras et al. 2020; Huong et al. 2020).

Under these circumstances, wild animals tend to be confined in tightly enclosed spaces, which creates favourable conditions for the transmission of viral, bacterial, and parasitic pathogens (Magouras et al. 2020; Naguib et al. 2021; Warwick & Steedman 2021). Crowding, confinement of large numbers of animals, transport, species mixing, injuries,

sickness, pain and fear have all been shown to raise physiological stress levels (Linder et al. 2023; Wyatt et al. 2022; Bergin & Nijman 2019), which in turn are known to compromise immune function and alter pathogen susceptibility, shedding and transmission dynamics (Maas 2000; Moberg 2000; Huong et al. 2020). These conditions are further exacerbated by poor hygiene, which elevates the risk of contact with blood, faeces urine, and other effluent that may contain high concentrations of pathogens. The common presence of diverse wild and domestic species creates further opportunities for pathogens to come into contact with previously unfamiliar hosts.

For practical and commercial reasons, live animal markets are frequently located in close proximity to human settlements, including densely populated urban settings. As a result, both people and wild animals move in and out of high-risk markets, often covering considerable distances. This human–animal interface increases the potential for rapid pathogen spread during outbreaks. The slaughter of animals in markets, or in preparation for them, poses an additional risk for the transmission and spillover of bloodborne and airborne pathogens. This is exemplified by the HIV-1 pandemic, which is thought to have originated as a result of blood transfer between primates and humans during hunting, or more likely during butchering for markets, where the likelihood of cuts and contact with animal blood is elevated (Sharp & Hahn 2011; Sharp & Hahn 2010).

Live wildlife markets are also often connected to extensive transportation and trade networks that facilitate the movement of wild animals and their pathogens across regions and international borders. This can facilitate the spread of pathogens to new areas and host communities and, in doing so, contribute to the development of new pathogens and spillover events. The documented presence of illegally sourced wildlife in live animal markets illustrates that such markets can operate outside regulatory frameworks, making it challenging to monitor and control the health status of affected animals (Fuller et al. 2018). This can further facilitate the introduction and spread of diseases.

Live wildlife trade and markets also carry ecological risks. When different species are kept or mixed together, pathogens have opportunities to adapt to a greater variety of hosts. This was the case, for example, with SARS-CoV-2 in mink and highly pathogenic avian influenza H5N1, which can evolve in captive birds and spill over into wild birds and mammals (Oreshkova et al. 2020; Oude Munnink et al. 2021; Caserta et al. 2024; Koopmans et al. 2024).

The movement of pathogens, hosts, or mixed species assemblages away from their normal ecological context can disrupt established patterns of host immunity and pathogen evolution, potentially leading to unintended zoonoses-related consequences. Ecological disturbance associated with sourcing wildlife for trade, including incursions into previously less-disturbed habitats, can increase spillover risk through multiple pathways. These include increased human-wildlife contact, displacement and stress of wildlife, changes in host abundance and community composition, disruption of predator-prey and other ecological relationships, and disturbance of established host–pathogen dynamics (Plowright et al. 2017; Gibb et al. 2020; Plowright et al. 2021; Plowright et al. 2024; Glidden et al. 2021; Keesing & Ostfeld 2021).

These risks strongly support the need for policies and remedial actions directed towards proactive zoonotic disease prevention rather than primary reliance on outbreak control after spillover has occurred. Primary prevention can therefore reduce the ecological and trade-related conditions that enable pathogen emergence, amplification, transmission, and spillover.

5. Human Health and Economic Impacts

5.1 Human morbidity and mortality

COVID-19 caused a mortality burden far beyond officially confirmed deaths. WHO estimates indicate that the pandemic was associated with approximately 14.8–14.9 million excess deaths globally in 2020–2021 alone, around 2.7 times the number of reported COVID-19 deaths for the same period. Excess mortality captures both deaths directly caused by infection and deaths indirectly associated with the pandemic, including those resulting from overwhelmed health systems, disrupted care, and wider social and economic impacts. Beyond mortality itself, long COVID has resulted in a major continuing morbidity burden: at least 65 million people worldwide were estimated to suffer as a result of long COVID-related health problems in 2023. The condition can affect multiple organ systems and often impairs the daily function of patients for months or years (Msemburi et al. 2023; Davis et al. 2023).

5.2 Economic costs of zoonotic outbreaks and pandemics

The economic costs of pandemics can be severe. COVID-19 triggered the sharpest global economic downturn since the Great Depression, with global GDP declining by approximately 3.0–3.4% in 2020 (Statista 2023; Gagnon et al. 2023). In the United States alone, the economic toll of the pandemic was estimated at approximately USD 14 trillion by the end of 2023, reflecting lost GDP and wider economic disruption (Walmsley et al. 2023). These figures clearly illustrate that zoonotic outbreaks and pandemics create costs far beyond immediate healthcare expenditures, such as productivity losses, disrupted services, overall fiscal pressure, social disruption and long-term impacts on human well-being. From a fiscal perspective alone, repeatedly paying for outbreak response, emergency relief, economic disruption, and long-term health consequences after spillover has occurred is a profoundly inefficient use of public resources.

5.3 Benefits of prevention at source

Primary prevention should be the central policy objective for reducing the risk of zoonotic outbreaks and pandemics associated with live wildlife trade. Response-based approaches remain necessary, but come into play only after spillover has occurred, when pathogens may already be spreading among people, animals, or both. Prevention at source aims to reduce the ecological, commercial, behavioural, veterinary, socio-

economic, and regulatory conditions that allow pathogens to emerge, amplify, spread and cross species barriers in the first place.

Primary prevention is more cost-effective than response. Bernstein et al. (2022) estimate that improved surveillance of pathogen spillover, reduced deforestation, and more effective management of wildlife trade and hunting would cost less than 1/20th of the value of lives lost each year to emerging viral zoonoses, while also generating substantial co-benefits. Dobson et al. (2020) similarly argue that the costs of reducing pandemic risk through measures addressing wildlife trade and tropical deforestation are small compared with the costs of a pandemic. This should be of direct interest to policymakers because, even from a narrow fiscal perspective, prevention is more rational than repeatedly absorbing the multifaceted human, institutional, and economic costs of outbreaks after they occur (Dobson et al. 2020; IPBES 2020; Bernstein et al. 2022).

In the context of live wildlife trade, "management" should not be understood as a vague substitute for risk reduction. Where trade pathways involve high-risk human-animal interfaces, effective prevention may require robust binding restrictions, prohibitions, traceability, health screening, quarantine, market controls, enforcement and demand reduction. Such measures can curtail both direct and indirect economic losses, such as healthcare costs, productivity losses, pressure on health systems, and wider social and economic disruption. More broadly, better human health contributes to economic growth by expanding labour-force participation and productivity (Bernstein et al. 2022; Remes & Singhal 2020).

