Evidence Note

What we know about zoonotic threats and how we can we minimise their future impact

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KNOWLEDGE FOR LIFE

Highlights

Introduction

The COVID-19 pandemic demonstrated how zoonotic spillover events can rapidly escalate into global crises with profound health, economic, and social consequences. It exposed longstanding weaknesses in zoonotic disease prevention, including fragmented surveillance across sectors, limited attention to environmental drivers of spillover, and chronic underinvestment in preparedness relative to response. These lessons have driven renewed political and financial commitment to upstream prevention, including the establishment of The Pandemic Fund and the growing emphasis on One Health approaches. This Evidence Note responds to this post-COVID context by synthesising current evidence on zoonotic threats and options to reduce their future impact.

A zoonotic disease is a disease or infection that can be transmitted naturally from vertebrate animals to humans or from humans to vertebrate animals. More than 60% of human pathogens are zoonotic in origin[1]. This includes a wide variety of bacteria, viruses, fungi, protozoa and parasites. Zoonotic diseases cause significant morbidity (numbers of people getting sick) and mortality (number of human deaths), but the consequences of zoonoses extend well beyond human illness. Zoonotic disease outbreaks can disrupt and destabilise livestock systems, economies, and trade and travel networks, while also degrading biodiversity, livelihoods and wellbeing, and public trust.

Their emergence and spread are shaped by complex interactions between behavioural, environmental, and climatic factors, domesticated animal management practices, changes in land-use, wildlife exploitation practices, and socioeconomic conditions.

This Evidence Note brings together current understanding of the issues surrounding zoonotic disease to support more effective responses. It explores the impacts and underlying drivers of zoonotic diseases and examines how globalisation creates new opportunities for transmission, and how increasing human-animal-environment interactions escalate zoonotic threats. It considers approaches to reducing disease occurrence and highlights the growing importance of surveillance, monitoring, and predictive systems. Recognising that zoonotic risks sit at the intersection of human, animal, and environment health, the Evidence Note highlights the value of a One Health approach to tackling zoonotic disease and reflects on the political and institutional challenges associated with implementing such an approach.

This Evidence Note is evidence-based and draws on information from a literature review and expert opinion, see **Annex 1**.

1. Impacts of zoonotic disease

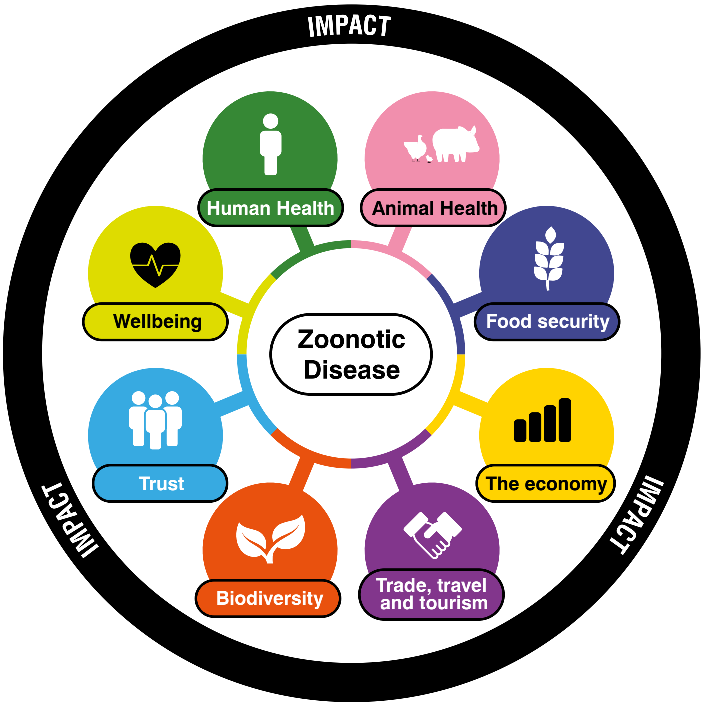


Figure 1. Zoonotic disease has far-reaching impacts on human and animal health that extend beyond economic cost.

Zoonotic diseases can have far-reaching consequences that extend beyond human and animal health, affecting economies, trade, travel, and tourism, biodiversity, overall wellbeing, and public trust (Figure 1). The breadth and severity of impacts highlights the urgency of strengthening prevention, preparedness and intervention strategies.

Mortality and morbidity

Zoonotic diseases represent more than 60% of human infectious diseases[1] and cause significant morbidity and mortality. COVID-19 alone is estimated to have caused 14.83 million excess deaths worldwide between January 2020 and December 2021[2]. This figure is likely to be conservative as statistical models that estimate excess deaths using reported mortality data often underestimate true mortality[2]. Estimating the impact of zoonoses, in terms of both mortality and morbidity, is complex, as demonstrated by COVID-19. Estimation processes are subject to several potential biases, including in data quality, which itself depends on the quality and capacity of each country's surveillance system[3], and which directly influences the accuracy of impact estimates. These issues are often compounded when considering impacts on livestock or wildlife.

Economics and livelihoods

Zoonotic disease outbreaks carry sweeping economic costs, spanning healthcare expenditure, public-sector response, and disruptions to trade, labour, and tourism. COVID-19 illustrates the scale of this burden: the International Monetary Fund (IMF) estimated cumulative global output losses of approximately USD 13.8 trillion through 2024[4], dwarfing earlier outbreaks like severe acute respiratory syndrome (SARS) (USD 13 billion), and the 2009 H1N1 pandemic (USD 55 billion)[5]. Even these figures may understate the true impact, as aggregate estimates tend to both underestimate the indirect costs of an outbreak, and overlook the disproportionate burden borne by marginalised groups including low-income populations, women, and Indigenous communities.

Beyond discrete outbreaks, zoonotic diseases, more broadly, generate both direct and indirect economic costs. Direct costs include healthcare expenditure, animal culling, and veterinary expenses, while indirect costs, often harder to quantify, encompass lost productivity, disrupted trade, and downstream effects on food value chains and consumer markets. Agriculture and livestock sectors are particularly vulnerable. For example, the Rift Valley fever epidemic in Somalia (1998–2002) resulted in USD 435 million in livestock export losses alone[6]. Indirect costs can be equally substantial, for example, during the 1998 Nipah outbreak in Malaysia, biosecurity interventions and slaughterhouse controls added USD 229 million on top of the costs of direct culling compensation[7].

The economic burden of zoonoses often falls unevenly, hitting small farmers, rural communities, and vulnerable populations hardest.

Culling

The number of animals culled during a zoonotic disease outbreak can be extremely high. For example, in Europe, between 2021 and 2022, 2,467 outbreaks of highly pathogenic avian influenza (HPAI) were identified in poultry, leading to the culling of 47.7 million birds across 37 European countries[8]. Wildlife farming can also be affected: following the detection of SARS coronavirus-2 (SARS-CoV-2) in several mink farms, the Danish Ministry of the Environment and Food announced the culling of all mink in the country, totalling approximately 17 million animals[9].

Food security

Zoonotic diseases can substantially affect food security by disrupting livestock systems that supply meat, milk, and eggs[10]. Diseases such as highly pathogenic avian influenza, bovine tuberculosis, Nipah virus, Rift Valley fever, anthrax, and brucellosis can reduce animal productivity, leading to lower milk yields, fewer eggs, impaired growth, and increased livestock mortality. In addition, disease control measures may further constrain food availability. For example, culling of infected or exposed animals removes them directly from production, as observed during large-scale avian influenza outbreaks involving millions of birds. Zoonotic disease epidemics can also restrict the movement of people, animals, and goods, disrupting markets, increasing food prices, and weakening supply chains.

Biodiversity

The effects of zoonotic disease outbreaks on biodiversity can also be significant but are often overlooked. For example, the recent HPAI H5N1 panzootic, the largest animal disease outbreak in recent decades, affected more than 400 species of wild birds and 40 species of mammals, including several already endangered species[11,12], and killing over 600,000 birds in South America in 2023 alone. Such losses can trigger cascading effects across ecosystems, disrupting food webs and broader ecological functions[13].

Wellbeing

The psychosocial impacts of zoonotic disease outbreaks on mental health remain poorly understood, even in the case of long COVID-19. However, exposure to, or risk of, zoonotic disease can adversely affect the mental health and wellbeing of healthcare professionals, field veterinarians, agricultural workers, and others. This can include, for example the significant psychological distress associated with animal culling operations. Social isolation and loneliness can also result from movement restrictions imposed during outbreaks, as reported during the COVID-19 pandemic in Denmark[14]. In some cases, cultural stigma surrounding practices such as bushmeat consumption and traditional slaughter methods can compound this distress, creating barriers to reporting and help-seeking behaviour.

Trust and misinformation

With the COVID-19 pandemic came a simultaneous erosion of public trust in governments and scientific institutions, and an unprecedented infodemic of misinformation and disinformation, both of which had measurable consequences for vaccine uptake and adherence to public health measures[15]. The legacy of this distrust and misinformation is likely to pose a significant challenge to the management of future zoonotic disease outbreaks.

Key messages

- **Zoonotic diseases have wide-ranging impacts beyond health:** Zoonoses affect human and animal health, but also economies, livelihoods, trade, travel, tourism, food security, biodiversity, wellbeing and public trust.
- **The full burden of zoonoses is significant but often underestimated:** Zoonotic diseases cause substantial mortality and morbidity, yet their true impact is difficult to measure because of gaps in surveillance, data quality and reporting, particularly in livestock and wildlife.
- **Zoonotic outbreaks can cause major economic and livelihood losses:** Outbreaks generate direct costs, including healthcare, veterinary response and animal culling, as well as indirect costs such as lost productivity, disrupted trade, reduced tourism and impacts on food value chains. These burdens often fall hardest on small farmers, rural communities and marginalised groups.
- **Zoonotic diseases can threaten food security and animal production:** By reducing livestock productivity, increasing animal mortality, disrupting supply chains and triggering large-scale culling, zoonotic outbreaks can affect the availability and affordability of meat, milk and eggs.
- **Impacts on biodiversity and ecosystems are often overlooked:** Zoonotic disease outbreaks can cause large-scale mortality in wildlife, with cascading effects on ecosystems, food webs and ecological functions.
- **Zoonotic outbreaks can undermine wellbeing, trust and response efforts:** Outbreaks can harm mental health and social wellbeing, while stigma, misinformation and declining public trust can weaken reporting, help-seeking, vaccine uptake and adherence to public health measures.

2. Factors influencing the emergence and spread of zoonotic disease

Understanding the factors that influence zoonotic disease occurrence and recurrence, and how changes in these factors may contribute to disease emergence, is important in supporting the design of effective and targeted prevention, mitigation, and control strategies. However, the factors driving the emergence and spread of zoonoses are numerous and often interacting, shaping disease dynamics (i.e. how diseases spread and persist) in both direct and indirect ways. The relative importance of different factors can vary across geographic, environmental, cultural, and political settings, as well as across pathogen types (e.g. virus, bacteria, fungi), pathogen species or sub-species, and host species (Figure 2).

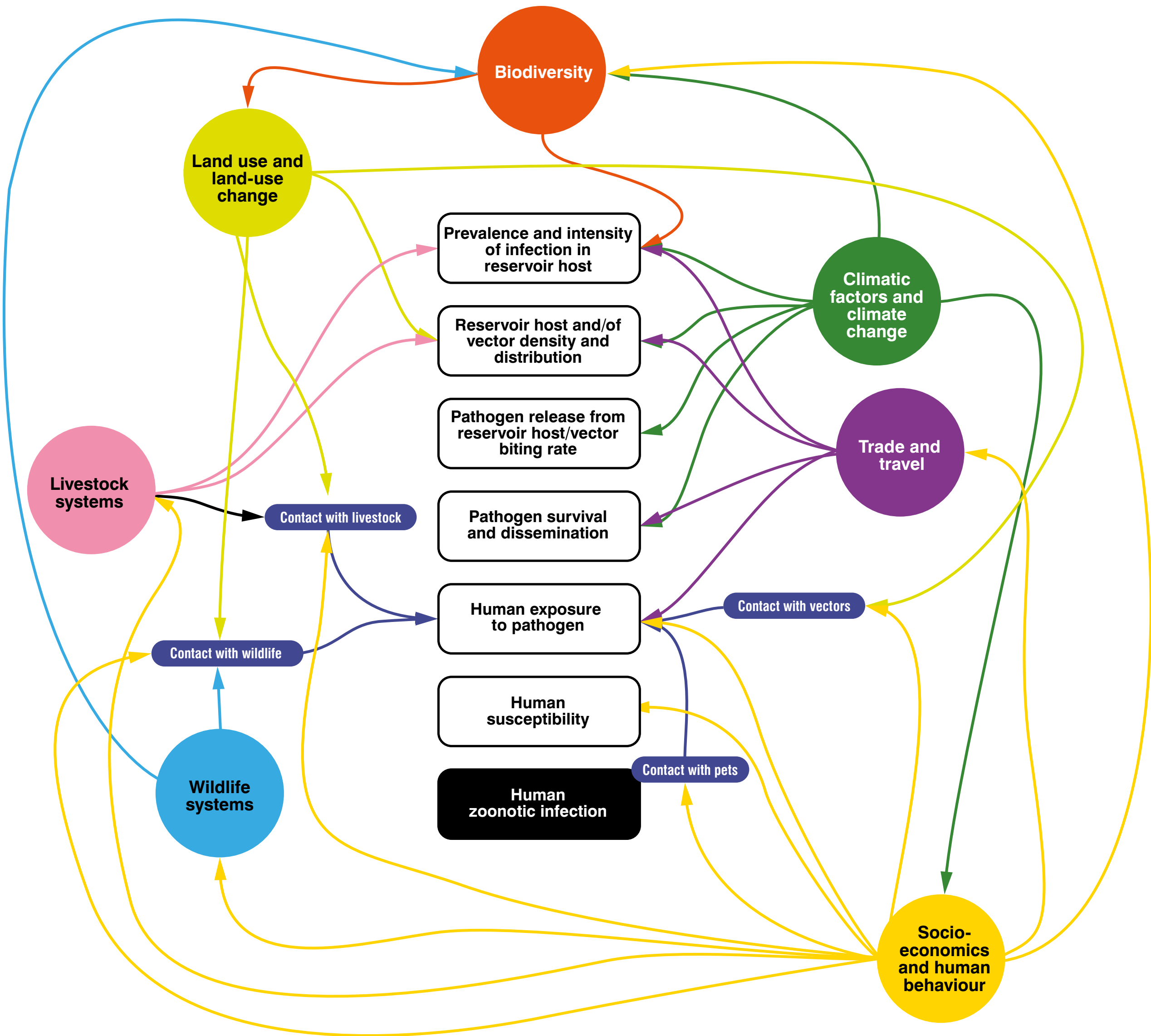


Figure 2. Conceptual framework illustrating the barriers to zoonotic pathogen transmission from animal reservoirs to humans (adapted from Plowright et al. 2017)[16] and the major drivers of zoonotic disease emergence and transmission, including their interactions (derived from a systematic evidence synthesis of the literature and subject expert input). Arrows indicate hypothesised pathways through which drivers may directly and indirectly influence transmission risks.

