

Links between ecological integrity, emerging infectious diseases and other aspects of human health - an overview of the literature

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SUMMARY

1. Environmental degradation has significantly altered ecological systems worldwide and continues to expand into new areas.
2. The majority of emerging infectious disease¹ threats are zoonotic and often cause major social and economic impacts.
3. Ecological degradation by humans increases overall emerging zoonotic disease risk.
 - a. This relationship has been shown for multiple individual diseases, in regional and global studies and in theoretical models, although the proportion of cases of degradation that lead to substantially increased risk is not well understood.
 - b. The increased risk results from multiple interacting pathways including increased human contact with pathogens and disruption in pathogen ecology.
 - c. The key “ingredients” that accentuate the risk of an emerging infectious disease spillover event are activities (e.g., creation of new habitat edges, wildlife trade, consumption, agricultural intensification) in areas of high biodiversity that elevate contact rates between humans and certain high-risk wildlife species.
4. Degradation of ecosystems also has complex effects, feedback loops, and some notable negative impacts on many other aspects of human health, including: the prevalence of long-established (endemic) zoonotic diseases, vector-borne and water-borne diseases; air quality; nutrition; mental health; and access to traditional medicines; as well as effects on human health through the impacts of climate change.
5. Avoiding environmental degradation (by keeping ecosystems as intact as possible and avoiding the creation of high-risk interface zones and high-risk activities that increase human-wildlife contact), combined with broader One Health² approaches that address the full range of risk factors, will help to reduce the risk to humanity from emerging zoonoses and can have other beneficial health outcomes as well.
 - a. Hence, protecting ecological integrity should be a priority action within any comprehensive plan to avoid future zoonotic outbreaks, alongside other critical measures such as addressing the wildlife trade, building surveillance and response systems, providing global access to health care, and mitigating disease risks associated with domestic animals.
 - b. A One Health approach, optimizing human health and ecological integrity, can be used to find solutions for different landscape contexts (e.g. remote intact landscapes, mixed, partly natural landscapes, and heavily human-dominated landscapes).

The evidence supporting each of the points of the argument is outlined below, using a selection of key references. There are numerous publications supporting the argument given here, based on a range of evidence types including detailed examples, global analyses, modelling, and broad expert consensus.

Whilst the key conclusions are clear, it is important to acknowledge that the science is still somewhat incomplete and it is difficult to make predictions at the scale of individual ecosystems, locations or infectious agents, especially as outbreaks are inherently rare events and the exact relationship between pathogen dynamics and ecosystem change is often context-

¹ ‘Emerging infectious diseases can be defined as infections that have newly appeared in a population or have existed but are rapidly increasing in incidence or geographic range’ (Morse 1995).

² www.wcs.org/one-planet-one-health-one-future; www.onehealthglobal.net/what-is-one-health/

specific and subject to interactions with many other environmental, socio-economic, political and cultural factors. Outbreak or spillover frequency is a function of human-wildlife contact rates and the severity of an outbreak is driven by the pathogen's pathogenicity and transmissibility as well as other factors like public health surveillance and response capacities.

In addition to lowering disease spillover risk, avoiding environmental degradation has many related benefits, including: climate change mitigation; climate change adaptation and environmental resilience; maintenance of watersheds and rainfall patterns; biodiversity conservation; and the protection of the homelands and livelihoods of Indigenous Peoples and local communities.

It should be noted that many other emerging zoonotic diseases arise from non-wildlife sources, for example livestock production. Even though these domestic animal systems are more understood and monitored they carry a large ongoing burden of endemic disease and pandemics, like avian influenza, still occur. So a world without environmental degradation, though much safer, would not be wholly free of pandemic risk.

INTRODUCTION

The devastating emergence of the virus causing COVID-19 has led to increased interest in the factors that result in pandemics and other disease outbreaks. There is an extensive body of literature on emerging infectious diseases that originate from wild animals, much of it built up since the SARS epidemic of 2002-2004 raised global awareness of the topic. The wildlife trade has been identified as one key risk factor and has rightly drawn a great deal of attention. This study reviews information relating to another commonly postulated risk factor - damage to the integrity of ecosystems. It was developed to underpin the institutional position WCS takes on this topic, and the advice we share with our many partners around the world.

The review considers publications through to March 2020, with a focus on the peer-reviewed literature, and draws on the combined expertise of scientific and policy staff from across WCS, including our dedicated programs on wildlife health and on the conservation of intact forests.

Damage to the integrity of ecosystems can take many forms, including deforestation, fragmentation, logging and the draining or flooding of natural habitats. As described below, such changes often increase the likelihood that humans will be exposed to unfamiliar and sometimes deadly micro-organisms. We do not review data on the wildlife trade in detail, but it is closely linked to the issue of ecological integrity, because so much of the wildlife trade is associated with areas where degradation is taking place, often enabled by increases in access to newly fragmented or exploited frontier regions. Furthermore, the loss of wildlife populations ('defaunation') is itself an important form of environmental degradation, disrupting many ecological processes.