The COVID-19 pandemic illustrates the costs of relying primarily on response after spillover or outbreak emergence, rather than investing in prevention measures that can avoid or reduce loss of life, long-term morbidity, economic disruption, and wider societal harm. Assessing the risks and drivers of live wildlife trade and markets can therefore help policymakers and other stakeholders identify practical approaches to reduce risks to human, animal, environmental and economic health.

6. Animal health, welfare, biological stress and pathogen risk

Animal health and welfare are integral to zoonotic and pandemic risk reduction because compromised welfare reflects biological states that can negatively affect immunity, pathogen susceptibility and shedding, morbidity, mortality and transmission dynamics. Across live wildlife trade chains, wild animals may experience capture, restraint, handling, confinement, transport, crowding, social disruption, mixing with unfamiliar individuals or species, dietary change, dehydration, thermal stress, injury, poor hygiene and exposure to unfamiliar pathogens. These conditions are not merely welfare concerns in an ethical sense; they are physiological, behavioural, immunological and ecological stressors that can affect animal health and alter disease risk (Maas 2000; Broom & Johnson 1993; Moberg 2000; Lambert et al. 2025).

The underlying biological mechanisms are important. Animals exposed to acute or chronic stressors activate neuroendocrine stress pathways, including sympathetic-

adrenal and hypothalamic-pituitary-adrenal responses. These responses are adaptive in the short term, helping individuals to respond to immediate threats. However, when stressors are severe, repeated, prolonged, or inescapable, as is the case during capture, handling, transport, confinement, crowding and poor husbandry, they can exceed an animal's biological capacity to cope. Such stress responses are known to alter metabolism, suppress growth and reproduction, impair immune function, increase susceptibility to infection and contribute to elevated morbidity and mortality. These effects can be present even when individuals appear outwardly normal at inspection (Maas 2000; Broom & Johnson 1993; Moberg 2000).

Stress effects are likely to accumulate across the wildlife trade chain. Weaknesses at any stage, be it capture, local holding, transport, export, import, quarantine, markets, retail, fairs, or private keeping, can affect the subsequent health status of animals and produce delayed morbidity or mortality that may not be visible when the stressor(s) occurred. This is particularly relevant in the live wildlife trade context because animals of uncertain health status are often subject to long and complex supply chains, mixing with other species or individuals from different locations, and close contact with collectors, traders, transporters, market workers, veterinarians, enforcement personnel, consumers, domestic animals, and other wildlife. In the context of international live wildlife trade capture, domestic and international transport, holding and post-import conditions form a continuous biological chain and should therefore not be regarded as separate stages to be assessed in isolation (Maas 2000).

The welfare impacts of these events are well documented across a wide range of taxa and trade sectors. A recent review of commercial wildlife trade case studies found that wild animals may experience negative welfare states including chronic stress, pain, fear, thirst, hunger, frustration, depression, sickness, exhaustion and distress, with impact durations lasting from hours to lifetimes depending on trade pathways and end use. The 2000 Prepared and Shipped review similarly concluded that mortality and morbidity are affected from the moment of capture and by subsequent handling, transport, and captivity, and that road transport, loading, unloading, handling, crates, containers and associated conditions can be potent stressors with primary and secondary effects on morbidity and mortality. Repeated or cumulative stressors are especially relevant because animals may survive the initial stage of trade but subsequently succumb to the effects of injury, disease, immunosuppression, or poor adaptation to captivity.

The link between compromised health and welfare, and zoonotic risk is therefore far from speculative. In a study of wildlife supply chains for human consumption in Viet Nam, coronavirus detection increased along the supply chain, and the authors identified stress, dehydration, poor nutrition, reduced animal condition, altered immune function, increased viral shedding by infected animals and increased susceptibility of other animals in the chain as biologically plausible contributors to rising transmission risk (Huong et al. 2020). More generally, wildlife trade can create repeated opportunities for pathogen exposure, amplification, recombination and host switching, particularly where live animals are crowded, mixed, transported, slaughtered, or held under poor hygienic conditions.

The implications of these realities exceed concerns over the suffering of individual animals. Poor welfare conditions can increase the probability of pathogen amplification and transmission along live animal trade chains, while morbidity and mortality also compromise conservation outcomes and the sustainability of trade. Animal health and welfare safeguards should therefore be treated as integral components of One Health risk reduction, alongside prevention at source, surveillance, traceability, hygiene, quarantine, enforcement, and demand reduction. This framing is important because welfare is often dismissed in policy discussions as a purely ethical or sentimental concern, whereas in live wildlife trade it represents a very real biological risk factor. Pathogens moved, amplified, or redistributed through human-mediated animal movements and live animal trade can also have serious consequences for wild, captive, and domestic animals. SARS-CoV-2 has been detected in captive, domestic, and free-living mammals, including zoo animals, farmed mink, companion animals and free-ranging white-tailed deer, raising concerns about animal health, reverse zoonosis, and the establishment of wildlife reservoirs. Highly pathogenic avian influenza H5N1 continues to cause extensive mortality in wild birds and poultry and has now increasingly been reported in mammals. These examples show that disease risks associated with live animal trade and broader human-animal interfaces are not just risks to humans, but also to animal health, welfare, conservation, and ecosystem integrity.

Similar principles apply to conservation interventions involving captive breeding, reintroduction, or translocation. Although these activities are distinct from commercial live wildlife trade, they can also carry animal-health and disease risks if they are not accompanied by effective health screening, quarantine, genetic management and post-release monitoring. These conservation interventions illustrate the broader One Health principle that moving live wild animals across ecological, geographic, or management boundaries can have unintended deleterious consequences for animal health, pathogen transmission and conservation outcomes (Fraser 2008; Williams & Hoffman 2009; Warne et al. 2023).

7. Biodiversity and Ecological Implications

Global biodiversity is declining faster than at any time in human history. Direct exploitation of wild fauna and flora is recognized as one of the chief destructive drivers, second only to changes in land- and sea-use (IPBES 2019). Wildlife trade can therefore damage biodiversity directly through the removal of target species, and indirectly through bycatch, incidental mortality, habitat disturbance, invasive species introductions, pathogen movement, and disruption of ecological interactions (Hinsley et al. 2023; Hughes et al. 2023a). Important mechanisms include the disruption of ecological interactions such as predation, herbivory, competition, seed dispersal and trophic relationships. Removing target species from ecosystems can change the abundance or behaviour of other species, allowing some populations to expand while others decline. Such changes can cascade through food webs and affect ecosystem structure, functioning and resilience (Estes et al. 2011; IPBES 2019; Morton et al. 2021; Hughes et al. 2023a).