Animal and vector contact

Contact between humans, livestock, companion animals, wildlife, and disease vectors (mosquitoes, ticks, sandflies etc.) is a central determinant of zoonotic disease transmission[17]. Many of the upstream drivers of zoonotic disease emergence and transmission (including land use, animal management factors, environmental and socio-economic factors) influence zoonotic disease risks by shaping patterns of contact between these populations[18–20]. These drivers influence who interacts with whom, how often, and through which pathways (e.g. direct handling or indirect exposure to environmental contamination or disease vectors).

However, contact alone does not determine infection. The likelihood that contact results in an infection depends on the nature of the contact (Figure 3), the prevalence and intensity of the infection in the source host, and the susceptibility of the exposed individual. These elements are themselves shaped by human and animal behaviours, environmental contexts, and socio-economic conditions. As a result, the zoonotic disease risks posed by contact are highly context dependent. Evidence shows that even within the same disease-host system, risk can vary depending on the specific species involved in the contact[21], the exact pathogen species or sub-species causing the disease[22], human demographic characteristics[23], and geographic location [24,25].

Livestock contact

Contact with infected livestock has resulted in several historic and contemporary zoonotic disease outbreaks in humans including an outbreak of Q-fever in goat farm workers in the Netherlands in 2007[26], and the Nipah virus outbreak among pig farmers in Malaysia in 1998[27]. In humans, livestock contact is considered an important risk factor for a range of other zoonotic diseases including bacterial infections like tuberculosis[28] and brucellosis[29]; parasitic infections such as cryptosporidiosis[23] and echinococcosis[22]; and viral infections such as Crimean-Congo haemorrhagic fever[30] and hepatitis E[31]. Individuals who are occupationally exposed to livestock, such as farmers, abattoir workers and veterinarians, are often at a greater risk of acquiring such diseases[22,28,30,31]. However, recreational exposure to livestock (e.g. via farm visits or petting zoos) has also been implicated as a risk factor for human infection under certain conditions[31–33]. Livestock exposure can also influence zoonotic disease prevalence in other animals. In African wildlife, for instance, the risk of brucellosis generally increases with contact with domesticated livestock, although this risk varies with the wildlife species in question[21].

Companion animal/pet contact

In recent years, pet ownership has surged globally[34] and with it, risks of exposure to zoonotic disease. In humans, pet ownership or contact has been implicated as a risk factor for a range of established zoonotic diseases including toxoplasmosis[32,35,36], cryptosporidiosis[23], leptospirosis[24], and echinococcosis[22]. Free roaming, or community-owned dogs and cats may pose a particular risk because they may be more likely to encounter pathogens from livestock and wildlife and are less likely to receive regular veterinary care[37]. There is regionally specific evidence that these groups are more likely to harbour certain zoonoses (including bartonellosis, leptospirosis, and echinococcosis) compared to their housebound equivalents[25,38,39].

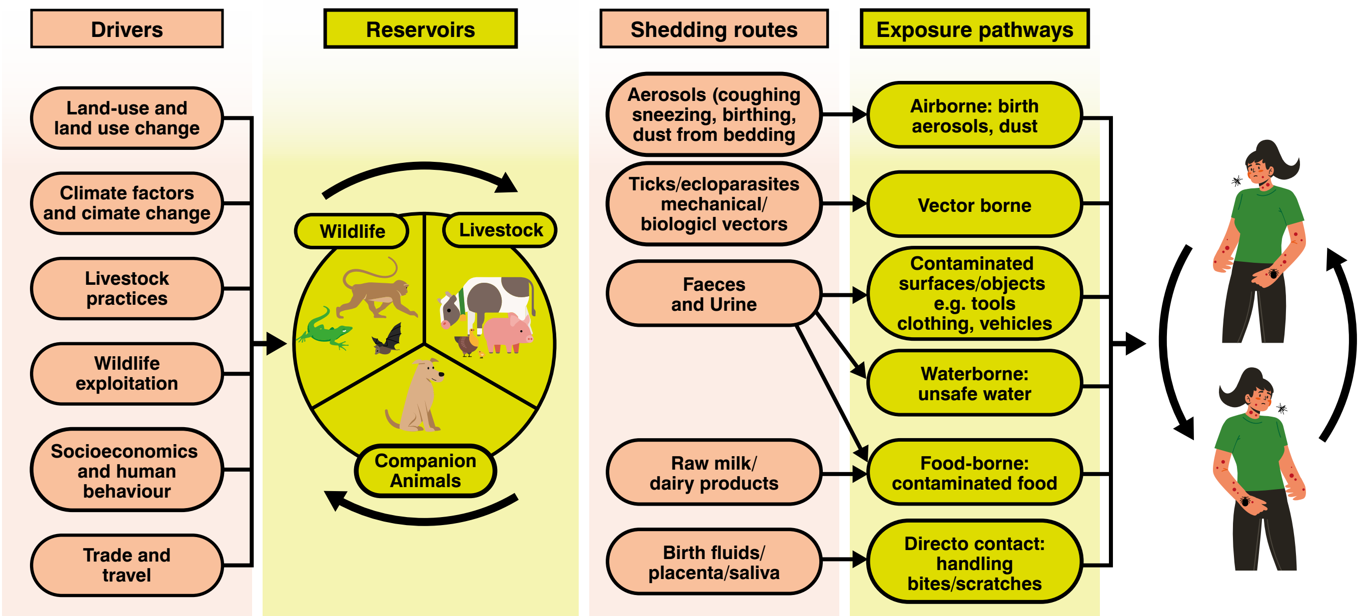


Figure 3. Transmission pathways of zoonoses.

Wildlife and rodent contact

It has been estimated that the majority of zoonoses classified as emerging infectious diseases[i] originate from wildlife hosts, which serve as reservoirs for the transmission of a wide range of zoonotic pathogens to humans and domesticated animals. Key examples of historic and more recent emerging zoonotic diseases for which wildlife hosts have been implicated include: Middle East respiratory syndrome (MERS), Ebola, and Nipah all of which are thought to originate in bats[40–42]; HIV/AIDs which evolved from a similar virus in primates[43]; and avian influenza thought to originate in waterfowl[44]. Wildlife contact has also been implicated in the transmission of established zoonoses, such as toxoplasmosis in humans[32]. Humans may be exposed to disease-harbouring wildlife through hunting, trekking, outdoor work, recreational activities, or environmental changes which force wildlife and humans into closer contact[45,46]. Activities like hunting which involve close contact with bodily fluids during slaughter and butchering can be particularly high risk[45,47]. Contact with peri-domestic and/or wild rodents (or their excrement) has also been implicated in the transmission of a range of zoonotic diseases, including toxoplasmosis[32], leptospirosis[48] and hantavirus[49].

Vector contact

Many zoonotic diseases are vector-borne, including mosquito-borne diseases like Rift Valley fever, Japanese encephalitis, West Nile fever, and zoonotic malaria; tick-borne diseases like Lyme disease and Crimean-Congo haemorrhagic fever; and sandfly-borne diseases like leishmaniasis[50,51]. Occupations and activities that bring people into closer contact with known vector habitats often present the greatest risk for these diseases. For example, globally, individuals engaging in outdoor activities are at greater risk of contracting the tick-borne zoonoses Lyme disease[52] and babesiosis[53]. Livestock are also at risk from tick-borne zoonoses in their environment; for example, in domesticated ruminants, exposure to ticks increases the risk of Q-fever[54].

Human contact (reverse zoonosis)

There are increasing reports of reverse zoonosis (the transmission of infectious diseases or pathogens from humans to animals). Reverse zoonosis may contribute to the ongoing transmission and dissemination of zoonotic pathogens and is therefore considered an important animal and public health issue. This growing concern is supported by several primary reports that have documented COVID-19 infections in pets, livestock, wildlife, and zoo animals that had recent contact with an infected human[55]. In North American white-tailed deer, multiple spillover events from humans have been followed by sustained transmission within deer populations, raising the possibility that they may act as a reservoir host for this virus[56]. Evidence that pet dogs are more likely to be infected by human influenza viruses than non-domiciled strays provides an additional indication that reverse zoonotic transmission is also occurring in other disease systems[57].

Climatic factors and climate change

Environmental conditions shape zoonotic disease emergence and spread through multiple interconnected pathways. Climate and weather can impact pathogen survival, replication, and transmission, as well as host behaviour, vector abundance, and exposure[58]. These effects operate over short (e.g. seasonality, extreme weather events) and long (e.g. climate change) time scales[57].

Climatic factors

A global analysis of pathogen-climate sensitivity found that zoonotic disease risk more commonly increased, than decreased, under warmer, wetter conditions, though this effect was not universal[59]. Several disease-host systems seem to broadly follow this trend. For example, the risk of parasitic roundworm (ascariasis) infection in humans in endemic areas[60], and the risk of trichinellosis in pigs[61], increases at higher temperature levels. While the risk of brucellosis, in African wildlife[21] and cryptosporidiosis, in equines globally[62], increases in higher rainfall environments. However, contrasting and context-dependent effects are also common. For example, at the global scale, the risk of toxoplasmosis in foxes[63] decreases with increasing temperature. In other cases, climatic effects differ by host or setting. For example, in China, while warmer temperatures are associated with an increased risk of babesiosis infection in domesticated bovines (cattle, buffalo, yak etc.), no temperature effect is observed in equines or sheep[64].

Despite some general trends, it should be noted that climatic effects tend to be non-linear: disease risk may increase (e.g. with temperature) up to a system-specific optimum, and then plateau or decline beyond that range, rather than increasing indefinitely[58,65,66]. For example, the bacteria causing plague circulates between rodents and the fleas that feed on them. Warmer conditions can stimulate rodent populations and accelerate flea development, thus increasing opportunities for disease transmission[67]. However, when the temperature exceeds a certain threshold the ability of the flea to transmit the bacterium reduces, which consequently reduces plague transmission[68].

[i] Emerging infectious diseases are defined here as diseases that have appeared in human populations for the first time, or for which there has been a recent increase in incidence, virulence, or distribution[1].

Climate change

As indicated in the previous section, numerous high-level analyses have shown that many important zoonotic diseases are sensitive to climatic conditions, suggesting that climate change may substantially alter future disease distributions. In fact, zoonotic pathogens may be more climate-sensitive than pathogens infecting only humans or only animals, meaning that their transmission dynamics and/or disease outcomes are more consistently influenced by variation in climatic variables[69]. This may be a reflection of the complex transmission ecology of zoonoses, which often includes multiple host or vector species and environmental stages, all of which are potentially affected by climate[59]. Climate change may influence zoonotic disease risks in a number of ways. For example:

- Model-based projections indicate that climate change will shift the geographic ranges of several mosquito vectors, increasing transmission risks for certain vector-borne zoonoses in some regions (e.g. Europe), while reducing habitat suitability, and therefore transmission risks, in others (e.g. Southeast Asia and West Africa). These changes could expose millions of people to new diseases[70].
- A global analysis found that airborne viral emerging infectious disease outbreaks (which were predominantly zoonotic in origin) were more likely to occur following extreme weather events[71]. Such events are projected to increase under climate change[72,73].
- Climate change may also increase zoonotic disease risks indirectly, for example through forced displacement resulting in crowding, the breakdown of services, and increased human-animal contact[74].

Zoonotic disease risks can fluctuate with climatic variables. Evidence-based predictions indicate that climate change may alter the geographic distribution of zoonoses, and in many cases, ultimately increase transmission risks.

Land use and land-use change

Land use and land-use change shape zoonotic disease risks through several key mechanisms, including by: altering the spatial coverage and distribution of natural ecosystems; altering the density and spatial distribution of humans, wildlife or livestock; modifying patterns of human-livestock-wildlife contact; and affecting the abundance of disease vectors (mosquitoes, ticks, sandflies etc)[75,76].

Land use

Land use can influence zoonotic disease risk across multiple spatial scales, from broad rural-urban gradients to fine-scale landscape heterogeneity (e.g. variations in soil types and vegetation)[77]. Relationships between land use and disease can be complex as they are shaped by a number of interacting environmental and social factors (Figure 2).

Across rural-urban gradients for example, higher zoonotic disease burdens in rural populations may (among other things) reflect increased wildlife or livestock contact and/or more limited access to sanitation and healthcare[78]. Conversely, urban landscapes frequently support high populations of synanthropic (adapted to live near humans) wildlife species, like rodents and bats, that commonly act as reservoirs for zoonotic disease[79], while inadequate waste collection and management, particularly in developing countries, can sustain populations of other disease-harbouring reservoir species, such as free-roaming dogs[80].

In some systems, differences in zoonotic disease burden across land-use types are evident. For example, zoonotic disease burdens are higher in rural than urban populations for brucellosis in Türkiye[81], cryptosporidiosis globally[23], toxoplasmosis in Iran[35], and hepatitis E globally[82], while in animal hosts, rabies infections in African wild dogs and cloven-hooved animals are more prevalent in urban and peri-urban environments[83]. Ultimately, these relationships are highly context dependent. For example, although a global meta-analysis found an overall higher prevalence of hepatitis E in rural populations[82], the opposite pattern was observed in a population-based surveillance study in China, which reported a higher prevalence of hepatitis E in urban populations[84]. These findings indicate that while land use should be considered when targeting interventions, these must be tailored to specific disease systems and local contexts.

Importantly, disease risks can also vary within broader land categories. For example, in China, echinococcosis risks in cattle are higher in pastoral than agricultural areas[85]. While zoonotic malaria risks in non-human primates in Southeast Asia are higher in landscapes with more fragmented forest, denser tree canopy cover, and higher local human populations[86]. These examples illustrate how broad land-use labels can mask important local variations in exposure and transmission.

Collectively, the evidence indicates that land use shapes zoonotic disease risk in complex and context-dependent ways.

Land-use change

The same land-use factors that shape local disease occurrence and transmission can also operate at broader scales to influence disease emergence. Evidence from large-scale modelling studies indicate that emerging zoonotic disease events are associated not only with particular land-use types, such as tropical forested areas or pasture-dominated systems[87], but also changes in land use. These changes are often linked to urbanisation and agricultural expansion. For example:

- Zoonotic disease emergence events from wildlife hosts become more frequent as human populations grow[1].
- Increases in zoonotic disease outbreaks are linked to deforestation (often associated with agricultural expansion) in tropical regions, and reforestation in temperate regions[88].
- Habitats that have undergone human-driven changes, including urbanisation and agricultural expansion, support higher abundance of animal hosts predicted to carry zoonotic pathogens[79,89].
- As the area of land available for wildlife habitat declines human-wildlife contact rates increase, which in turn increases the risk of zoonotic disease transmission and disease outbreaks.