Beyond the health aspects discussed here, high ecological integrity is also important for a wide range of other critical values and benefits to humanity, as reviewed recently by Watson et al. (2018).



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DETAILED EVIDENCE

The following headings match points 1-4 of the summary.

Point 1. Environmental degradation has significantly altered ecological systems

Humanity has been reshaping Earth's ecosystems for millennia. We engage in large-scale conversion of natural habitats to agricultural crops and urban areas to feed and house our burgeoning population, and we change the state of natural systems through activities like hunting, logging, resource extraction, infrastructure construction, recreation and fire management. There have been a myriad of recent attempts to map the level of anthropogenic environmental degradation across the land and ocean with some estimates showing that ~80% of both realms have clear evidence of anthropogenic modification, varying in extent across particular ecosystems (Venter et al, 2016; Jones et al 2018).

The IPBES global synthesis report released in 2019 (IPBES 2019) clearly outlined the recorded evidence of the multitude of impacts of environmental degradation on ecological systems, including:

- significantly altered global patterns of species composition and abundance,
- loss and appropriation of primary productivity,
- changes in land-surface hydrology and albedo,
- alterations to the biogeochemical cycles of carbon, nitrogen, and phosphorus.

Many natural scientists argue that the anthropogenic degradation placed on ecosystems has meant Earth has entered a human-dominated geological era termed the Anthropocene (Malhi et al 2014) and we are increasingly transgressing catastrophic environmental boundaries (Steffen et al 2015).

Point 2. The majority of emerging infectious disease threats are zoonotic and often have major

The International Bureau for Zoonotic Diseases (OIE) defines zoonotic diseases ‘as infectious diseases that are naturally transmitted from vertebrate animals to humans and vice versa’ (Wang and Crameri 2014). Emerging infectious diseases can be defined as infections that have newly appeared in a population or have existed but are rapidly increasing in incidence or geographic range (Morse 1995). An outbreak is the occurrence of one or more cases in a group of individuals in a defined region. An outbreak of an emerging zoonotic disease is sometimes called a ‘spillover’.

2a) The majority of emerging infectious disease threats are zoonotic

- More than 335 emerging infectious disease outbreaks (involving 183 distinct pathogens) were reported worldwide during 1940-2004, more than 50/decade, and the rate of outbreaks is increasing (Jones et al 2008).
- In recent years, 52% of all emerging infectious disease events originated in wildlife. Among emerging zoonoses specifically, 72% of outbreaks have originated in wildlife (with the rest from domestic animals). The frequency of outbreaks originating in wildlife is increasing. All facts under this bullet are from Jones et al (2008).
- Populations of wild animals carry a high diversity of the types of infectious agents that could potentially jump to humans, with higher diversity of such agents where the diversity of host animals is higher (e.g. Anthony et al 2017). Most diseases in wild animals remain very poorly studied, many pathogens remain unidentified, and many spillover events are overlooked (Johnson et al 2020).
- The global connectivity of human society greatly increases the long-distance transport of disease vectors (Tatem et al 2006) and of animals infected with infectious pathogens (Can et al 2019), increasing the number of human-wildlife interfaces where pathogens can spill over into humans. Connectivity also facilitates subsequent human-human transmission.

2b) Economic and societal impacts

- Zoonoses, domestic and wildlife combined, are mostly endemic (i.e. long-established) threats. The 13 top ranked zoonotic diseases largely fall into this category and annually they are estimated to be responsible for over 2 million deaths and 2 billion illnesses (ILRI 2012).
- Emerging (ie non-endemic) zoonoses have significant implications in terms of both public health and economic stability, with the costs of many individual recent major outbreaks such as SARS, MERS and Ebola reckoned in the tens of billions of US dollars and exceeding 1-2% of GDP in less wealthy countries (GPMB 2019).
- The costs of a single severe future influenza pandemic were predicted to reach US\$1.5 trillion or 3.1% of global GDP for one year at 2006 prices (Burns et al 2006), whilst the annualized cost to the global economy of occasional severe pandemics averaged over long periods was estimated at \$80-\$500 bn/year (up to 0.6% of global GDP) depending on whether or not deaths were ascribed an economic cost (Fan et al 2018).
- Recent estimates suggest that the cost of the unfolding COVID-19 pandemic to the world economy, in purely monetary terms, will be US\$1-2 trillion, possibly more (UNCTAD 2020), with huge additional costs to human life and wellbeing.