Such biodiversity impacts are also relevant in the One Health context. Wildlife species involved in live trade may serve as reservoirs, hosts, or carriers of pathogens, while changes in the distribution, abundance and composition of wildlife communities can alter pathogen dynamics and opportunities for spillover (IPBES 2020; Keesing & Ostfeld 2021). Modifying the distribution and abundance of reservoir species through extraction can also alter the prevalence of diseases in both wildlife and human populations. The trade in live animals therefore facilitates the migration of pathogens across ecological and geographic boundaries. For example, fatal human encephalitis cases in Germany between 2011 and 2013 were linked to a novel zoonotic bornavirus, variegated squirrel bornavirus 1, associated with the keeping and breeding of exotic squirrels as pets. Subsequent investigations detected the virus in variegated and Prevost's squirrels in Germany and the Netherlands. This scenario illustrates how the trade and keeping of exotic pets can create unexpected interfaces between wildlife pathogens and people (Hoffmann et al. 2015; Schlottau et al. 2017; Petzold et al. 2019).

The intentional or accidental introduction of non-native species through live wildlife trade is yet another area of concern. Invasive species can compete with, prey upon, or displace native fauna, disrupt ecological communities, and carry pathogens or parasites that can affect native wildlife, domestic animals, or humans (Azami-Conesa et al. 2021; Beltrán-Beck et al. 2012; Lockwood et al. 2019). These impacts reinforce the urgent need to treat biodiversity protection, animal health, ecosystem integrity and zoonotic-risk prevention as interconnected elements of One Health.

8. Actors and drivers of live wildlife trade and markets

Live wildlife markets and trade chains are shaped by a complex set of actors and drivers. These include national and local governments, regulatory authorities, market operators, traders, hunters, breeders, transporters, commercial intermediaries, online platforms, consumers, enforcement agencies and communities whose livelihoods, food security, or cultural practices may be linked to wildlife use.
The relative importance of these actors varies between contexts. In some settings, live wildlife trade may be associated with subsistence needs or limited livelihood alternatives; in others, it is driven by sophisticated commercial supply chains, urban demand, luxury consumption, exotic pet ownership, or government-supported production and trade systems. For this reason, risk-reduction strategies need to be context-specific and should avoid treating "the public" or consumers as the sole or primary drivers of live wildlife markets.
Hunters, market operators, traders, transporters, breeders and intermediaries shape the conditions under which animals are sourced, moved, held, sold, slaughtered, or kept. These conditions can affect animal stress, species mixing, hygiene, traceability and opportunities for pathogen transmission. Hunters, collectors, and others involved at the

point of capture or supply may face direct exposure to wildlife, animal exudates, blood, faeces, urine, and tissues. Enforcement staff, inspectors, veterinarians, customs officials, police, and other frontline personnel may also be exposed during inspection, seizure, transport, quarantine, or market-control activities.

Consumers and the public also play important roles, but their influence differs by context. Consumer demand can create or reinforce financial incentives for live wildlife markets, wild meat, exotic pets, traditional medicines, luxury products, or rare species. Public attitudes may also influence whether risky practices are tolerated, regulated, reduced, or socially challenged. However, consumer behaviour is shaped by availability, price, cultural norms, social status, perceived need, marketing, online access, and the presence or absence of acceptable alternatives. Demand-side interventions therefore need to be carefully targeted and should distinguish between subsistence reliance, livelihood dependence, commercial profit, luxury consumption and discretionary demand.

Risks associated with live wildlife trade arise within complex socio-ecological systems rather than from isolated human, animal, or environmental factors. They are shaped by interactions between biodiversity loss, ecosystem disturbance, animal health and welfare, livelihoods, commercial incentives, cultural practices, governance, regulation, enforcement capacity and consumer demand. For this reason, reducing zoonotic and pandemic risks cannot rely only on technical health interventions such as surveillance, testing, or outbreak response. These measures are important, but they need to be complemented by prevention-oriented approaches that address the underlying ecological, economic, political and behavioural drivers that create and sustain high-risk human-animal interfaces in the live animal trade context.

Understanding who is involved, who benefits, who bears the risks and who has the power to change existing practices is essential for designing fair and effective One Health interventions. Measures that focus only on individual behaviour are unlikely to succeed where structural incentives, weak regulation, poverty, corruption, or commercial interests continue to sustain high-risk trade chains. The following subsections consider key governance, economic, social, behavioural and supply-chain drivers in more detail.

8.1 Governance and policy drivers

Governments influence live wildlife trade through policies, laws, incentives, permissions, prohibitions and enforcement systems. Government policies and incentives can actively create, expand, or legitimise live wildlife trade systems. In China, for example, wildlife farming and trade were promoted over several decades as part of rural development and poverty-alleviation strategies, including through supportive legal frameworks, loans, training and official promotion of wildlife farming as an economic opportunity. Such policies led to a significant expansion of commercial wildlife supply chains, which illustrates why live wildlife trade should not be understood solely as a matter of individual consumer demand. Government-supported or tolerated trade systems should therefore be assessed not only in the context of their intended economic or livelihood benefits, but their implications for biodiversity conservation, animal welfare, biosecurity and zoonotic risk (Xiao et al. 2021).

8.2 Economic incentives, profit motives, and rarity-driven demand

The economic incentives for individuals and businesses involved in legal and illegal live wildlife trade and related contact chains can be substantial. High prices for certain wild animals or wildlife products, including exotic pets, traditional medicines, luxury items and rare species, can drive continued sourcing, trade, ownership and use irrespective of wider consequences for human health, animal welfare, biodiversity and ecosystem integrity. Online platforms further amplify these incentives by expanding market reach, connecting buyers and sellers across jurisdictions and increasing access to rare or newly available products and species.

Consumer preferences for rarity can also contribute to unsustainable exploitation. As species become rarer in the wild, their perceived scarcity has been shown to increase desirability and market value, thus further incentivising collection, trade and speculative demand. Understanding how perceptions of rarity, market scarcity, status, novelty and value shape consumer behaviour can help inform more effective conservation, education, demand-reduction and policy interventions (Hausmann et al. 2023).

8.3 Food security, livelihoods, and differentiated dependence

Food security, livelihoods, and cultural practices can be important drivers of wildlife use in some contexts, and risk-reduction measures must distinguish genuine subsistence dependence from discretionary, commercial, luxury, status-driven, or speculative demand. Interventions that ignore livelihood constraints or local dependence may be ineffective or inequitable. At the same time, the existence of subsistence use should not be a reason to legitimise avoidable high-risk trade where wildlife use is commercially amplified, poorly regulated, or associated with preventable biodiversity, animal welfare, or zoonotic risks. Differentiated approaches are therefore needed to ensure that prevention measures are fair, locally appropriate and focused on reducing high-risk trade pathways.