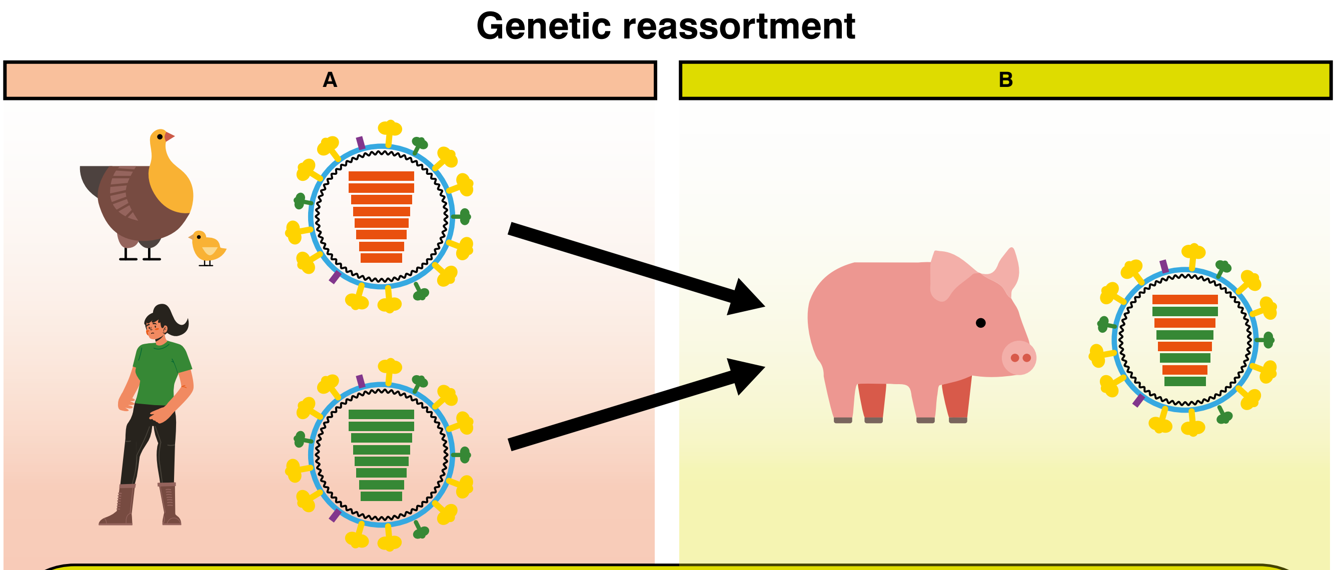
A consequence of this is that the economic benefits of wildlife habitat conversion (e.g. to agricultural or urban developments) can be outweighed by the economic costs of a zoonotic disease outbreak, particularly when the remaining wildlife habitat area is small[90].

Livestock production systems

In recent decades, demand for livestock-derived food has risen substantially and consistently[91]. A range of livestock management and production systems are employed to meet this demand. Livestock management practices can alter zoonotic disease risks by influencing the intensity and type of contact between humans, domesticated animals, and wildlife, as well as by creating conditions that alter host susceptibility and opportunities for transmission[92].

All livestock production systems (intensive, extensive, and traditional etc.) involve some level of zoonotic risk; however, the nature of these risks varies across production systems. For example, animals maintained in extensive or free-range systems, which typically involve low stocking densities over large areas, may be more likely to encounter diseases from local wildlife[93]. While in traditional (e.g. backyard) systems, zoonotic risks may stem from increased wildlife contact, the close day-to-day interactions between humans and livestock, and low biosecurity practices[93]. In contrast, in intensive systems, where animals are maintained at high densities in confined spaces, stricter biosecurity measures can reduce the risk of pathogen introduction. However, once a pathogen is introduced into intensive systems, the stressful or suboptimal rearing conditions which impair animal health, combined with close genetic relatedness between animals which results in shared susceptibilities, can enable infectious agents to spread rapidly through populations and drive large-scale outbreaks[93,94].

Accordingly, depending on transmission pathways and disease-host dynamics, certain zoonotic diseases may be more prevalent in particular livestock production systems than in others. For example, in China, the risks of tuberculosis in dairy cattle, and, globally, microsporidiosis risks in beef-cattle are higher in intensive compared to free-range systems[95]. While conversely, in China, the risks of cryptosporidiosis in pigs[96] and toxoplasmosis in chickens[97] are higher in free-range compared to intensive farming systems. For certain viral pathogens (e.g. influenza), other management factors, such as the mixing of livestock species (particularly poultry and swine) can increase opportunities for the emergence of new zoonotic diseases through a process known as genetic reassortment (Figure 4).



The genome of the influenza virus is composed of several separate segments of RNA. Viruses that have segmented genomes can undergo a process called genetic reassortment, where segments can be exchanged between different viral strains if they infect the same host cell[98]. Pigs are considered ‘mixing vessels’ for influenza viruses because their lung cells possess receptors for both avian and human strains. This allows for the genetic reassortment of different influenza strains[99]. New influenza strains, created through genetic reassortment, could have significant pandemic potential as the human population would have little to no preexisting immunity against them. A clear example of this is the 2009 influenza A pandemic (S-OIV), which is estimated to have caused 200,000 deaths within nine months of its emergence[100], and which arose via the triple reassortment of avian, human, and swine influenza strains[101]. Risks of genetic reassortment are heightened in mixed farming systems, particularly when pigs and poultry are co-reared under low biosecurity conditions[102,103].

Figure 4. Genetic reassortment of avian and human influenza viral strains in a pig[98].

Socioeconomics and human behaviour

Social, economic, and demographic factors can shape the conditions under which humans and animals interact, and how likely interactions are to result in disease transmission:

- Income inequality can increase vulnerability by limiting access to preventative measures such as vaccines, safe water, and sanitation, or by forcing people to live and work in environments with higher exposure risks[104,105].
- Education and community awareness influence risk by shaping animal handling and hygiene practices thus influencing exposure[106].
- Foodborne zoonotic disease transmission risk can be influenced by dietary practices/preferences (e.g. consumption of high-risk foods), food preparation habits (e.g. heating or hygiene practices), and contamination and inadequate food safety controls along the production chain[107].
- War and conflict can result in the destruction of health systems and infrastructure, the curtailment of existing disease control programmes, and cause population movement, which can increase exposure and susceptibility to infectious diseases, including zoonotic diseases[108,109].

Income inequality

While links between economic development status and zoonotic disease risks are not always clear[110–117], where meta-analytical evidence for impact does exist, disease risks are consistently higher in LMICs. For example, in humans: the risk of contracting ascariasis in endemic regions decreases with increasing gross national income[60], while globally, rates of toxoplasmosis decline as per capita income rises[118]. This trend also holds for animal hosts of zoonoses. For example, at a global scale, evidence indicates that klebsiella in dairy cattle[119], cryptosporidiosis in cats[120], and microsporidiosis in pigs[121], are more common in developing than developed countries. Evidence from primary research likewise indicates that, where such associations are observed, zoonotic disease risks tend to increase with decreasing household income[122–124].

These patterns align with broader trends that indicate that zoonotic diseases disproportionately affect LMICs[125,126]. However, effects remain context specific. For example, while microsporidiosis risks are higher in pigs in developing countries[121], no corresponding effect is observed in cows[112]. This highlights how even well-established disease drivers (like income inequality) can be obscured or outweighed by other ecological, behavioural, or management factors.

Specific conditions linked to income inequality can also influence disease risks. For example, drinking untreated water is associated with increased risk of zoonotic diseases including echinococcosis in China[22], cryptosporidiosis globally[23], and toxoplasmosis, both globally[32] and regionally[35,36]. Beyond zoonoses, drinking untreated or unsafe water is also associated with a range of other diseases, including typhoid, certain cancers, and cardiovascular disease[127].

Despite clear context dependencies in certain systems, there is a disproportionate burden of zoonoses in LMICs.

Education and community awareness

Levels of personal educational attainment alongside general community awareness can influence how likely someone is to come into contact with pathogens in their environment and how well protected they will be if they do. Generally, higher levels of education or disease awareness are linked to lower levels of zoonotic disease occurrence. For example, in Ethiopia, toxoplasmosis occurrence among pregnant women decreases with greater knowledge of the disease[36], and hepatitis E occurrence in humans is higher among individuals with lower educational attainment[82]. However, efforts to reduce disease risks through community awareness and education can be hindered by mistrust in authorities and the spread of misinformation [see **Trust and misinformation**].

Food habits and dietary practices

Food habits and dietary practices encompass not only what people eat, but how food is sourced, prepared, stored and consumed. These practices are often shaped by cultural or religious traditions, and locally-embedded norms surrounding slaughter, food sharing, and preparation[128]. For example, the consumption of raw or undercooked meat and raw or unpasteurised dairy products may be perceived as nutritionally beneficial, a delicacy, or a culturally-important tradition[129,130]. However, such practices can increase the risk of certain zoonotic diseases, including toxoplasmosis[32] and hepatitis E[31,82]. While raw and undercooked animal-source foods are often identified as higher risk, evidence indicates that zoonotic diseases can be associated with a range of food products including red meats, poultry, dairy, seafood, produce, and composite foods (foods containing multiple ingredients, e.g. soups or sandwiches)[23,31,32,131]. These risks likely arise through contamination and inadequate food safety controls along the production chain.

Beyond conventional food production systems, there are also zoonotic disease risks associated with the consumption of wild animals. Disease transmission via wild meat (also referred to as bushmeat or game meat) has been reported across continents and across a range of wildlife sources including ungulates (like boar and deer), rodents, non-human primates, bats, and carnivores[132]. While consumption is often emphasised as a risk factor, the slaughter and preparation of wild meat that results in exposure to the bodily fluids of an infected animal, can also pose significant transmission risks[132,133]. Taken together, these findings highlight that zoonotic disease risks can be posed by both formal and informal food systems.

War, conflict and, security

Wars, armed conflicts, and persistent security threats, represent complex but often overlooked drivers of zoonotic disease risk. These crises disrupt public, human, and veterinary health systems (such as disease surveillance, laboratory capacity, vector control programmes, and livestock vaccination); damage infrastructure; compromise basic water, sanitation and hygiene systems; and force humans and animals into closer contact. The convergence of these forces establishes environments where zoonotic diseases can emerge or intensify[108,134–136]. Significant zoonotic outbreaks associated with conflict in recent years include:

- Crimean-Congo-haemorrhagic fever, Sudan 2023, which had a case fatality rate of 57%. Outbreaks were linked to disrupted veterinary services and the displacement of humans and livestock increasing exposure to infected animals and vectors[134].
- Cutaneous and visceral leishmaniasis, Syria, 2013, where the breakdown of services and garbage accumulation resulted in increasing populations of stray dogs, which served as reservoirs of the disease. Malnutrition in the human popula tion was predicted to further increase susceptibility to infection once exposed[137,138].
- Lassa fever, Sierra Leone, 2002, where outbreaks in Liberian refugee camps were linked to poor housing infrastructure and high rodent infestation[139].

Wars and conflict can lead to the collapse of animal, human health, and hygiene systems, which, when paired with displacement and environmental disruption, amplifies the risks of infectious disease outbreaks, including zoonoses.

Wildlife systems

Wildlife exploitation, which can include the legal and illegal trade in wildlife, wildlife farming, and wild meat hunting and consumption [see **Wildlife farming**], is frequently identified as a key driver of zoonoses[18,76,93,140,141]. These practices, which are often inadequately and inconsistently regulated[142,143], increase wildlife-human contact thereby creating opportunities for zoonotic pathogen transmission.

Wildlife trade

The legal trade in wildlife represents a substantial global market, valued at up to USD 220 billion per year[144]. In addition, the illegal trade in wildlife is estimated to generate approximately USD 23 billion per year and ranks as the fourth-largest illicit activity worldwide[145]. The zoonotic risks associated with the wildlife trade are likely to be considerable: for example, an analysis of mammal-virus associations indicated that zoonotic viruses are disproportionately concentrated in traded species compared to non-traded or domesticated mammals[146]. Wildlife markets have also been implicated in the spread of novel coronaviruses, including SARS-CoV-1 (the pathogenic agent responsible for the 2002–2004 SARS outbreak), where palm civets (Paguma larvata) were identified as key animal reservoirs for a SARS-like coronavirus[147]. Wet markets, traditional food, and live animal markets create high-risk interfaces where animals from multiple species are kept in close proximity under stressful and unsanitary conditions. Such conditions can promote stress-induced immune suppression, which increases viral shedding (the release of virus from an infected host into the environment), while poor hygiene increases opportunities for cross-species transmission[148].

Wildlife farming

Wildlife farming is the commercial breeding and legal sale of non-domesticated wildlife species for the purposes of meat production, trade, or production and procurement of animal products[149]. Wild animals from a range of taxa are farmed globally including amphibians, reptiles, birds, and mammals[150]. These practices can be intensive in nature, and animals may be maintained at a high density in poor health[151–153]. This can create opportunities for the establishment and spread of zoonoses between and within wildlife species and subsequent opportunities for human spillover[151]. Surveillance in these systems is often limited[151], however a sampling study of animals farmed for fur in China, which included racoon dogs, mink, and muskrats, identified the presence of 125 viral species, 39 of which were categorised as high risk for cross-species transmission, including zoonotic spillover. Viruses detected in this study included several coronaviruses and influenza A viral subtypes, highlighting the potential for farmed wildlife to act as reservoirs for zoonotic pathogens[154].

Overall, the scale of wildlife exploitation, combined with the high zoonotic potential of traded and farmed species, and the additional amplifying risks posed by poor animal husbandry in these systems can generate high-risk interfaces for zoonotic disease transmission and emergence.

Biodiversity

Many of the drivers of zoonotic disease emergence and transmission, including climate change, habitat destruction, agricultural expansion, urbanisation, and wildlife exploitation are also drivers of biodiversity[ii] loss[156]. Notably, however, biodiversity loss has itself been implicated as a driver of zoonotic disease emergence, creating complex feedback loops between ecosystem disruption and disease risks[157]. Two conflicting hypotheses have been proposed to explain the relationship between biodiversity loss and zoonotic disease risks. Both hypotheses are founded on the principle that not all animal species are equally capable of becoming infected with and transmitting the same pathogens.

- The dilution effect proposes that as biodiversity increases pathogens are more likely to encounter species that cannot transmit them, therefore reducing (diluting) opportunities for transmission.
- The amplification effect proposes that as biodiversity increases, pathogens are more likely to encounter species that can transmit them, therefore increasing (amplifying) opportunities for transmission.

Empirical evidence exists in support of both hypotheses[158–160], and includes evidence that dilution and amplification effects can act simultaneously on different components of transmission (e.g. host density, contact rates, transmissibility) within the same system[161]. These hypotheses have been criticised for oversimplifying the complex mechanisms and interaction dynamics that shape disease transmission. Ultimately, the effect of biodiversity loss on zoonotic disease outbreaks is highly context dependent[162].

[ii] Biodiversity or biological diversity is defined by the Convention on Biological Diversity as "the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems"[155].

Trade and international travel

Trade in agriculture and food and the expansion of international travel have accelerated economic growth and cultural exchange, with international trade in animal products having an estimated value of EUR 152 billion in 2018[163]. But they have also created new pathways for the spread of infectious diseases (Box 1). The movement of people, animals, and goods across borders, which has significantly increased over recent decades, enables zoonotic pathogens to cross ecological and geographical barriers, increasing the risk of cross-species transmission (spillover), subsequent outbreaks, and in some instances pandemics. Both the extent of poor hygiene-related exposures and epidemiological risk factors such as animal density, accidental vector transport, and weak biosecurity play significant roles in shaping these risks. Some countries, such as Australia and New Zealand, have brought in strict regulation on importations to protect against both invasive species and foreign diseases (including zoonoses).

Wildlife trade and live animal markets

Wildlife and mixed-species markets have been implicated in the spread of novel coronaviruses; similarly, traditional food and live animal markets create high-risk interfaces [see **Wildlife trade**].

International trade and movement of animals and animal products

The movement of animals through international trade provides a critical route for zoonotic disease introduction. For example, in 2003, an illegal shipment of small mammals from Ghana brought mpox virus into the United States, infecting prairie dogs which were sold as pets, and subsequently transmitted the virus to humans[164].

Long-distance transport of livestock, especially by ship or truck, is known to weaken immune defences, fostering the shedding of pathogens such as *Salmonella*, *Escherichia coli* O157, or respiratory agents. The live export of cattle and sheep from Australia to the Middle East exemplifies this risk[165], and while this will have been phased out in Australia by 2028, lessons can be learned worldwide.

In addition, the close proximity of animals in markets, and during transport, can contribute to genetic reassortment and the spread of reassorted strains (Figure 4). Modifications to small-holder systems and live animal markets are necessary to reduce cross-species interactions.

Human travel and the global spread of disease]

International travel by tourists and workers is a powerful driver of zoonotic disease spread. For example, the global rise in air travel, with an estimated 9.5 billion passengers in 2024[164], has played a pivotal role in the rapid dissemination of mpox, particularly after the easing of COVID-19 travel restrictions. Airports thus represent critical monitoring points for emerging communicable diseases[166].

Box 1. Pathways for spread of zoonotic disease through trade and international travel

The pathways through which zoonotic diseases spread via trade and international travel can be grouped into four broad categories:

1. **Hygiene-related zoonoses** – Pathogens such as Salmonella or E. coli spread through direct exposure or contaminated food. Outbreaks are generally limited and self-contained.
2. **Vector-borne zoonoses** – Transport of competent vectors can result in localised outbreaks, particularly if climatic conditions support their establishment. For example, tiger mosquito larvae were likely transported in car tyres from endemic countries to the United States[170].
3. **Re-emerging diseases of animal origin** – Re-emerging zoonotic diseases with limited human-to-human transmission, such as mpox, have rapidly spread through international travel[171]. Mpox has spread from Africa to Europe and the United States through infected travellers.
4. **Animal-origin pathogens with sustained human-to-human transmission** – Animal-origin pathogens that achieve sustained human-to-human transmission, such as influenza and coronaviruses, can cause large-scale outbreaks and pandemics, exemplified by COVID-19. Even in the advanced stages of the pandemic, migrants faced higher infection risks and disproportionately suffered from the consequences of COVID-19 disease, including deaths[172], and migration can be considered a driver of zoonotic disease.

Similarly, travel has facilitated the spread of antimicrobial-resistant pathogens. International travellers have been identified as carriers of extended-spectrum beta-lactamase (ESBL)-resistant *E. coli*, contributing to the global dissemination of antimicrobial resistant zoonotic pathogens[167].

Vector-borne zoonoses and climate change

Vector-borne diseases such as Dengue fever, Chikungunya, and West Nile virus (WNV) are expanding into temperate areas in unprecedented ways [see **Climate change**]. Increased travel and transport also contribute to the spread of vectors. For example, mosquitoes and mosquito larvae can be distributed by international trade and travelling. Climate change allows vectors to survive in previously uninhabitable areas enabling the transmission of vector-borne zoonoses. Improved surveillance contributes to the rising number of detected cases[168,169].

Key messages

- **Zoonotic disease risk is shaped by interactions, not single drivers:** No individual factor can consistently influence or predict zoonotic disease risk across systems. Risks emerge from interacting biological, environmental, and social processes.
- **Context matters:** The same factor can increase, decrease or have no effect on disease emergence and transmission depending on the host species, pathogen strain, management systems, or geography.
- **Contact between humans, animals and vectors is a central determinant of zoonotic disease transmission:** Most of the upstream drivers of zoonotic disease emergence and transmission influence risk by shaping patterns of contact between human, animal and vector populations. Human activities can reshape disease risk by increasing contact rates.
- **Climate change is likely to redistribute and increase zoonotic disease risks:** Changes to climatic conditions can alter zoonotic disease transmission rates. The direct impacts of climate change, such as shifts in host and vector ranges, may redistribute disease risks to new areas, while indirect effects (such as extreme weather events which force animals and humans into closer contact) may act to further amplify transmission risks across systems.
- **Land use and land-use change can create opportunities for disease transmission:** Risks can vary depending on how land is used. Areas experiencing human-driven land use change (such as deforestation, reforestation, urban expansion or agricultural intensification) may be particularly susceptible to zoonotic disease outbreaks.
- **All livestock production systems involve some level of zoonotic risk:** Extensive (free range) systems may increase exposure to wildlife pathogens, traditional (backyard) systems may involve closer contact between humans and livestock, and intensive systems, while typically benefiting from stronger biosecurity, can facilitate the rapid spread of a disease once pathogens are introduced.
- **Poverty, inequality, conflict, and limited access to services increase vulnerability to zoonoses.** Social and economic factors can increase pathogen exposure, reduce access to prevention and treatment, weaken disease surveillance, and limit the capacity of individuals and communities to respond to outbreaks.
- **Wildlife exploitation creates opportunities for (often novel) pathogen transmission:** Wildlife trade, farming, hunting, and consumption increase contact between humans and wildlife creating high risk interfaces for disease transmission.
- **Biodiversity loss may alter zoonotic disease risks:** Changes in species composition and ecosystem structuring can affect pathogen dynamics, but impacts vary across disease systems and environments.
- **Global trade and international travel enable zoonotic diseases to spread rapidly across borders:** Zoonoses may spread through contaminated goods and food products, the inadvertent transport of vectors, the movement of infected animals, and/or travel by infected individuals.

3. Interventions to reduce the occurrence of zoonotic diseases

Zoonotic diseases can be caused by a range of infectious agents including viruses, bacteria, fungi, and parasites, and occur in many settings, from farms and natural environments to households, markets, and cities. There are over 200 zoonotic diseases, each differing in their epidemiology (mode of transmission, host range, ecological dynamics), and each presenting with their own challenges, meaning control measures need to be tailored to the specific characteristics of each disease.

Practical interventions to reduce the occurrence of zoonoses have been developed using the Zoonosis Stage Model[173]. Five distinct stages are defined by their reproductive potential in humans (Figure 5). Pathogens may progress through the stages over time, as a result of evolution, however, there is no inevitable progression of microbes from Stage 1 to Stage 5.

The Zoonosis Stage Model helps governments and policymakers identify appropriate points for intervention — from controlling infections in animals (Stages 1 and 2), through containing limited human-to-human transmission (Stage 3), to preventing regional outbreaks and pandemics (Stage 4).

Each stage calls for different prevention and control strategies, and each zoonosis requires a specific approach for control. The sections below give an overview of cross-cutting approaches relevant to all stages as well as describing general approaches for stages 2 to 4 followed by specific examples. Additional guidance can be taken from **A Tripartite Guide to Addressing Zoonotic Diseases in Countries 2019**; **Monitoring and Evaluation for Effective Management of Zoonotic Diseases 2024**.

Cross-cutting strategies for all stages

There are a number of cross-cutting strategies that create the foundation for effective zoonotic disease prevention and control (Figure 6). Investments in vaccination, biosecurity, and One Health governance not only reduce outbreak risks but also strengthen food security, economic stability, and sustainable development (Table 1). Such early prevention strategies are considered cost-effective.

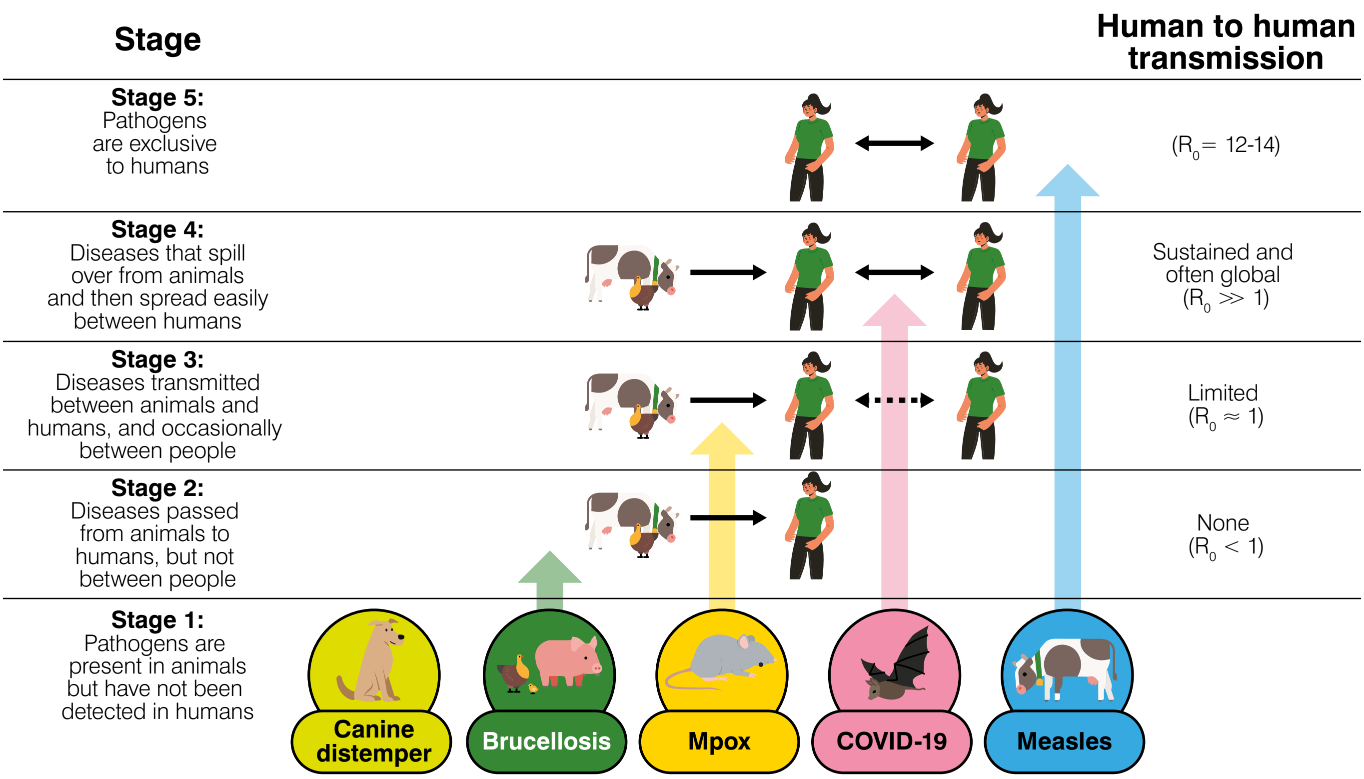


Figure 5. The Zoonosis Stage Framework. Note, R0 indicates how contagious an infectious disease is. It represents the average number of people a single infected person will spread the disease to, assuming no one has immunity and there are no preventive measures in place.

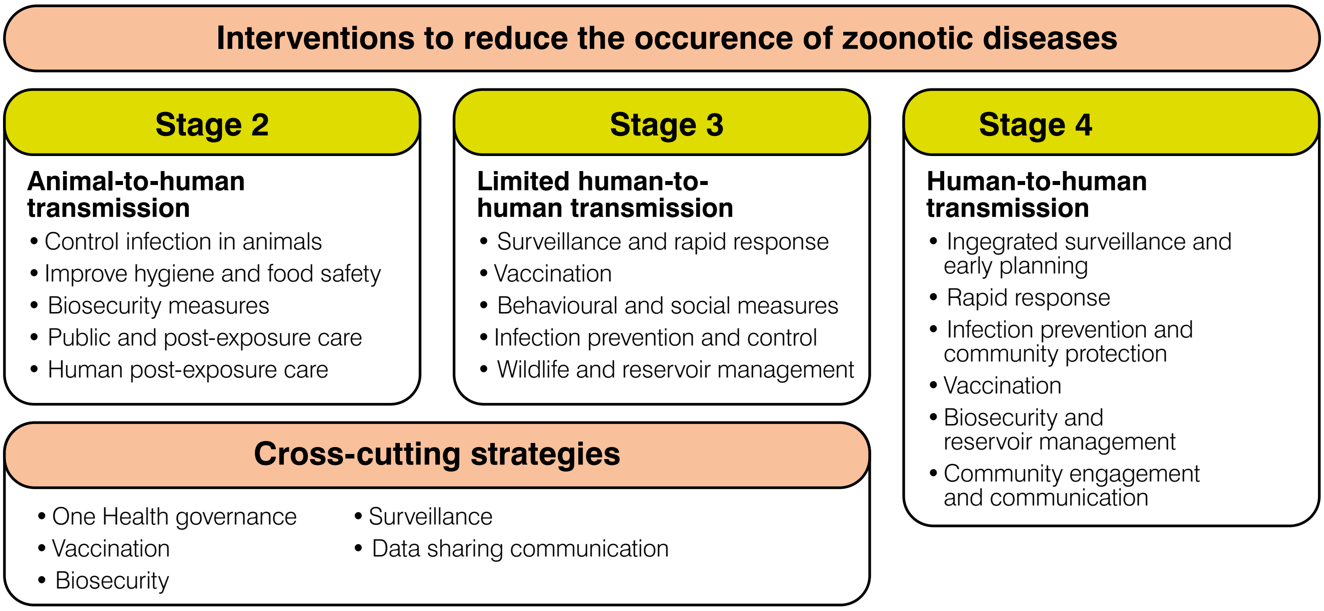


Figure 6. Intervention strategies across zoonotic disease Stages 2, 3 and 4.