8.4 Awareness, incentives, and barriers to action

Perhaps one of the biggest challenges in tackling risks to human, animal, environmental and economic health arising from the human-wildlife interface along the wildlife trade chain is the persistent gap between available knowledge, policies and effective interventions. Policy makers and the public may have limited awareness of the complex interactions between zoonotic pathogenesis, biology, ecology, socio-economics, governance and human behaviour, as well as effective available prevention options. This awareness gap can hinder effective One Health responses, particularly because the underlying hazards of zoonotic spillover and pandemics may be invisible or delayed until a crisis occurs. The complexity of these risks can also make it difficult to communicate them in ways that translate into timely and appropriate action.

This gap is not just informational. Vested interests, corruption, economic pressures, weak governance and cultural or commercial practices can also influence political reluctance to adopt policies that challenge existing norms and/or profitable activities. Civil society

organisations and experts have highlighted that corruption can enable environmental crimes across complex supply chains involving wildlife, forests, fisheries and other natural resources, while undermining transparency, accountability, the rule of law, public health, biodiversity protection and sustainable development. Addressing these barriers requires robust, fair and inclusive approaches to generate, combine and disseminate knowledge, as well as stronger transparency, accountability, anti-corruption safeguards and protection for those exposing environmental crime and corruption.

Public awareness and the willingness to adopt meaningful behavioural changes are important elements to reduce the spread of existing zoonotic diseases and the emergence of new ones. However, awareness alone is insufficient where structural incentives, weak regulation, corruption, or commercial interests continue to sustain high-risk trade chains. As illustrated by responses to other slow-moving environmental crises such as climate change and biodiversity loss, knowledge may fail to alter behaviours or policy choices without changes to incentives, governance, accountability and enforceable rules. Bridging this gap to effect much needed transformative change requires proactive risk communication, education, recognition of shared responsibilities and political leadership and will to promote a holistic and fact-based approach to safeguarding global health and biodiversity.

By proactively fostering awareness about the risks and opportunities for positive change at both grassroots and governance levels, policymakers, civil society, communities and other stakeholders can help catalyse the collaborative efforts needed to safeguard shared health and ecosystem integrity.

8.5 Behavioural and cognitive factors

Human behaviour can exhibit a surprising lack of plasticity when confronted with scientific evidence, even where failure to act may have serious consequences for individual or collective well-being. Biodiversity loss, climate change and their links to the emergence and spread of zoonotic diseases pose growing threats to local, regional and global sustainability. Despite the high profile of these issues, the risk of severe and potentially irreversible impacts and the many formally adopted goals and targets set since the 1980s, prevailing approaches have so far failed to catalyse action at the speed, scale, or depth required. One underlying reason is that these challenges are often framed primarily as technical problems (Wamsler et al. 2021).

Cognitive and behavioural predispositions rooted in human evolutionary history (Perreault 2012; Pratarelli 2016; Waring & Wood 2021), high levels of complexity, ingrained cultural practices (Rees 2023; Bernardini et al. 2022), vested interests (Beder 2014; Mihai 2019; Gierth & Bromme 2020) and psychological and social factors can converge to generate or maintain resistance to urgently required behavioural change. Adherence to traditions that have become harmful, limited awareness and reluctance to disrupt established norms can impede timely and effective responses individually and collectively. Overcoming these hurdles requires effective communication, a solid understanding of human psychology and the difficulties associated with aligning behaviour with the imperatives of global health and ecological integrity.

Responses to zoonotic and pandemic risks are also shaped by temporal discounting and political short-termism (Nan & Qin 2019; Hunter 2016). The costs of prevention are immediate, visible and often politically difficult, while the benefits are longer-term, uncertain and may only become apparent when a crisis has been avoided. This can lead governments, institutions, businesses and individuals to prioritise short-term economic, political, or personal gains over preventive measures, even where the potential consequences of inaction are severe. Recognising this bias is important for designing policies, incentives and communication strategies that make prevention more visible, politically feasible and institutionally durable.

Policy and public debates may also be shaped by misplaced confidence in simple explanations or single-solution responses to complex zoonotic risk scenarios. Where ecological, epidemiological, economic and behavioural dynamics are poorly understood, there is a risk that intuitive but inadequate solutions gain more traction than evidence-based, interdisciplinary approaches. Effective One Health governance therefore requires transparent evidence review, appropriate expertise and adaptive learning.

8.6 Global supply chains and telecoupling

The interconnectedness and dynamics of global supply chains are important factors that influence demand for live wildlife, wildlife parts and wildlife products. Some species are highly sought after in well-established legal and illegal international markets, including the exotic pet trade, wild meat, luxury products, and traditional medicine markets. The resulting cross-border movement of live animals can create opportunities for pathogen exposure, amplification, spillover, and spread, particularly where animals of uncertain origin and health status move through long supply chains involving capture, holding, transport, export, import, wholesale, retail, online sale, fairs, or private keeping.

CITES trade data illustrate the scale and geographic connectivity of legally reported wildlife trade. Between 2011 and 2020, approximately 3.5 million CITES shipments were reported in direct trade by exporters. This amounted to over 1.3 billion individual organisms, including 1.26 billion plants and 82 million animals, and an additional 279 million kilogrammes of products reported by weight. Asia and Europe represented both the top exporting and importing regions, with Asia accounting for 37% of export transactions and 31% of import transactions and Europe for 34% of export transactions and 38% of import transactions (CITES Secretariat 2022). These figures highlight the urgent importance of effective trade monitoring, traceability and risk assessments for biodiversity conservation and One Health.

International live wildlife trade in particular can threaten global health security because live animals and their pathogens are transported across borders. Importing countries are therefore at risk of introducing zoonotic hazards through legal, illegal, or poorly monitored trade pathways, especially where species-specific reporting, quarantine, disease screening and traceability are weak (Knobler et al. 2006; Pavlin et al. 2009). This is not only a matter of where animals are captured or sold first: demand in one region can drive extraction, transport, handling, and pathogen-exposure risks in another. These telecoupled supply chains mean that health, biodiversity and welfare impacts may be

displaced geographically, while the benefits and risks of trade are distributed unevenly across countries, sectors and communities.

8.7 Online platforms and digital trade

Online and social media platforms provide a rapidly growing infrastructure for both legal and illegal wildlife trade, including live wild animals, exotic pets, wild meat and wildlife parts and products. The global reach and relative anonymity of e-commerce and social media platforms, coupled with rapidly expanding technological capacity, appeal to both sellers and consumers, including illegal traders and criminal networks.
Online trade can connect geographically distant suppliers, intermediaries, and buyers; enable rapid shifts between platforms; obscure the origin, legality, and health status of animals; and facilitate private communication and difficult-to-trace payment systems. These features pose significant regulatory and enforcement challenges, with clear implications for biodiversity conservation, animal welfare, biosecurity and One Health. Furthermore, social media users were found to express limited awareness of the spectrum of challenges associated with the exotic pet trade, such as animal welfare and legality (Anagnostou & Doberstein 2024; Pascual & Wingard 2021a,b; Spee et al. 2019).
A large proportion of documented online live animal trade relates to exotic pets. However, digital live wildlife trade is not limited to this sector. For example, a TRAFFIC survey of online wildlife trade in Cameroon, Chad, the Democratic Republic of the Congo, Gabon and Nigeria found 1,267 CITES-listed wildlife products or specimens from a minimum of 43 species offered for sale in 428 unique advertisements across 72 online platforms between March 2018 and June 2021. Live wild animals represented 70% of all online advertisements, with live birds and monkeys prominent among the taxa offered for sale (Woolloff et al. 2022). CITES permits were not visible in any of the observed online advertisements, and only three advertisements made reference to CITES formailties; sales were often likely to proceed through private messaging and difficult-to-trace payment arrangements (Woolloff et al. 2022).