Table 1. Cross cutting strategies for all zoonotic disease stages

Strategy	Key Actions
Strengthen One Health governance	• Coordinate animal, human, and environment health sectors through shared data and joint planning. • Create integrated surveillance and response systems that detect outbreaks early. • Use One Health platforms for decision-making and resource mobilisation.
Invest in vaccination as a core prevention tool	• Support routine vaccination of animals and humans as a cost-effective prevention measure. • Maintain livestock and pet vaccination programmes (e.g. brucellosis, rabies). • Ensure public health immunisation systems are ready for emerging threats (e.g. influenza, COVID-19). • Keep vaccine supply chains strong and build public trust through clear communication.
Strengthen biosecurity across sectors	• Enforce biosecurity standards in farms, slaughterhouses, markets, and transport. • Control livestock movements and reduce wildlife–livestock contact. • Improve environmental biosecurity through waste and water management. • Promote personal biosecurity (PPE, disinfection) for animal workers.
Improve data sharing and risk communication	• Ensure timely information exchange between ministries and sectors. • Develop joint analysis and reporting (where possible through digital platforms) linking veterinary, human health, and environmental data. • Communicate risks clearly, using trusted local channels and accessible language.
Build capacity and workforce skills	• Train veterinarians, health workers, and environmental professionals together in outbreak response. • Strengthen laboratory networks for diagnostics and genomic surveillance. • Support continuous professional development in One Health competencies.
Engage communities and stakeholders	• Involve communities in identifying risks and developing local solutions. • Use participatory approaches that respect local culture and social norms. • Foster trust through open dialogue and inclusion of local leaders and civil society.
Address environmental and social drivers	• Tackle root causes such as land-use change, and high-risk livestock practices. • Integrate One Health approaches into land use, agriculture, and urban planning. • Support sustainable livestock and natural resource management to protect biodiversity.

Preventing animal-to-human transmission (Stage 2 zoonoses)

General approaches

Stage 2 diseases are spread from animals to humans, but not between people under normal conditions. The main goal is to reduce exposure of humans to infected animals or animal products, and to control the infection in animal populations.

Key interventions include:

- Control of infection in animals: Vaccination, treatment, and surveillance in livestock or wildlife reservoirs. Reservoir animals harbour pathogens, often without getting ill themselves, for example, in some areas the natural reservoir for *Yersinia pestis*, which causes plague, is the marmot. Test and slaughter may be required for elimination.
- Improved hygiene and food safety: Reduce contamination of food (e.g. through pasteurisation of milk), water, and the environment.
- Biosecurity measures: Improve biosecurity practices in farming, slaughter, transport, and markets.
- Public and occupational protection: Educate communities and protect people who work with animals through reduced exposure (e.g. wearing protective clothing).
- Human post-exposure care: Use preventative medication (e.g. rabies post-exposure prophylaxes (PEP)) when contact occurs.

Examples of Stage 2 zoonoses interventions

1. Brucellosis – caused by bacterial infection

Overview:

Caused by bacteria transmitted through contact with the bodily fluids from infected livestock or unpasteurised milk. It causes recurrent fever and fatigue in humans, and reproductive losses in animals.

Interventions:

- Livestock vaccination: Regular mass vaccination in cattle, sheep, and goats.
- Protective equipment: Direct exposure can be avoided by wearing personal protective equipment (PPE) like gloves and gowns when working with at-risk livestock. This is particularly important for obstetrical work, like calving or lambing, and at slaughter.
- Food safety: Exposure can be largely avoided by boiling milk and using pasteurised milk for products. Education will support such measures.
- Human treatment: Use effective antibiotics such as tetracycline or rifampicin[174].

Constraints:

It should be noted that there may be constraints on the interventions that can be used. For example, farmers may not have access to PPE, and in many countries a livestock brucellosis vaccine is not readily available.

Outcome:

Countries with long-term livestock vaccination and food safety programmes have reduced human infections[175].

2. Echinococcosis (also called hydatid disease) – caused by parasitic infection

Overview:

A parasitic infection involving dogs (definitive hosts) and livestock (intermediate hosts). People are infected by accidentally ingesting eggs from contaminated soil or food.

Interventions:

- Prevent dogs from eating raw offal particularly in slaughterhouses.
- Regularly deworm dogs and vaccinate susceptible sheep[176].
- Promote handwashing and food hygiene.

Constraints:

Many informal abattoirs do not prevent dogs from eating offal. Hand washing may be difficult in semi-arid areas. Medications to deworm dogs are not readily available in many countries.

Outcome:

Coordinated dog deworming and safe offal disposal programmes have led to large declines in human cases[176].

3. Rabies – caused by viral infection

Overview:

A fatal viral disease transmitted through bites or scratches from infected animals. Rabies reservoirs in temperate areas of the world are mostly wildlife, such as foxes, racoons, and wolves.

Interventions:

- Animal vaccination:
  - Oral bait vaccines have eliminated wildlife rabies in Western Europe[177].
  - Mass dog vaccination campaigns are the most successful and cost-effective approach in many developing countries[178,179].
- Human PEP: Immediate vaccination after exposure prevents disease[180].
- Public awareness: Educate communities and encourage prompt reporting of animal bites and safe handling of animals.

Constraints:

In many countries, human post-exposure prophylaxis and dog vaccines are not readily available.

Outcome:

Sustained vaccination and education have nearly eliminated human rabies deaths in regions with strong programmes[180].

4. Salmonella and Campylobacter – foodborne zoonoses

Overview:

Bacteria that contaminate meat, particularly poultry, and cause foodborne illness in humans.

Interventions:

Improve slaughterhouse practices and food processing.

- Encourage handwashing after handling raw meat.
- Educate consumers about preventing cross-contamination in the kitchen[181].
- Reduce antibiotic use in animal production to limit antimicrobial resistance (AMR)[182,183].

Outcome:

Better hygiene and reduced antibiotic use have decreased foodborne infections and slowed AMR spread[184].

Managing limited human transmission (Stage 3 zoonoses)

General approaches

Stage 3 zoonoses can spread between animals and humans and occasionally between people, but human transmission usually stops quickly. The focus is on early detection, containment, and community education.

Key interventions include:

- Surveillance and rapid response: Early detection and isolation of cases. This would also, in some diseases, include contact tracing.
- Vaccination: Use vaccines for high-risk groups where available.
- Behavioural and social measures: Promote awareness and risk reduction in affected communities.
- Infection prevention and control: Apply PPE, isolation, and sanitation in clinics and homes.
- Wildlife and reservoir management: Reduce exposure to potentially infected animals and regulate trade.
- Community engagement: Build trust and encourage reporting without stigma[185].

Examples of Stage 3 zoonoses interventions

1. Mpox

Overview:

Mpox is a viral infection transmitted to humans by contact with infected wild animals (e.g. rodents, non-human primates) through bites, scratches, or handling of infected carcasses. Transmission occasionally occurs between people through close or intimate contact, or via contaminated food or objects, but is self-limiting and does not lead to large outbreaks. It is endemic in regions of West and Central Africa.

Interventions:

- Vaccination: The JYNNEOS vaccine can prevent infection and is used routinely in high-risk groups or during outbreaks[186].
- Behavioural modification: Avoid close contact with infected individuals; promote health education and stigma-free communication.
- Community engagement and education: Targeted outreach, especially among populations disproportionately affected, improves awareness, encourages preventive actions, and counters stigma.
- Infection prevention: Use PPE in healthcare settings, isolate infected individuals, adopt stringent hygiene practices in clinical and community settings.
- Surveillance and rapid response: Early case identification, contact tracing, and robust surveillance systems allow prompt interventions to contain outbreaks and monitor emerging risk factors[187].
- Animal reservoir management: Limit contact with wild animals and strengthen regulations on wildlife trade[186].

Outcome:

Countries that used combined vaccination, communication, and surveillance strategies contained outbreaks effectively[188].

Preventing and responding to human-to-human transmission (Stage 4 zoonoses)

General approaches

Stage 4 zoonoses are those diseases, mostly caused by viruses, with natural reservoirs in wildlife and domestic animals, that spill over from animals but then spread efficiently between people. These have the greatest pandemic potential. Prevention requires a whole-of-society approach combining early detection, vaccination, and coordinated response.

Key interventions include:

- Integrated surveillance response systems (iSRS) [see **Towards integrated surveillance response systems**] that can detect a novel emerging pathogen early and communicate detection to all other sectors in public and animal health through a One Health governance mechanism[173,187].
- Use of genomic epidemiology (the use of genetic information e.g. DNA from pathogens like viruses or bacteria) to track transmission chains and distinguish between new spillovers and ongoing human amplification[189,190].
- Rapid case identification and isolation through aggressive case finding and isolation in outbreak zones, testing, quarantine, and early treatment to curtail spread[191].
- Infection prevention and community protection through strict adherence to infection prevention and control protocols: PPE, hand hygiene, environmental disinfection, social distancing, and ventilation in healthcare and congregate settings. Community-wide non-pharmaceutical interventions (NPIs) can include mask mandates, event limitations, and school or workplace closures depending on transmission intensity.
- Vaccination and prophylaxis through deploying mass vaccination or ring-vaccination strategies for pathogens where vaccines are available (e.g. influenza, SARS-CoV-2), targeting at-risk or amplifying populations[192].
- Animal reservoir management through intensive monitoring and management of animal reservoirs, improving biosecurity at the animal-human interfaces in animal production, transport, and marketing[193].
- Community engagement and risk communication fostering trust, compliance, and timely reporting of suspected illness or animal death. Public health interventions can influence social norms through participatory transdisciplinary processes[187].
- Ecological, social, and systems-level interventions to address broader determinants via One Health approaches: environmental and ecosystem management, urban planning, and reduction of high-risk human-animal interactions[194].

Examples of Stage 4 zoonoses interventions

1. COVID-19

Overview:

Caused by the SARS-CoV-2 virus, likely originating from wildlife. It spreads mainly through airborne droplets.

Interventions:

- Integrated surveillance and genomic tracking to monitor variants[189,190].
- Widespread testing, isolation, and vaccination.
- Infection prevention measures: masks, hygiene, and ventilation.
- Transparent, science-based communication to maintain trust.
- Coordinated action between governments and sectors. Transparency and data sharing (e.g. adoption of the WHO Pandemic Agreement).

Outcome:

The pandemic highlighted the importance of early detection, international coordination, and investment in vaccine research.

Translating the Zoonosis Stage Model into action

Preventing zoonotic disease requires coordinated One Health action, investment in vaccination and biosecurity, and effective communication and community engagement. By integrating these principles into national health, agriculture, and environmental policies, governments can protect public health, support livelihoods, and safeguard the ecosystems that sustain all life. Translating these broad principles into action, however, requires frameworks that identify where interventions can be applied along the pathway of zoonotic disease emergence.

One such framework is the 2007 Zoonosis Stage Model outlined above. In 2023, the One Health High-Level Expert Panel (OHHLEP) produced their *Prevention of Spillover and Pandemic Risk Reduction* report. OHHLEP's spillover-prevention framing is broadly compatible with the earlier Stage Model, as both approaches identify opportunities for intervention along the pathway of zoonotic disease emergence, albeit at different levels of resolution. While OHHLEP broadly distinguishes primary prevention before spillover from secondary prevention, preparedness and response after spillover, the Stage Model provides a more granular framework for identifying intervention opportunities at successive stages of emergence. It therefore complements operational guidance, including the Tripartite Zoonoses Guide and its associated tools, by providing a detailed lens through which prevention, preparedness and response measures can be mapped across the emergence pathway.

4. Surveillance, monitoring, risk assessment and prediction

Zoonotic threats are escalating with the increase in human–animal–environment interactions, meaning that it is becoming more important to have surveillance systems that are able to anticipate disease emergence rather than merely documenting disease events[195]. Traditional surveillance systems, such as passive, indicator-based, or notifiable disease reporting, are essential but can often be slow, incomplete, and may miss early ecological or behavioural signals.

Earlier detection and more precise targeting of interventions can be made possible if certain drivers of zoonotic disease, such as human mobility, land-use changes, contact patterns, AMR profiles, and demographic susceptibility, are embedded into the surveillance system[196]. Early detection and risk assessment would further benefit from input from data sources like electronic medical records, health surveys, demographic monitoring, and pharmacy records, which could link into analytic platforms but are currently underused, likely for data protection reasons[197].

What are the requirements for effective surveillance?

Effective surveillance systems need to bring together information on:

- Hazards – for example specific pathogens such as viruses or bacteria.
- Risks – how likely these hazards are to spread or cause disease, and the mode of transmission.
- Vulnerabilities – who or what is most at risk, such as certain communities, animals, or environments.

Climate change is reshaping zoonotic patterns; therefore, early-warning systems should incorporate ecological observations and internet-based intelligence[195]. It is not enough to simply track reported cases of disease – notifiable disease reports should be paired with environmental biosurveillance (checking things in the environment like air, water, soil, or wastewater) for microbes or biological threats so outbreaks can be detected early), as well as information obtained from wildlife sampling, information about changing habitats from remote sensing and the changes in vector distributions. An integrated One Health surveillance system would require a strong multisectoral collaboration enabling cross-sectoral data sharing and involvement of all relevant stakeholders. It would also require buy-in from farmers and others in the field required to submit data. Such a system also depends on strong technical foundations, including appropriate tools, infrastructure, and capacity development/building, as well as clear operational criteria such as data quality and the timely detection, communication, and response to threats[198,199].

When a new or poorly-understood threat appears, the focus should be on the highest-risk species, area, or production system. Using advanced data analysis and network tools helps detect unusual patterns before outbreaks become widespread[200]. Strong risk assessment frameworks (Figure 7), help decide where to act first and how to use limited resources effectively. Despite their value, comprehensive risk assessment frameworks remain rare, particularly in the post-detection window where quick decisions are critical.