9. The international exotic pet trade: scale, risks, and distribution channels

The growing global exotic pet market is a multi-billion-dollar industry with considerable implications for biodiversity conservation, invasive species introductions, animal health and welfare and the spread and development of zoonotic pathogens (Chomel et al. 2007; Lockwood et al. 2019; Sinclair et al. 2021). It includes the capture, breeding, transport, sale and keeping of non-native wild animals as pets, spans thousands of species and millions of individuals and is driven by novelty, rarity, status, unusual species and the desire to keep wild animals as distinctive companion animals (Altherr & Lameter 2020; Harrington et al. 2021; Marshall et al. 2020; Hughes et al. 2023b). Demand for rare or newly available species can generate conservation risks because rarity itself may increase desirability and market value, further incentivising collection from the wild

(Hausmann et al. 2023). Although the precise scale of the exotic pet trade is difficult to quantify because it includes legal, illegal, domestic, international, online, captive-bred and wild-caught trade, much of it poorly monitored, available evidence indicates that it represents a substantial global trade involving thousands of species and very large numbers of individual animals (Lockwood et al. 2019; Sinclair et al. 2021).

The legal international transport of undomesticated vertebrates as pets alone involves billions of dollars and millions of animals each year, but key data gaps concerning source regions, trade volumes, species composition and within-country distribution remain (Sinclair et al. 2021). CITES records capture only part of this trade: one analysis reported approximately 2.2 million individual live wild animals from 1,316 species exported every year to 189 countries, while noting that many additional pet-trade species are not listed on the CITES appendices and therefore lack comparable international monitoring (Harrington et al. 2021).

National examples further illustrate the scale of this issue. In the United States, the exotic pet trade was estimated to include hundreds of species, to be worth up to USD 15 billion annually and to involve approximately 113 million animals. Roughly 14% of U.S. households reportedly own one or more exotic animals. The same report describes the United States as a dominant driver of the global pet trade and notes that the American exotic pet trade sources animals legally and illegally from the wild as well as from captive-breeding facilities around the world (Linder et al. 2023).

The exotic pet trade, encompasses both domestic and international commercial transactions in wild animals kept as pets. It presents a multifaceted catalogue of risk factors for zoonotic disease transmission and spillover because it combines conditions known to raise disease risk: species mixing, high-density holding, poor health, inadequate health monitoring, domestic and international transport, confinement, stress-induced susceptibility, uncertain origin and close contact between animals, traders, retailers, hobbyists, and private owners (Chomel et al. 2007; Warwick & Steedman 2021; van Roon et al. 2019). For instance, an assessment of exotic animal imports to the Netherlands found that the vast majority of individuals were imported by trading companies, creating potential exposure risks for retail workers, hobbyists and pet owners; the authors also highlighted that illegal imports may pose risks because the health status of animals is often unknown (van Roon et al. 2019).

Poor health monitoring is of particular concern. Infected exotic pets may remain undetected carriers of zoonotic pathogens, thus posing risks to humans and other animals in close contact. For example, a screening of reptiles from pet shops and private households in Romania found that 43.28% carried *Salmonella* spp.; all isolated strains showed resistance to at least one antibiotic and 79.32% were multidrug-resistant (Dégi et al. 2023).

Health-screening gaps are not limited to illegal imports. In the UK, for example, animal-health import requirements for exotic pets vary substantially by taxon, and systematic pathogen testing for zoonotic pathogens is not carried out for all imported exotic pets. Pet reptiles, amphibians, and invertebrates are not subject to general animal-health import requirements, with limited exceptions, while exotic pets bred domestically may also be traded without mandatory testing for zoonotic pathogens of concern. Animals

may therefore enter or move through the pet trade with uncertain pathogen status, giving rise to potential exposure risks for breeders, sellers, transporters, veterinary staff, owners, household contacts and the public (Born Free Foundation & RSPCA 2021).
In Europe, fairs, together with online platforms, are among the main sales and exchange channels for exotic pets (Altherr et al. 2020). International pet fairs bring together thousands of animals from a diverse range of species and geographic origins (Altherr et al. 2010; Altherr et al. 2020). In addition to captive-bred animals, wild-caught animals that may carry pathogens are also available. These events therefore reproduce many of the risk conditions associated with other live animal markets, including the presence of sick, injured, or stressed animals; mixing of animals of different origins and uncertain health status; limited or absent hygiene protocols; and close contact among animals, traders, hobbyists, retailers, and visitors. Warwick & Steedman (2021) argue that wildlife markets share common structures and practices that raise concerns for animal welfare, public health and safety, agricultural animal health and other One Health issues. They conclude that such markets are incompatible with responsible standards and practices and recommend that such events be abolished globally to address the significant inherent risks.

10. Legal, regulatory, and enforcement challenges

Legal, regulatory and enforcement systems play a central role in determining whether live wildlife trade pathways are prevented, permitted, restricted, monitored, or left largely unmanaged. At present, many relevant frameworks remain fragmented across conservation, animal health, public health, agriculture, customs, trade, food safety and animal welfare mandates. This fragmentation can leave zoonotic-risk prevention under-addressed, even where trade is legal or formally regulated. The central regulatory challenge is therefore not only whether live wildlife trade is legal or illegal, but whether legal frameworks reduce the conditions that allow pathogens to emerge, amplify, spread, and spill over.

10.1 International legal frameworks and guidance

The UN Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) is tasked with regulating international trade in wildlife to ensure that it does not threaten the survival of affected species. CITES currently does not have an explicit mandate concerning zoonotic disease prevention. However, the zoonotic potential of trade in CITES-listed species has recently been examined (UNEP-WCMC & JNCC 2021, 2022). UNEP-WCMC and JNCC found that legal international trade included substantial numbers of live CITES-listed animals from species, and broader taxonomic groups, associated with WHO R&D Blueprint priority diseases, while also highlighting major data limitations and the need to interpret these figures cautiously (UNEP-WCMC & JNCC 2021, 2022). In 2022, CITES member states adopted Decisions 19.17 and 19.18 on the role of

CITES in reducing the risk of future zoonotic disease emergence associated with international wildlife trade, which may help pave the way towards reducing zoonotic disease emergence and transmission risks associated with international wildlife trade in the context of CITES (CITES 2022).