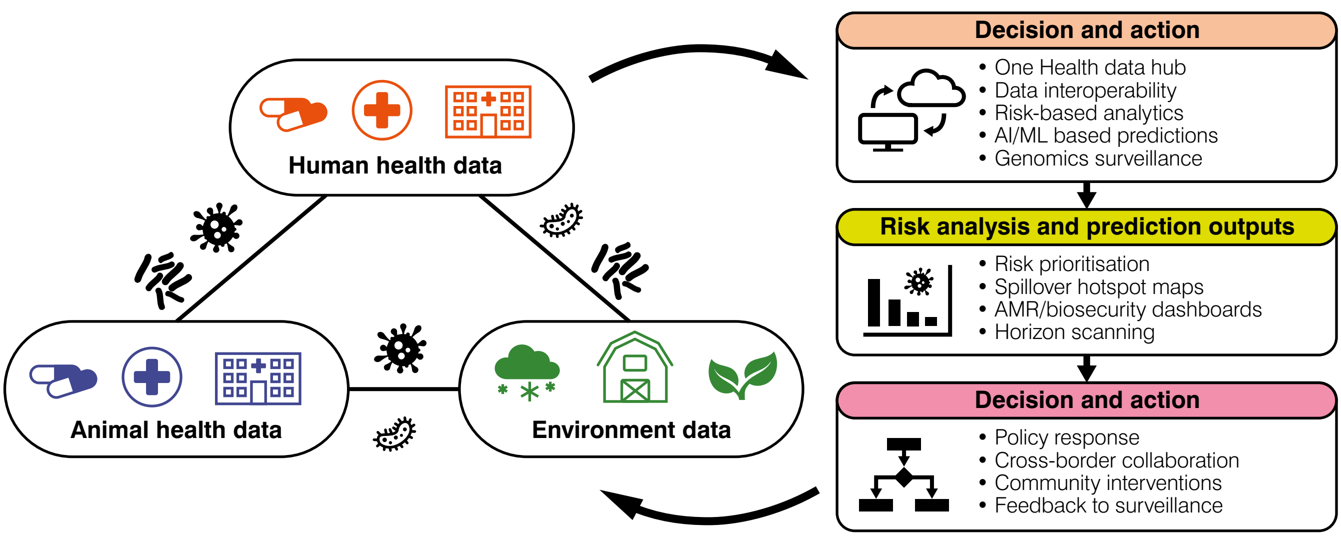


Figure 7. Predictive risk analysis and decision support through One Health data integration.

Advances in predictive modelling

Predictive modelling has advanced substantially since the COVID-19 pandemic, with machine-learning algorithms now prioritising viruses with zoonotic potential, narrowing candidates for laboratory characterisation, and mapping out where spillover risks are highest and why[201]. New modelling approaches combine different techniques, including explainable artificial intelligence (AI), to improve predictions and make them more useful[202]. These models consider the above-mentioned requirements for effective surveillance of human activity, environmental changes, and differences in how diseases are reported. Instead of just creating static hotspot maps, predictive modelling tools aim to provide actionable insights that policymakers can use; however, to be effective, they need to be part of flexible, real-time surveillance systems that can quickly confirm and respond to potential threats.

Standardised datasets and the need for shared surveillance

Evidence clearly shows that open, standardised datasets, such as early case records, movement data, and virus databases, help identify risks faster and focus disease control. For example, the Global Initiative on Sharing All Influenza Data (GISAID) and the PREDICT and Global Virome Projects have demonstrated that transparent, shared data accelerate early warning and response capacity[203,204].

Global initiatives to map viral diversity and strengthen One Health capacity illustrate the benefits of sharing data; however, for these gains to be sustainable, access to data must be equitable, with transparent governance and shared benefits. Without these safeguards, predictive and analytic capacity may become disproportionately concentrated in high-income settings, undermining global trust and limiting the generalisability of surveillance outputs[201].

Barriers to decision-making

The critical barriers to decision-making are built into how systems are structured. Governance silos between human, animal, and ecosystem health slow cross-sector data exchange, and without pre-agreed standards, roles, and thresholds, joint analysis and rapid response are delayed. Many countries report that guidance and capacity for risk assessment are weak at the county or district level, and that surveillance for unknown emerging infectious diseases is lacking[195]. Information sharing across borders is inconsistent, and within livestock systems, low biosecurity and interconnected value chains allow pathogen amplification and AMR dissemination. Currently most systems fail to integrate farm management data (such as animal movement, feeding practices, or health records) with real-time pathogen data.

Towards integrated surveillance-response systems

Future pandemic prevention requires iSRS where environmental-animal-human domains communicate with each other[173]. In Europe, the first iSRS exists for West Nile virus in Northern Italy, integrating surveillance of mosquitoes, wild birds, horses, and humans at the same time[205]. In LMICs relatively simple iSRS have emerged that include community-based surveillance involving Community Animal Health Workers (CAHWs) and Community Health Workers (CHWs). They are the frontline for the rapid detection of outbreaks in humans and animals at community level. They communicate through cell phones and SMS to One Health Surveillance Units at district level, which are connected to national surveillance-response systems and diagnostic laboratories[205].

Key messages

- **Zoonotic surveillance needs to anticipate emergence, not just document events:** Surveillance systems must move beyond recording reported disease cases and become better able to detect early signals of where and when zoonotic threats may emerge.
- **Traditional surveillance is essential but insufficient on its own:** Passive, indicator-based and notifiable disease reporting remain important, but they can be slow or incomplete and need to be strengthened with ecological, behavioural, environmental and real-time data.
- **Effective surveillance depends on linking hazards, risks and vulnerabilities:** Systems need to capture information on pathogens, transmission routes, exposed communities, animal populations and environmental conditions to understand where threats are most likely to spread or cause harm.
- **Drivers of zoonotic emergence should be embedded into surveillance:** Human mobility, land-use change, contact patterns, AMR profiles, demographic susceptibility and climate change all shape disease emergence and should inform early detection and risk assessment.
- **Early-warning systems require multiple data streams:** Notifiable disease reports should be combined with environmental biosurveillance, wildlife sampling, remote sensing, vector monitoring, internet-based intelligence and underused health and pharmacy data.
- **One Health surveillance depends on collaboration and trust:** Integrated systems require multisectoral data sharing, clear roles, stakeholder engagement and buy-in from farmers, frontline workers and others who generate or submit data.
- **Surveillance systems need strong technical and operational foundations:** Effective systems depend on appropriate tools, infrastructure, analytical capacity, data quality standards and clear processes for timely detection, communication and response.
- **Risk assessment should guide action when threats are uncertain:** For new or poorly understood threats, surveillance and response should focus first on the highest-risk species, areas or production systems, using risk frameworks and advanced analytics to target limited resources.
- **Predictive modelling can support earlier and more targeted prevention**: Machine learning, explainable AI and other modelling approaches can help prioritise zoonotic threats and identify spillover risks, but they must be linked to flexible, real-time surveillance-response systems.
- **Shared surveillance data must be open, standardised and equitable:** Data sharing can accelerate early warning and response, but access must be equitable, with transparent governance and shared benefits, to avoid concentrating predictive and analytic capacity in high-income settings.

5. The need for a One Health approach in zoonotic disease prevention

The emergence and re-emergence of zoonotic diseases are shaped by complex interactions within social-ecological systems (SES) with numerous transmission pathways[16] and multiple drivers [see **Section 2**], reinforcing the need for coordinated and preventative action. In this context, a One Health approach is essential for effectively addressing zoonotic disease risks. One Health is an integrated unifying approach that recognises that 'the health of humans, domestic and wild animals, plants, and the wider environment (including ecosystems) are closely linked and inter-dependent' and must be addressed together[206]. It is now widely accepted as essential for preventing zoonotic disease, improving food security, and strengthening resilience to global health threats.

Recent years have seen unprecedented progress for One Health governance:

- The development of the *One Health Joint Plan of Action*[207] by the Quadripartite organisations (FAO, UNEP, WHO, WOAH) as a framework to guide countries in implementing One Health.
- The constitution of OHHLEP that developed a global definition for One Health endorsed by the Quadripartite.
- The commitment to One Health strategies by political forums such as the G7, G20, regional institutions such as the Africa Centres for Disease Control and Prevention (Africa CDC), the European Union and many others. Many Latin American, African, and Asian countries have national One Health Platforms (Figure 7)[208].
- The publication of the 2025 landmark report by the Lancet One Health Commission.

Momentum for One Health is strong but fragile. Although an increasing body of evidence supports the benefits of a One Health approach (including a recent systematic review showing that 78 of 97 initiatives reported a positive return on investment or economic value[209]) more robust evidence is still needed. Without it, political support may wane. This section of the Evidence Note outlines four priority areas for action.

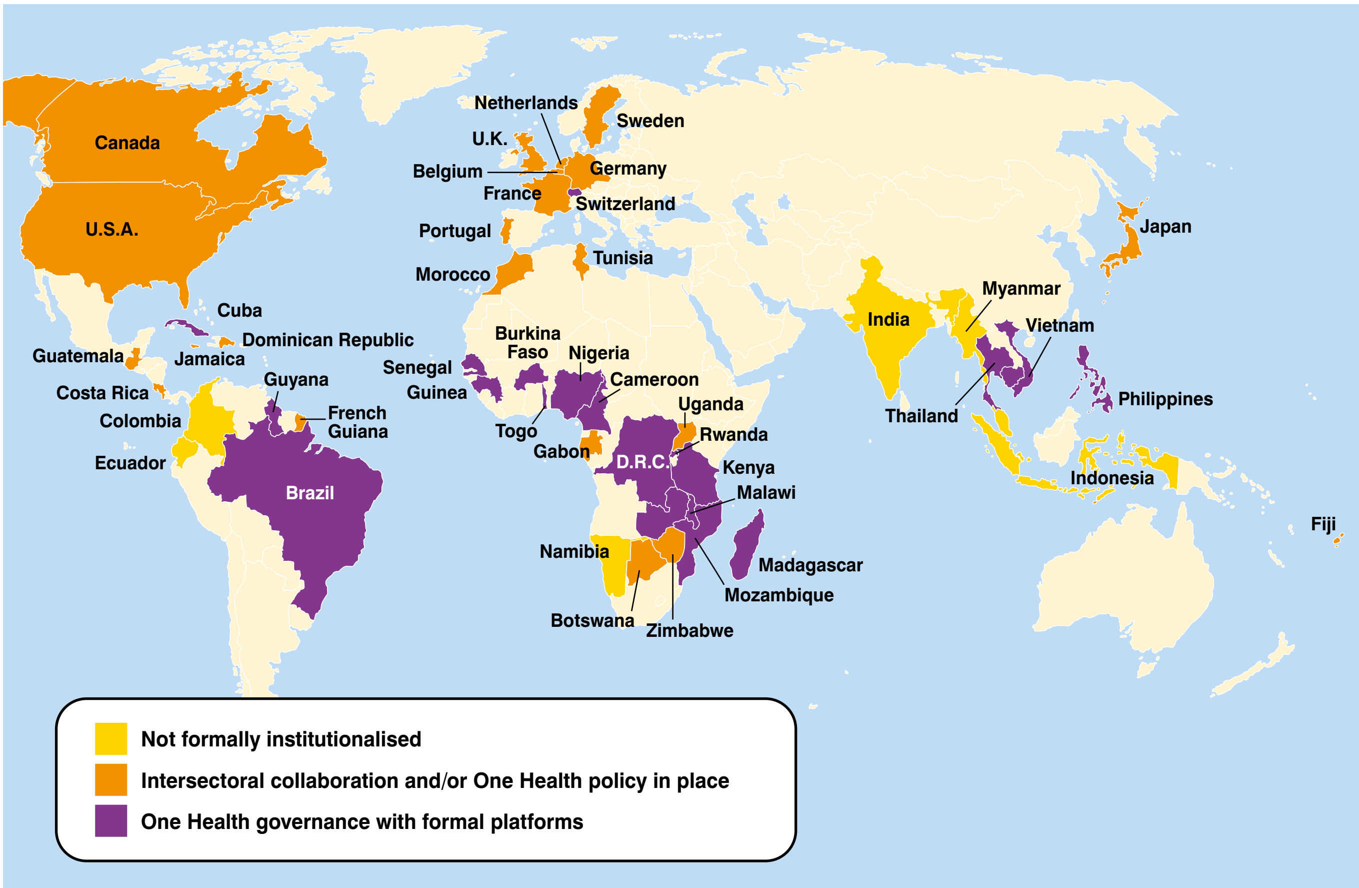


Figure 8. World mapping of One Health institutionalisation status at country level: One Health governance with formal platforms; intersectoral collaboration and/or One Health policies in place; not formally institutionalised.[202]

Priority area 1: Prevention and cross-sector cooperation

- Early, primary prevention, has been shown to be cost-effective: Detecting and managing zoonotic threats early reduces the health, economic, and social impacts of outbreaks (Figure 9)[173,210]. Furthermore, the identification and mitigation of the drivers of zoonotic spillover, such as land-use change, trade, and consumption of wild animals, could limit/reduce the occurrence of spillover and disease emergence [see **Section 2**]. More evidence is still needed to confirm the cost effectiveness of these upstream/primary prevention strategies[211].
- Integrated surveillance saves money and lives: Linking human, animal, and environmental monitoring enables earlier warning of zoonotic pathogens[212,213] and faster cross-sector responses [see **Section 4**].
- Example: Coordinated systems lower the cumulative costs of zoonotic outbreaks by addressing them before they spread widely. The iSRS set up by the Italian authorities in Italy to monitor the West Nile virus, can reduce exposure and save treatment cost[205].
- Policy implication: Investment in prevention through One Health is more sustainable than reactive spending during crises.

Priority area 2: Aligning strategies and methods

- The OHHLEP definition of One Health (balancing and optimising the health of humans, animals, plants, and the environment) is ambitious. Achieving this balance is complex, as different sectors and stakeholders may have different, and sometimes contradictory, priorities and incentives. Identifying and addressing trade-offs is key. Although it should be remembered that the creation of OHHLEP, as mentioned above, is progress in itself.
- Tools for alignment: Tools like SES models and game theory can help find solutions that benefit everyone. The OHHLEP One Health definition stresses the need to use natural resources — such as pastures, forests, and water — sustainably while protecting the health of all species. A social–ecological approach looks at how people, animals, the environment, and governance systems interact. By analysing how different groups make decisions using game theory, we can identify ways for everyone to protect natural resources and improve human and animal health together[214].
- Example: A study of the economic impact of brucellosis vaccination of yaks in Tibet demonstrated a benefit:cost ratio for brucellosis vaccination of 3.19 meaning that for 1 unit of cost, 3.19 units of benefits were accrued, based on the estimated annual cost of brucellosis[215].
- Policy implication: Demonstrating practical, evidence-based successes builds trust and commitment across sectors.