Existing wildlife trade monitoring systems fall short of providing a complete picture of zoonotic risk across live wildlife trade chains. Even where well-drafted regulations are present, many countries lack the resources, training, infrastructure, interagency coordination, or enforcement capacity to implement them effectively, undermining their real-world impact (UNODC 2020; Linder et al. 2023). CITES trade data can help identify some international movements of listed species, including taxa associated with pathogens of zoonotic concern, but CITES was designed primarily as a conservation instrument and only covers a proportion of globally traded wildlife or disease-relevant taxa. Many legally traded non-CITES species are not subject to comparable species-specific international reporting, while domestic, informal, online and illegal trade can be difficult to detect or quantify. These gaps limit the ability of authorities to assess trade volumes, trace animal origins and movements, identify high-risk pathways and integrate zoonotic-risk considerations into regulation and enforcement.

The World Organisation for Animal Health (WOAH) sets international standards for animal health and welfare and provides guidance relevant to zoonotic disease prevention, including its Guidelines for Addressing Disease Risks in Wildlife Trade (WOAH 2024). WHO, WOAH and UNEP have also issued interim guidance recommending that national competent authorities suspend the trade in live-caught wild mammals for food or breeding purposes and close sections of food markets that sell such animals as an emergency measure, while strengthening hygiene, sanitation, regulation, and risk-management measures in traditional food markets (WHO, OIE & UNEP 2021).

The Quadripartite Collaboration (FAO, UNEP, WHO and WOAH) provides the principal international coordination framework for One Health across human, animal, plant and environmental health. It's One Health Joint Plan of Action (2022–2026) was developed to support countries in strengthening One Health systems, preventing future pandemics and addressing health threats at the human-animal-plant-environment interface. The One Health High-Level Expert Panel (OHHLEP) provides scientific and policy advice to support this work and contributed to the development of the OHHLEP One Health definition used in this paper (FAO, UNEP, WHO & WOAH 2022).

The World Bank also emphasised One Health investment as a cost-effective approach to reducing the risks of emerging infectious diseases and future pandemics. Together, these frameworks and guidance documents provide important policy support for prevention-oriented approaches, but most remain guidance, coordination mechanisms, or investment frameworks rather than binding legal obligations directly regulating live wildlife trade and markets (World Bank 2022).

10.2 National regulation of live wildlife trade and markets

Since the emergence of COVID-19, some governments and international bodies have taken steps to reduce zoonotic risks associated with wildlife trade and markets, including

bans or restrictions on certain forms of wildlife consumption, market closures, strengthened enforcement, and recommendations to suspend the trade in live-caught wild mammals for food or breeding purposes. For example, in 2020 China adopted a decision prohibiting the consumption of terrestrial wild animals for food, while allowing other trade purposes or species to continue under certain conditions (Xiao et al. 2021; Whitfort 2021).

The European Union is also a major live wildlife market, including for exotic pets and has developed a comparatively detailed wildlife-trade regulatory system (European Union 1996; European Commission 2006). The EU Wildlife Trade Regulations implement CITES across EU Member States and include rules intended to ensure that wildlife entering the EU market is of legal and sustainable origin. However, these rules remain primarily structured around species protection, legality, and sustainability rather than comprehensive zoonotic-risk prevention. As in other jurisdictions, important gaps may remain for non-CITES species, domestic and intra-EU trade, online trade, private keeping, health screening, quarantine and post-import monitoring. The EU example therefore illustrates both the value of regional wildlife-trade regulation and its limitations where One Health risk prevention is not fully integrated into trade, animal-health, public-health and enforcement systems.

The WHO, OIE/WOAH and UNEP also issued interim guidance calling on national authorities to suspend trade in live-caught wild mammals for food or breeding purposes and to close sections of food markets selling such animals as an emergency measure (WHO, OIE & UNEP 2021).

Regulatory gaps are not confined to countries commonly associated with live wildlife markets. A review of animal markets and zoonotic disease in the United States identified 36 types of consumer-facing animal markets and supply chains relevant to zoonotic spillover risk and concluded that the United States has no comprehensive strategy to mitigate zoonotic risk. The report describes a patchwork regulatory system with no single unified authority responsible for zoonotic disease prevention, detection and regulation, despite the fact that animals, pathogens, products and people move across the artificial boundaries between wildlife, livestock, companion animals, markets and agencies (Linder et al. 2023).

The UK exotic pet example similarly illustrates that legal ownership and trade may proceed without systematic zoonotic-risk screening. Regulation may not restrict ownership based on zoonotic disease risk; domestic breeding and trade may occur without mandatory testing for zoonotic pathogens of concern; and surveillance may provide an incomplete picture where many potential zoonoses fall outside statutory systems (Born Free Foundation & RSPCA 2021).

These examples underscore that zoonotic risk-reduction measures are possible. They also highlight continuing gaps where measures are temporary, partial, focused only on selected taxa or uses, weakly enforced, or not rooted in or integrated into broader One Health legal frameworks. Incorporating such considerations into wildlife trade and market regulations would help ensure a more integrated and effective approach that acknowledges the links between environmental, animal and human health. Addressing legal gaps in live wildlife trade and markets is therefore crucial for prevention,

particularly where high-risk activities remain legal, poorly monitored, weakly regulated, or dependent on voluntary compliance.

10.3 Legal gaps in live wildlife trade and zoonotic-risk prevention

Major legal gaps remain in relation to live wildlife trade and zoonotic-risk prevention. Even where legal provisions aimed at regulating wild animal trade-related activities, including live animal markets and their supply chains, exist, implementation and enforcement can prove challenging. Many legal frameworks were designed primarily for conservation, animal health, agriculture, customs control, food safety, or animal welfare, rather than for integrated prevention of zoonotic spillover across live wildlife trade chains. As a result, legislation may regulate species conservation status, ownership, import/export documentation, animal welfare, or food safety without systematically addressing the conditions that create high-risk interfaces, including species mixing, confinement, transport, slaughter, poor hygiene, inadequate quarantine, limited traceability and animal origin and health status.

Definitions and classifications too are a recurring problem. Legal systems may distinguish between "wildlife," "livestock," "pets," "farmed animals," "captive-bred animals," "food animals," and "exotic animals" in ways that do not reflect either biological reality or disease risk. Wild animals bred or kept in captivity may be treated differently from wild-caught animals, even though they may still carry pathogens, experience stress, mix with other species and enter trade chains that create exposure risks. They may also be categorised incorrectly as domestic animals. Ambiguities of this nature create loopholes that facilitate increased disease, welfare, conservation and enforcement risks. In other cases, regulations may focus on the conservation status of species without adequately considering zoonotic risks.