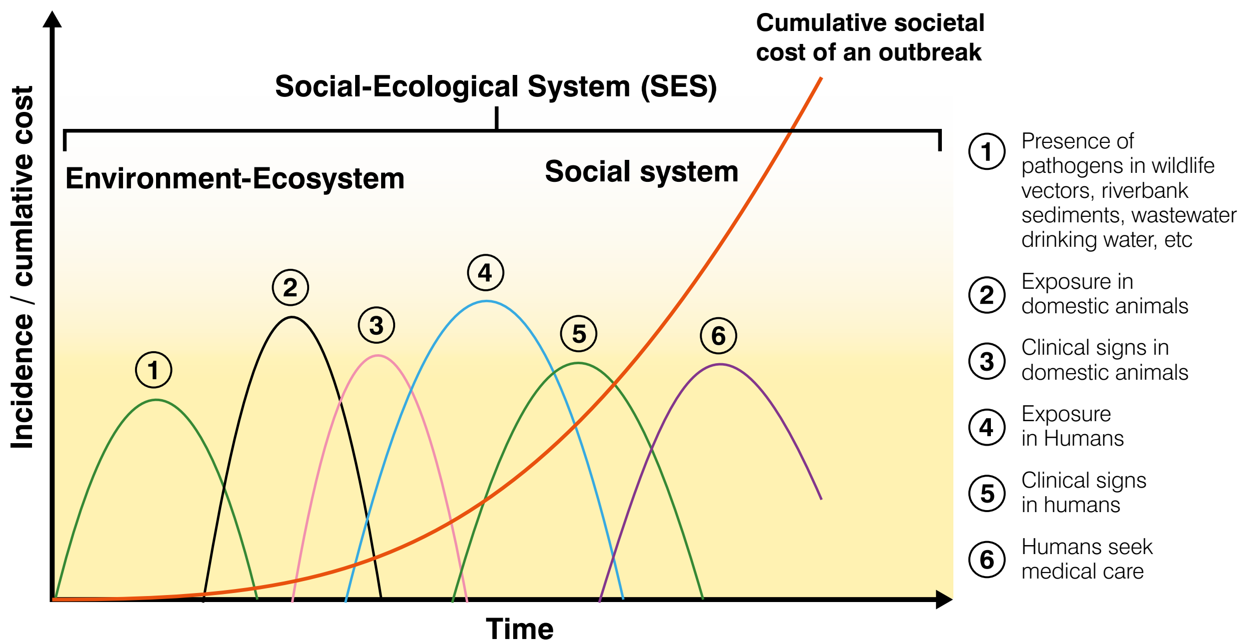


Figure 9. Schematic relationship of time to detection of an emerging pathogen and its cumulative cost of control. The changing left to right there is a continuum of the environmental to the social system (adapted and expanded from[174,212]). The diagram shows that over time the cost of disease caused by the pathogen increases considerably and demonstrates the cost benefits of implementing prevention strategies early.

Priority area 3: Harnessing genomics, digitalisation, and artificial intelligence

- There is huge potential for One Health approaches through genomics: Whole genome sequencing and metagenomics (which consist of the collection and analysis of samples from the environment) can trace pathogens across species and ecosystems. For example, studies in Palestine showed near-identical genetic sequences of *Salmonella* in poultry, food products, and humans, confirming cross-domain transmission[181,216].
- Digital tools can link patient care, animal surveillance, and supply chains. For example, systems like BlockRabies use blockchain to integrate patient data, animal exposures, and vaccine supply chains, increasing efficiency and cost-effectiveness[217]. There is a huge, untapped potential for the interconnection of patient registration and animal disease monitoring through such digital applications; however, there are also significant technical, political, and privacy issues.
- Artificial Intelligence (AI): AI can analyse complex genomic and ecological data to detect early warning signs of emerging zoonoses and enhance preparedness for pandemics.
- Policy implication: Strategic investment in these technologies can transform zoonotic disease monitoring and prevention [see **Section 4**].

Priority area 4: Building competence, institutions, and legal frameworks

For One Health to succeed, capacity must grow at every level:

- Workforce development: Global One Health university networks and online training platforms are rapidly expanding capacity.
- Institutional change: Countries are developing national One Health platforms and integrated research centres to coordinate efforts (Figure 8).
- Legal frameworks: Policies enabling data exchange across sectors accelerate response. For example, the European Union has advanced legislation on zoonoses data-sharing, and the African Union is preparing the Pan-African Strategy for the Elimination of Rabies in Africa[218].
- Global governance: The WHO Pandemic Agreement is a proposed global, legally-binding international agreement being developed by member countries of the World Health Organization (WHO) to prevent, prepare for, and equitably respond to pandemics. The Pandemic Agreement has a dedicated article (Article 5) on One Health, signalling its importance in global preparedness for pandemics of zoonotic origin.
- Policy implication: Sustained political will, institutional reform, and supportive legislation are essential to embed One Health into national and international systems.

Key messages

- **One Health is essential for addressing zoonotic disease risk:** Zoonotic emergence is shaped by complex interactions between humans, animals, plants and ecosystems, so prevention and response must be coordinated across sectors rather than handled in isolation.
- **Momentum for One Health is strong but needs sustained evidence and political commitment:** Global governance has advanced through the One Health Joint Plan of Action, OHHLEP and national platforms, but continued support depends on robust evidence of impact, value for money and practical success.
- **Prevention is more sustainable than crisis response:** Early detection, integrated surveillance and action on spillover drivers such as land-use change, wildlife trade and consumption can reduce the health, economic and social impacts of zoonotic outbreaks.
- **One Health implementation requires alignment across sectors and stakeholders:** Different groups may have competing priorities and incentives, so tools such as social–ecological systems approaches and game theory can help identify trade-offs and support solutions that benefit human, animal and environmental health.
- **Genomics, digital tools and AI can transform zoonotic disease monitoring:** Whole genome sequencing, metagenomics, digital surveillance systems and AI can improve detection of cross-species transmission and early warning, but their use requires strategic investment and attention to technical, political and privacy challenges.
- **One Health must be embedded through capacity, institutions and law:** Workforce development, national platforms, integrated research centres, data-sharing legislation and global agreements are needed to make One Health part of routine national and international preparedness systems.

6. Political economy issues in tackling zoonotic disease threats systematically

Zoonotic diseases pose escalating global threats, as underscored by recent pandemics. Fragmented governance, competing political and economic interests, and uneven political power may result in countries and institutions under-investing, despite the clear benefit–cost ratio of investing in preparedness. The requirements for preparedness — a sound legal framework, trained health workforce, surveillance systems, laboratories, and multisectoral coordination — span multiple ministries and funding streams, making alignment both politically and institutionally difficult.

Policy prioritisation and institutional barriers

Policy prioritisation around zoonoses is frequently shaped more by visibility and vested interests than by epidemiological evidence. For example, despite strong evidence for the profitability of livestock vaccination against brucellosis[219–221] few countries have implemented such programmes, reflecting siloed regulatory systems and limited cross-sectoral data sharing. Prioritisation is often shaped by compartmentalised regulatory systems and the interplay of social, cultural, and institutional factors[222]. Limited and unsustainable financing is a challenge[223–225]. Some of the key policy and institutional challenges to tackling zoonotic disease threats are in terms of governance and constraints.

Lessons and opportunities from COVID-19

The economic impact of the COVID-19 pandemic opened opportunities for reform, promoting greater cross-sectoral engagement. This led to better understanding of the benefits of institutionalisation of the One Health approach (which seeks to integrate human, animal, plant, and ecosystem health governance), and the expansion of the Tripartite (World Health Organization (WHO), the Food and Agriculture Organization of the United Nations (FAO), and the World Organisation for Animal Health (WOAH)) to include the United Nations Environment Programme (UNEP), becoming the Quadripartite. Yet implementation remains hampered by fragmented responsibilities, weak incentives, and lack of sustained financing.

Global inequalities and the agrifood dimension

Globally, zoonotic disease control reflects structural inequalities, fragmented governance, and market-driven priorities promoting economic growth, while undervaluing ecosystem protection and exacerbating the conditions for disease emergence. The ability of evidence-based advocacy to mobilise political will has been demonstrated in Africa through AU-IBAR and Africa CDC's rabies elimination strategy[218,226].

Balancing disease prevention with poverty reduction is a critical political and economic challenge in global health governance. For example, addressing future pandemic risks from zoonotic diseases such as influenza and coronaviruses requires strengthening biosafety measures across the entire livestock value chain — from animal production to transport and marketing. High-risk environments, including live animal markets where different species are confined and slaughtered in close proximity, create ideal conditions for cross-species virus transmission. Reforms to both intensive and smallholder livestock systems are therefore essential to minimise interactions between wild birds, poultry, and pigs, which can serve as reservoirs for future influenza pandemics. However, these interventions must be designed and implemented with sensitivity: overly stringent measures could inadvertently harm the livelihoods of hundreds of millions of small-scale livestock producers who depend on animal agriculture for food security and income[193].

Global health security is a public good that requires commitment from governments and international institutions through integrated, cross-sector surveillance and response systems as the first line of pandemic prevention[187]. In support of this, private companies involved in intensive farming and animal-based food production should strengthen biosecurity across the entire supply chain, leading by example and reinforcing collective efforts to prevent pandemics.

Socioeconomic and environmental drivers of risk

Socioeconomic vulnerability and environmental degradation further complicate zoonotic disease management. Displacement[135,227] as a result of conflict[220] or climate change, poverty, and lack of access to health and veterinary services increase the risk of disease transmission, particularly among marginalised populations [see **Section 2**][229,230]. Addressing these risks requires a transdisciplinary, multilevel approach that integrates social, economic, and ecological considerations into policy and humanitarian responses[231].

Reframing governance

Tackling zoonotic disease threats systematically is as much a political and economic challenge as it is a scientific one. Progress depends on reframing policy narratives, strengthening cross-sectoral governance, addressing structural inequalities, and embedding health equity and sustainability into global and national strategies.

Key messages

- **Tackling zoonotic threats is a political and economic challenge, not only a scientific one:** Preparedness depends on legal frameworks, trained workforces, surveillance, laboratories and multisectoral coordination, but these span multiple ministries and budgets, making sustained investment and alignment difficult.
- **Policy priorities are not always driven by evidence:** Decisions about zoonotic disease control are often shaped by visibility, vested interests, siloed regulation and limited data sharing, which can lead to underinvestment even where interventions, such as livestock vaccination, are cost-effective.
- **COVID-19 created momentum for One Health reform, but implementation remains fragile:** The pandemic strengthened recognition of cross-sector governance, yet fragmented responsibilities, weak incentives and unsustained financing continue to limit progress.
- **Zoonotic disease control must address global inequalities and agrifood trade-offs:** Pandemic prevention requires stronger biosecurity across livestock value chains, but reforms must avoid harming small-scale producers whose livelihoods, food security and income depend on animal agriculture.
- **Health security depends on shared responsibility across public and private sectors:** Governments, international institutions and private companies in intensive farming and animal-based food production all have roles in strengthening biosecurity, integrated surveillance and response systems.
- **Zoonotic risk is intensified by socioeconomic vulnerability and environmental degradation:** Conflict, climate change, displacement, poverty and limited access to health and veterinary services increase transmission risks, particularly for marginalised populations.
- **Governance must be reframed around equity, sustainability and prevention:** Progress requires stronger cross-sectoral governance, structural inequality reduction and policy narratives that embed health equity and environmental sustainability into national and global strategies.

7. Recommendations

The highly complex nature of global SES means that human exposure to zoonotic diseases cannot be prevented entirely. Policy efforts must therefore focus on strengthening resilience and managing risk.
This will require coordinated One Health governance, targeted action at key leverage points, and sustained, equitable investment in prevention through cross-sector collaboration.

Table 2 highlights the most actionable and policy-relevant recommendations arising from each section of the Evidence Note, targeting critical leverage points within socio-ecological systems. The order of the recommendations in the Table does not imply priority.

Those responsible for implementing the recommendations are highlighted in the final column. The lead actors are shown in bold, although it is recognised that integrated approaches across sectors/organisations are required.

Table 2. Zoonotic Disease Policy Recommendations

Recommendation	Implementation route	Alignment	Responsible actors
Strengthen upstream prevention of zoonotic disease (re)emergence	Invest sustainably in capacity, data sharing and cross-sector collaboration, with stronger integration of environmental, biodiversity and climate dimensions, including land-use planning and habitat protection and ecosystem-based risk reduction	**Quadripartite One Health Joint Plan of Action** and **IPBES Pandemics Report** and **the Convention on Biological Diversity (CBD), including the Kunming-Montreal Global Biodiversity Framework**	**National governments;** ministries of health, agriculture, environment, climate and finance; UNEP; national One Health platforms; development partners; research institutions; local authorities, and other relevant regulatory bodies
Catalyse international and regional coordination on zoonotic threats	Enable structured cooperation and joint action across borders to prevent, prepare for, and respond to shared zoonotic risks	**Quadripartite One Health Joint Plan of Action** International standards structure cooperation on animal health and trade: **WOAH International Standards**	**Quadripartite organisations;** FAO, UNEP, WHO and WOAH; regional bodies such as Africa CDC, AU, EU and ASEAN; national governments; regional economic communities; cross-border surveillance networks
Strengthen integrated surveillance and operational response systems	Invest in integrated One Health surveillance-response systems that connect surveillance with coordinated operational response. This should include data sharing, joint risk assessment, early warning, rapid response protocols, and targeted monitoring at high-risk wildlife–livestock–human interfaces, supported by tools such as biosurveillance, remote sensing and symptom-based reporting	**Quadripartite One Health Joint Plan of Action** and **Tripartite Zoonoses Guide: Surveillance and Information Sharing Operational Tool** and **Tripartite Zoonoses Guide: Joint Risk Assessment Operational Tool** and **WHO Pandemic Agreement** and **International Health Regulations (2005)** and **WOAH International Standards: Terrestrial Animal Health Code**	**National One Health platforms or equivalent multisectoral coordination bodies;** ministries of health, agriculture/livestock, environment and climate; national public health institutes and veterinary services; emergency operations centres; sub-national authorities; FAO, UNEP, WHO and WOAH
Shift from live animal trade to safer commodity-based trade	Replace longdistance transport of live animals with processed products wherever feasible, focusing sanitary controls on food safety outcomes	Aligned with WOAH's role in setting sanitary requirements for trade in live animals and animal products. **WOAH Safe Trade and Movement of Animals**, **WOAH Terrestrial Animal and Health Code** and **the Convention on Biological Diversity (CBD), including the Kunming-Montreal Global Biodiversity Framework**	**Ministries of trade, agriculture and livestock;** veterinary authorities; food safety agencies; customs and border authorities; UNEP; WOAH; private sector value-chain actors; producer organisations; smallholder and trader associations