This means that even high-risk species may be traded legally, which raises the potential for disease outbreaks, spillover and transmission. Similarly, legal controls often focus on threatened or high-value species rather than on disease-risk pathways, while non-endangered species may receive little regulatory attention despite their potential zoonotic relevance. Addressing this gap requires clearer and stronger legal mandates, greater intersectoral coordination, effective risk-reduction measures and appropriate resources for implementation and compliance.

International frameworks also leave gaps. CITES provides a critical mechanism for regulating international trade in listed species, but it was designed primarily to ensure that trade does not threaten species survival. It therefore does not as yet provide a comprehensive zoonotic-risk prevention framework. Many traded species are not CITES-listed, and large parts of the legal trade in non-CITES wildlife are not covered by a comparable species-specific international reporting system. Domestic, informal, online and illegal trade are even harder to detect, quantify and regulate. These gaps limit the ability of authorities to assess trade volumes, trace animal origins and movements, identify high-risk pathways and integrate zoonotic-risk considerations into licensing, permitting, inspection, and enforcement.

Even where international frameworks exist, their effectiveness depends on national implementation, enforcement capacity and cooperation between jurisdictions.

Differences in legal standards, permitting systems, inspection capacity, penalties and enforcement priorities can create uneven levels of risk control. These inconsistencies allow high-risk trade routes to shift towards jurisdictions with weaker regulation, lower detection rates, or limited enforcement capacity.

National implementation too is often patchy and fragmented. Responsibilities for wildlife, animal and public health, agriculture, customs, trade, food safety, veterinary services and law enforcement tend to sit with different agencies that operate under distinctly separate mandates. This can lead to non-overlapping or overlapping jurisdictions, weak information-sharing, inconsistent regulation and uncertainty about which authority is responsible. The resulting legal architecture is poorly suited to addressing the associated One Health risks, because pathogens transition across boundaries between wildlife, domestic animals, humans, products, markets and ecosystems, while regulatory systems often do not.

Additional legal gaps include insufficient requirements for health screening, quarantine, hygiene, biosecurity, record-keeping, traceability, veterinary oversight and post-import monitoring; weak regulation of online trade and informal markets; inadequate penalties where profits from non-compliance outweigh risks of detection; limited protection for whistleblowers and frontline enforcement personnel; and insufficient legal duties to provide public risk communication or demand-reduction measures. Even where relevant laws exist, they are vulnerable to being undermined by limited resources, lack of awareness and training, corruption, poor interagency cooperation, or weak enforcement capacity.

Addressing these gaps requires clearer legal mandates for zoonotic-risk prevention, enforceable standards for high-risk live wildlife trade pathways, stronger intersectoral cooperation, improved traceability and reporting systems and sufficient resources for implementation and compliance. Legal reform should be concerned not only with the legality of live wildlife trade, but whether existing laws adequately reduce conditions and activities which allow pathogens to emerge, amplify, spread and spill over.

10.4 Voluntary guidance versus binding obligations

Although numerous guidelines, recommendations, standards and voluntary frameworks address aspects of wildlife trade, animal health, welfare, biosecurity and One Health, binding legal obligations remain uneven, fragmented, or absent in many areas relevant to live wildlife trade and zoonotic-risk prevention. This creates a persistent gap between recognised risks and enforceable action, particularly where high-risk trade remains legal, poorly monitored, weakly regulated, or dependent on voluntary compliance.

10.5 Enforcement gaps

Enforcement gaps can further weaken the effectiveness of legal frameworks. In some jurisdictions, penalties for wildlife trafficking, environmental crime, or violations of trade, health, hygiene, biosecurity, or reporting requirements are weak, inconsistently applied, or disregarded. Such non-compliance can incentivise the circumvention of national and

international regulations, especially where detection rates are low, corruption is present, or enforcement agencies lack sufficient resources, training, infrastructure, or authority. The United Nations Office on Drugs and Crime reports that over half of all CITES-related seizures between 1999 and 2018 involved mammals (23%), birds (8.5%), and reptiles (21.3%) (UNODC 2020). There has also been a steady rise in the number of seizures. Under CITES rules, member states must submit Annual Illegal Trade Reports (AITRs). Yet only 78 of 183 countries did so between 2017 and 2020. These reporting gaps limit the ability of authorities to assess patterns of illegal trade, target enforcement and understand the scale and composition of disease-relevant trade pathways.

Enforcement priorities may also focus primarily on high-value or threatened species while overlooking non-listed or lower-value species that are nevertheless relevant to zoonotic risks. Online trade, informal markets and opaque supply chains create additional challenges because transactions can shift rapidly between platforms, jurisdictions and payment systems. As wildlife trade moves online, many legal frameworks struggle to keep pace in terms of regulation and monitoring of shifting digital platforms. At the same time, individuals who wish to report illegal or unsafe practices may not be adequately protected from retaliation, thus hindering the flow of critical information to enforcement agencies. Substantial volumes of trade may therefore go unnoticed. Public risk communication and demand-reduction provisions are often weak or absent, limiting the ability of legal frameworks to contain risky behaviour before enforcement becomes critical.

Effective enforcement therefore requires not only stronger penalties and capacity, but also anti-corruption safeguards, digital monitoring, whistleblower protection, interagency cooperation, public risk communication and sufficient resources for implementation. Addressing these enforcement gaps is important not only for wildlife conservation and sustainability, but also for global health security, because weak enforcement can allow high-risk trade pathways to persist despite recognised zoonotic risks.

10.6 Intersectoral collaboration

As our understanding of the complexities that underpin zoonotic disease emergence and transmission deepens, legal frameworks too must evolve. Regular reviews of legislation governing wildlife trade-related activities are vital to ensure they remain current, science-based and effective in mitigating zoonosis-related risks. Legal instruments governing wildlife trade often fall primarily under the mandate of either environmental, wildlife, forestry, agriculture, trade, or customs authorities, while public health agencies have limited involvement in their design, implementation, or enforcement. The resulting lack of intersectoral collaboration impedes integrated responses and a holistic understanding of zoonotic risks and their mitigation.

Effective zoonotic risk reduction strategies therefore require national and international legal frameworks that reflect the complex interlinkages that underlie zoonotic disease emergence and transmission. They also depend on formal collaboration between relevant sectors and legal instruments, including those related to wildlife, the environment, public health, occupational health and safety, veterinary services, agriculture and livestock, customs, trade, law enforcement and food safety authorities.

11. Prevention and Risk-Reduction Opportunities

Prevention at source translates into effective and practical risk-reduction measures across live wildlife trade chains. These may include risk-based restrictions or prohibitions for high-risk trade pathways, improved surveillance, quarantine and health screening, traceability, hygiene and biosecurity standards, market controls, enforcement, demand reduction, public risk communication and cross-sectoral One Health governance. Their purpose is to mitigate the ecological, commercial, behavioural, and regulatory conditions that enable pathogen emergence, amplification, transmission and spillover, rather than relying primarily on outbreak control.