Recommendation	Implementation route	Alignment	Responsible actors
Strengthen implementation of wildlife and travel regulatory frameworks	Promote effective enforcement of existing international agreements governing wildlife trade, farming, and travel to reduce zoonotic emergence risks	**IPBES Pandemics Report** and **WHO/WOAH/UNEP Guidance on Traditional Food Markets** and **CITES**	**Environment and wildlife ministries;** CITES management authorities; customs, border and quarantine agencies; public health authorities; transport and tourism ministries; law enforcement; judiciary; airport and port authorities
Embed intersectoral One Health collaboration across prevention and response	Institutionalise coordinated action across sectors for surveillance, early detection, and response, ensuring inclusive stakeholder engagement	**Quadripartite One Health Joint Plan of Action** and **Tripartite Zoonoses Guide**	**Heads of government or cabinet offices;** ministries of health, agriculture, environment, finance, trade and local government; national One Health platforms; parliamentary committees; sub-national authorities
Transform live animal and wet market risk management	Prioritise targeted surveillance and participatory biosecurity interventions that reduce transmission risks while safeguarding livelihoods of smallholders and traders	**WHO/WOAH/UNEP Guidance on Traditional Food Markets** and **WOAH Terrestrial Animal Health Code**	**Local governments; market authorities;** ministries of health, agriculture and environment; veterinary and food safety inspectors; trader associations; market committees; smallholder groups; community leaders
Engage communities as partners in zoonotic disease prevention	Support participatory approaches that involve communities in identifying risks and codeveloping solutions that respect local culture and social norms	**IPBES Pandemics Report** and **Tripartite Zoonoses Guide** and **WHO/WOAH/UNEP Guidance on Traditional Food Markets**	**Local authorities; community leaders;** civil society organisations; community health workers; community animal health workers; farmer and trader groups; women's groups; Indigenous and local communities; risk communication teams
Prioritise vaccination as a core prevention strategy	Sustain animal and human vaccination programmes, ensure readiness for emerging threats, secure supply chains, and build public trust	**WOAH Terrestrial Animal Health Code** and **United Against Rabies Forum** and **Tripartite Zoonoses Guide**	**Ministries of health and agriculture;** veterinary services; immunisation programmes; vaccine procurement agencies; cold-chain and logistics providers; public health authorities; community health and veterinary workers; donors and manufacturers
Strengthen biosecurity across animal, human, and environmental interfaces	Enforce standards across farms, markets, and transport, control animal movements, reduce wildlifelivestock contact, and improve waste and water management	**WOAH Terrestrial Animal Health Code** and **WHO/WOAH/UNEP Guidance on Traditional Food Markets**	**Veterinary authorities;** livestock ministries; farm owners and producers; transport operators; market authorities; slaughterhouse operators; environmental health agencies; water and waste management authorities; local governments
Enhance sub-national zoonotic risk assessment capacity	Invest in local guidance, skilled staff, and feedback mechanisms to support rapid, evidencebased decisionmaking and response	**Quadripartite One Health Joint Plan of Action** and **Tripartite Zoonoses Guide** and **Surveillance and Information Sharing Operational Tool**	**District and provincial health, veterinary and environment offices;** local governments; national public health institutes; veterinary laboratories; emergency operations centres; universities and training institutions; development partners
Establish global One Health risk governance mechanisms	Support integrative, intersectoral coordination and accountability across international organisations addressing zoonotic disease prevention and preparedness	**Quadripartite One Health Joint Plan of Action** and **IPBES Pandemics Report** and **WHO Pandemic Agreement**	Quadripartite organisations; WHO member states; FAO, UNEP and WOAH governing bodies; G7 and G20; multilateral development banks; Pandemic Fund; regional institutions; national governments; global health security and biodiversity governance bodies

Note: Responsible actors are indicative and should be tailored to country context, mandate arrangements and implementation level.

Annex 1: Research methodology

Most of the sections included in this Evidence Note have been written by experts who draw on available published evidence as well as their own experience. These sections can be considered evidence-based with the potential for author bias. Section 2 on *Factors influencing the emergence and spread of zoonotic disease* adopts a more structured and rigorous approach. Section 2 (excluding the final section on *Trade and international travel*) is informed by an umbrella review of systematic reviews with meta-analyses. Here, evidence obtained through systematic review constitutes the backbone of the discussion. However, additional high-level evidence identified non-systematically was also incorporated where it provides relevant context or helps to address factors not fully captured by the review. This approach ensures the section is grounded in robust evidence, without neglecting other relevant insights.

When reading this Evidence Note, people are encouraged to consider the relative risk of bias across the different sections.

Annex 2: Organisations involved in tackling zoonotic disease

The global health architecture has undergone significant revision in recent decades. The outbreak of SARS in 2003 highlighted the lack of a coordinated international mechanism for rapid detection and response to multi-country outbreaks of zoonotic origin, particularly those involving novel respiratory pathogens. In response, the WHO revised the International Health Regulations (IHR) in 2005 to strengthen global surveillance and reporting capacities. However, the 2009 influenza A (H1N1) pandemic demonstrated possible gaps in global preparedness for emerging zoonotic threats.

The COVID-19 pandemic, caused by SARS-CoV-2 and declared a Public Health Emergency of International Concern (PHEIC) by WHO, further exposed capacity constraints in cross-sectoral detection, risk communication, and multisectoral response mechanisms across human and animal health systems. In parallel, the 2022–2025 mpox epidemic (also designated a PHEIC), caused by the mpox virus and with sustained human transmission beyond historically endemic regions, underscored persistent vulnerabilities in global surveillance of orthopoxvirus zoonoses.

Recurring Ebola virus disease outbreaks in parts of Africa, including the 2025 outbreak in the Democratic Republic of Congo, continue to illustrate challenges in implementing integrated disease surveillance and response. Concurrently, persistent and widespread HPAI events affecting domestic and wild birds, associated with zoonotic risk and significant impacts on poultry production and trade, highlight the critical importance of animal health and agrifood system resilience.

These experiences reinforce the central role of the Quadripartite (WHO, FAO), WOAH and UNEP) in advancing One Health approaches, integrating human, animal, and ecosystem health to prevent, detect, and respond to zoonotic disease threats at source, particularly those linked to agrifood systems. This section highlights organisations involved in tackling zoonotic disease (Table 3).

Table 3. Zoonotic Disease Governance Landscape*

Actor Type	Key Actors	Primary Function
UN & intergovernmental bodies	FAO, UNEP, WHO, UNEP	Global norms, standards, and coordination across human, animal, environmental, and agrifood systems, including food safety, livestock health, and AMR
Quadripartite mechanism	FAO–UNEP–WHO– WOAH	Joint leadership on One Health linking public health, animal health, agrifood production, and environmental sustainability
Global partnerships & networks	CEPI, GARC, GHSA, OHHLEP, PREZODE	Operational support, science, and financing for prevention and preparedness across livestock, food value chains, and public health.
Surveillance & response platforms	GLEWS+, GOARN, PulseNet	Early warning and response for zoonotic risks arising from animal production, foodborne transmission, and spillover events.
Regional bodies	Africa CDC & RECs, ASEAN, ECDC, PAHO	Regional coordination on surveillance, laboratories, and workforce spanning health, agriculture, and food systems.
Environment & wildlife governance	CITES, CBD, IPBES, WCS	Address environmental and biodiversity pressures linked to land-use change, agricultural expansion, and zoonotic spillover.
Science & financing	World Bank, CGIAR/ILRI, Wellcome Trust	Evidence and financing to strengthen safe, resilient, and sustainable agrifood systems for zoonotic risk reduction.

*Note, acronyms are expanded in the following sections

Intergovernmental and UN organisations

Intergovernmental and United Nation (UN) organisations provide the normative, coordination, and implementation frameworks that shape global and national policy responses to zoonotic diseases, including standard-setting, surveillance, preparedness, and cross-sectoral cooperation under the One Health approach. Together FAO, UNEP, WHO and WOAH form the Quadripartite Alliance for One Health.

Food and Agriculture Organization of the United Nations (FAO)

- Focuses on zoonoses at the animal–livestock–food interface.
- Works on surveillance, biosecurity, food safety, and AMR.
- Supports countries in veterinary services, and animal health, plant health and One Health systems.

United Nations Environment Programme (UNEP)

- Addresses the environmental drivers of zoonoses (land-use change, biodiversity loss, climate change).
- Newer but increasingly central partner in One Health governance.

World Health Organization (WHO)

- Leads global human health responses to zoonoses (e.g. Ebola, COVID-19, rabies).
- Coordinates surveillance, outbreak response, and international health regulations.
- Co-leads the One Health agenda.
- The WHO **Pandemic Agreement** outlines a comprehensive framework to help countries prevent, prepare for, and respond to future pandemics, built on principles of equity, solidarity, and respect for national sovereignty. The Agreement covers key areas, including strengthening disease surveillance and a One Health approach; strengthening health systems; safeguarding the health and care workforce; coordinating research and development; improving local production capacity, including through technology transfer; better coordination across governments and societies; improved communication with the public; stronger international cooperation; and sustainable financing.

World Organisation for Animal Health (WOAH, formerly OIE)

- Sets international animal health standards.
- Manages global animal disease reporting (World Animal Health Information System (WAHIS)).
- Key authority for transboundary animal and zoonotic diseases.

Partnerships, networks, and non-governmental organisations

Partnerships, networks, and non-governmental organisations play a critical role in operationalising global zoonotic disease policy by translating international frameworks into coordinated action, mobilising technical expertise and financing, and supporting countries to implement One Health approaches in practice.

The Coalition for Epidemic Preparedness Innovations (CEPI)

- **CEPI** is a global partnership, bringing together public-sector, private-sector, and academic partners, to accelerate the development of vaccines and other biologic countermeasures against epidemic and pandemic threats.
- CEPI's 2022–2026 strategy, known as CEPI 2.0, is helping to prepare, transform, and connect the world so that it can respond to the next disease threat with a new vaccine in just 100 days — a goal known as The 100 Days Mission.
- CEPI's mission is to accelerate the development of vaccines and other biologic countermeasures against epidemic and pandemic threats so they can be accessible to all people in need.

Global Alliance for Rabies Control (GARC)

- **GARC** is focused specifically on eliminating human rabies.

The Global Health Security Agenda (GHSA)

- **GHSA** is a collaborative, multisectoral network to enhance global health security and accelerate implementation of the IHR (2005) and other relevant frameworks by strengthening countries' capacities to prevent, detect, and respond to infectious disease outbreaks.
- Launched in 2014 with 14 founding members, GHSA has grown to include more than 70 countries, non-governmental organisations, and private sector actors. The third phase of GHSA runs to the end of December 2028.
- The Zoonotic Disease Action Package (**ZDAP**) aims to support its members to develop and strengthen their capacity and capability to prepare for, prevent, detect, and respond to zoonotic disease threats using a One Health approach.

One Health High-Level Expert Panel (OHHLEP)

- **OHHLEP** is the scientific and strategic advisory group to the Quadripartite organisations (FAO, UNEP, WHO and WOAH) in their collaboration on One Health.

Preventing Zoonotic Disease Emergence (PREZODE)

- **PREZODE** is an international collaborative initiative, bringing together members to provide a scientific framework for pandemic prevention. It aims at enhancing prevention, early detection, and resilience to avoid or rapidly respond to emerging infectious diseases of animal origin that can turn into pandemics.
- PREZODE bases its framework on the One Health approach.
- Through its community of practice, PREZODE aims to improve coordination and synergy, and promote the sharing of lessons learned and best practices. It strengthens and integrates knowledge, innovation, capacity building, and operational actions. PREZODE deploys academic research, cross-sectoral collaboration in the field, and the engagement of operational actors on the frontline of epidemics, considering both livestock and wildlife.

Global One Health surveillance and response coordination platforms and networks

Global One Health and surveillance coordination platforms play a critical role in operationalising global zoonotic disease preparedness and response by enabling early warning, real-time information sharing, joint risk assessment, and coordinated action across sectors and countries.

Global Early Warning System for Major Animal Diseases including Zoonoses (GLEWS+)

- GLEWS is a joint FAO–WHO–WOAH initiative supporting real-time information sharing, joint risk assessment, and coordinated response to zoonotic threats.

Global Outbreak Alert and Response Network (GOARN)

- GOARN is a WHO-led network that mobilises technical expertise and rapid response teams during zoonotic and other public health emergencies.

PulseNet International

- PulseNet International is a network of national and regional laboratory networks dedicated to tracking foodborne infections worldwide. Each laboratory utilises standardised genotyping methods, sharing information in real-time.
- The resulting surveillance provides early warning of food and waterborne disease outbreaks, emerging pathogens, and acts of bioterrorism.

Regional bodies

To minimise the impact of emerging and re-emerging zoonotic diseases, the capacity of all countries — particularly LMICs — to prevent, detect, and respond to health threats at the human–animal–environment interface must be substantially strengthened. Regional bodies have a critical role to play in this process. By reflecting shared epidemiological risks, agrifood systems, trade patterns, and ecological contexts, regional institutions are well-placed to support harmonisation of standards, facilitate peer learning, and coordinate collective action to raise national capacities to agreed benchmarks. In Africa, for example, the Africa CDC, working with Regional Economic Communities (RECs), such as the Economic Community of West African States (ECOWAS), Intergovernmental Authority on Development (IGAD), South African Development Community (SADC), and East African Community (EAC), has emerged as a central actor in strengthening regional surveillance, laboratory networks, and workforce development under a One Health framework.

Comparable regional mechanisms exist elsewhere, including the Association of Southeast Asian Nations (ASEAN), which has advanced regional cooperation on zoonotic diseases and health security through ASEAN Health and Agriculture sectoral bodies; the European Centre for Disease Prevention and Control (ECDC), which supports coordinated surveillance and risk assessment across the European Union; and regional public health institutions in the Americas, notably the Pan American Health Organization (PAHO), which has long promoted integrated approaches to zoonoses, food safety, and animal health.

Across regions, countries increasingly recognise the added value of regional coordination, as reflected in the adoption of One Health strategies and the issuance of One Health Ministerial Communiqués and declarations by most RECs and regional groupings, signalling political commitment to multisectoral collaboration on zoonotic disease prevention and control.

Environment and wildlife governance

A number of other organisations are also working to tackle issues related to trade in wildlife, including the Convention on International Trade In Endangered Species of Wild Fauna and Flora (**CITES**), and biodiversity, such as the Convention on Biological Diversity (**CBD**), the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (**IPBES**), and the Wildlife Conservation Society

Through regulating international wildlife trade, promoting ecosystem conservation, and strengthening the science–policy interface, these bodies help reduce human–wildlife interactions that increase the risk of zoonotic disease spillover. Collectively, their work supports a One Health approach by addressing the underlying environmental and biodiversity drivers of emerging infectious diseases.

Science and financing organisations

Science, research, and funding organisations underpin zoonotic disease policy by generating the evidence base for decision-making, shaping global research priorities, and financing and informing investments in prevention, preparedness, and health system strengthening across the One Health spectrum.

CGIAR (incl. ILRI)

- Conducts research on livestock, agriculture, and zoonoses in LMICs.
- ILRI (International Livestock Research Institute) is especially prominent for zoonotic disease research.

Wellcome Trust

- Major funder of zoonotic disease, epidemic preparedness, and One Health research.
- Influential in shaping global research agendas.

World Bank

- Funds zoonotic disease prevention, pandemic preparedness, and health system strengthening.
- Strong focus on economic impacts and prevention investment.
- **The Pandemic Fund** is a Financial Intermediary Fund (FIF) hosted at the World Bank. It finances critical investments to strengthen pandemic prevention, preparedness, and response capacities at national, regional, and global levels, with a focus on LMICs.