11.1 Demand reduction as prevention

Demand for wildlife trade must be understood against the wider biodiversity context. Direct exploitation of organisms represents one of the leading drivers of global biodiversity loss, second only to land- and sea-use change in the IPBES global assessment. Unsustainable wildlife trade therefore directly and indirectly causes damage to target and non-target species, reduces population abundance, alters ecological interactions and contributes to failing ecosystems. For example, hunting has been estimated to cause partial defaunation of mammal populations across approximately half of the pantropical forest area. Wildlife trade was linked to significant declines in affected species and wider damaging ecosystem impacts, including altered seed dispersal, harmful trophic cascades, changes in plant communities and the introduction of invasive species (IPBES 2019; Benítez-López et al. 2019; Morton et al. 2021; Cardoso et al. 2021; Hughes et al. 2023a).

Legal and enforcement measures are clearly necessary but insufficient on their own. Demand reduction and behaviour-change interventions are essential where wildlife consumption, ownership, trade, or use drives overexploitation, illegal trade, poor animal health, ecosystem degradation, or avoidable zoonotic risk. This is particularly relevant to commercial, urban, luxury, status-driven, speculative, exotic-pet, medicinal, or novelty-driven demand, which accounts for much of the pressure associated with contemporary wildlife trade (D'Cruze et al. 2020; Moorhouse et al. 2021; MacFarlane et al. 2022). While genuine subsistence dependence and livelihood constraints require careful, equitable and locally appropriate responses, they should not obscure the need to reduce the enormous demand of discretionary, commercially amplified, or avoidable wildlife use (Luiselli et al. 2019; Campbell et al. 2021).

Genuine subsistence dependence should not be used to legitimise avoidable, commercial, luxury, status-driven, or speculative wildlife use that contributes to biodiversity loss, poor animal health, ecosystem degradation, or zoonotic risk. Even where wildlife use is not luxury- or status-driven, aggregate demand can become unsustainable when human population growth, urbanisation, commercialisation, improved market access, or expanding supply chains increase offtake beyond ecological limits or create high-risk trade pathways. Demand-reduction strategies should therefore distinguish genuine subsistence dependence from discretionary or commercially

amplified demand. while recognising that non-luxury markets may also require risk reduction interventions where scale, sourcing methods, animal and environmental health impacts, or zoonotic-risk pathways exceed sustainable or safe limits (IPBES 2019; Benítez-López et al. 2019; Morton et al. 2021; Hughes et al. 2023a).

The importance of addressing demand, alongside supply and enforcement, has been recognised by the United Nations, UNODC, CITES and SDG Target 15.7, which calls for urgent action to end poaching and trafficking of protected species and to address both demand and supply of illegal wildlife products (UNGA 2015; UNODC 2020; CITES n.d.). Demand reduction should therefore not be treated as a narrow consumer-awareness exercise. Instead, it should be evidence-based, context-specific and informed by social norms, motivations, affordability, identity, trust, legality, availability and the wider ecological and health consequences of trade (Campbell et al. 2021; MacFarlane et al. 2022). In many contexts, the appropriate policy response should be to reduce and delegitimise harmful demand rather than normalise or accommodate it. Reducing demand for high-risk wildlife trade can lower the number of animals captured from the wild, transported, held, sold, slaughtered, or kept in conditions that facilitate pathogen transmission, while also supporting biodiversity conservation, animal welfare and ecosystem integrity (D'Cruze et al. 2020; Osofsky 2023).

12. Conclusion

Live wildlife trade and markets sit at the intersection of human health, animal health and welfare, biodiversity, ecosystem integrity, markets and governance systems. The zoonotic, animal health and welfare, biodiversity, ecological, and economic risks associated with these trade chains are therefore not limited to public-health concerns, nor are they confined to illegal trade, a single region, or a particular market type. Instead, they arise because wild animals are removed from their ecological contexts, moved through commercial and informal supply chains and exposed to confinement, mixing, handling, sale, slaughter, or private keeping under conditions that compromise their health and welfare, disrupt ecological and host-pathogen relationships and create opportunities for pathogen exposure, amplification, transmission, recombination and spillover.

The core conclusion of this paper is that prevention at source must become a central policy objective because it addresses risk before pathogens cross species barriers, amplify and spread, and before the resulting human, animal, ecological and economic harms can escalate. Response capacity remains necessary, but cannot substitute for lowering upstream conditions that allow pathogens to emerge, amplify and spread. The human and economic costs of COVID-19 and other zoonotic outbreaks clearly demonstrate the dangers of relying primarily on detection, containment and response after spillover has occurred. From a One Health perspective, preventing high-risk interfaces before they give rise to crises is more rational than repeatedly paying for their consequences.

Effective zoonotic and pandemic risk reduction requires a fundamental shift in the assessment and governance of live wildlife trade, with prevention at source as the

guiding objective. The key question is not whether a wildlife trade pathway is legal, but whether it is compatible with biodiversity protection, animal and public health and clear, mandatory, and effectively implemented One Health safeguards. Legal status alone neither determines zoonotic nor pandemic risk. Live wildlife trade that is legal but poorly monitored, weakly regulated, dependent on voluntary compliance, or difficult to enforce can still give rise to conditions that promote pathogen emergence, amplification, and spread, while undermining animal health, species conservation, ecosystem integrity, and biodiversity.

A credible zoonoses and pandemic prevention agenda must therefore combine legal reforms, risk-based restrictions or prohibitions, traceability, quarantine, health screening, hygiene and biosecurity standards, market controls, enforcement capacity, anti-corruption safeguards, public risk communication, and cross-sectoral One Health governance. It must also address demand where wildlife use is discretionary, commercially amplified, luxury-oriented, status-driven, speculative, novelty-driven, otherwise avoidable, or where aggregate demand drives offtake, trade conditions, or exposure pathways beyond levels compatible with ecological sustainability, animal health and zoonotic-risk prevention.

At the same time, prevention must be equitable. Genuine subsistence dependence and livelihood constraints require careful, locally appropriate responses and should not be conflated with avoidable commercial or luxury demand. Such considerations cannot legitimise high-risk live wildlife trade pathways that cannot be robustly regulated, monitored, and enforced to precautionary and evidence-based standards. This conclusion is directed specifically at live wildlife markets and high-risk live wildlife trade pathways, where the removal, transport, confinement, mixing, sale, slaughter, or keeping of live wild animals can create distinctive and potentially severe One Health risks. Where such trade cannot be reliably regulated, monitored, and enforced, any perceived or real benefits are outweighed by the risks of zoonotic pathogen emergence, amplification, transmission, spillover and spread, as well as animal health impacts, biodiversity loss, ecosystem disruption and economic harm. Where these risks cannot be sufficiently reduced, precautionary restrictions or prohibitions are warranted. Treating prevention as a secondary option leaves societies, economies, wild and domestic animals, ecosystems and future generations to bear the harmful and avoidable consequences.

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