- The impact of the 2003 SARS Coronavirus epidemic (774 deaths) on tourism, food and travel in mainland China alone was estimated at US\$8.5bn (Beutels et al, 2009). The total global cost, associated with lost economic activity, is estimated to have been around \$40 billion (Knobler et al 2004).
- The 2013 Ebola outbreak in West Africa cost an estimated US\$2.2bn in GDP alone and wiped out many of the recent development gains in Guinea, Liberia, and Sierra Leone, which had been among the fastest growing economies in the world (CDC, 2016; International Working Group On Financing Preparedness, 2017).

Point 3. Ecological degradation by humans increases emerging zoonotic disease risk

There are multiple interacting lines of evidence that support this conclusion, which is reflected in numerous recent reviews of the topic (e.g. Patz et al 2004, Karesh et al 2012, Gottdenker et al 2014, Murray et al 2016, UNEP 2016, Watson et al 2018, DiMarco et al 2020). The issue is also reflected in the recently issued 'Berlin Principles on One Health'³.

The land-use changes that tend to elevate disease risk include deforestation, forest degradation (eg through logging), fragmentation, expansion of infrastructure (eg roads, railways, powerlines, dams), changes in drainage, and hunting and capture for trade (Patz et al 2004, Loh et al 2015). Risks are further multiplied by large movements of human populations, agricultural intensification near to natural areas, and climate change, among other factors (Gebreyes et al 2014, Karesh et al 2012).

The main lines of evidence summarized below are (a) case studies, (b) global/regional analyses and (c) theoretical modelling. They point to (d) a range of different pathways or mechanisms by which the effects take place.

a) Case studies

Multiple examples of zoonotic disease outbreaks from wildlife have been reported in the literature as being associated with forest degradation, human encroachment on forests, and wildlife trade chains that connect biodiverse forests to markets:

- SARS and COVID-19. The evolutionary host of the SARS virus (SARS-CoV) and the closely-related COVID-19 virus (SARS-CoV-2) are bats and in both cases, index cases were associated with wildlife markets. It is thought that SARS-CoV passed through civets (wild or farmed) before infecting humans and it is unknown at this stage if SARS-CoV-2 also passed through an intermediate host (Hu et al 2017; Lu et al 2020; Li et al, 2006). Here the main issue is the volume, mixing, unsanitary conditions, and overcrowding of wildlife that brought a bat virus into contact with a variety of animals in wildlife trade chains originating in natural habitats and ending at urban markets.
- Hendra virus. In Australia, science suggests declining eucalyptus habitat has altered flying fox foraging behaviour and increased spillover risk of Hendra virus to humans (Giles et al 2018).
- Nipah virus in Malaysia. The emergence of Nipah virus in 1998 is linked to bat ecology. During this time period, Pteropid fruit bats experienced a large reduction of flowering and fruiting trees as a result of slash and burn deforestation and an ENSO-linked

³ <https://www.wcs.org/one-planet-one-health-one-future>

drought. This led to these bats ranging into cultivated fruit orchards that adjoined pig farms which had recently expanded into forest-edge situations (Chua et al 2002).

- Nipah virus in Bangladesh. Case villages with Nipah virus spillovers had human higher population density than control villages and more forest fragmentation than other parts of the country. The number of bat roosts increased with fragmentation and was thought to be associated with home gardens of diverse fruit trees that may provide a more reliable food source than nearby intact forests (Hahn et al 2014).
- Ebola. In Central Africa, an association was found between Ebola outbreaks and fine-scale measures of forest fragmentation, consistent with suspected transmission pathways from forest-dwelling bats to forest-edge human communities (Rulli et al 2017, Wilkinson 2018).
- HIV. Human AIDS viruses have resulted from at least four cross-species spillovers of simian immunodeficiency viruses involving the Sooty mangabey, chimpanzee, and western gorilla, all of which live in extensive forests. These lentiviruses can penetrate mucous membranes so it is believed contact with ape bodily fluids associated with the hunting, butchering and consumption of animals in trade led to the spillovers. One of these transmission events, likely occurring between 1910 and 1930, gave rise to the HIV strain behind pandemic AIDS (Sharp and Hahn, 2011).

b) Global and regional analyses

There are few truly global-scale quantitative analyses of the relationship between emerging infectious disease risk and land-use change, but those large-scale studies that do exist support the conclusion that large-scale disturbance of ecosystems is associated with increased risk of spillover events.

- During 1940-2004 34% of emerging zoonoses were believed to be associated primarily with either land-use change or activities relating to bushmeat (Loh et al 2015, UNEP 2016).
- Mapping outbreaks globally suggests that land-use change in tropical forest regions is one of the key risk factors associated with disease spillovers from wildlife into humans (Allen et al 2017).
- Two regional multi-pathogen studies present strongly suggestive evidence that biodiversity decline and loss of ecosystem integrity play a role in driving zoonotic outbreaks, for the Asia-Pacific (Morand et al 2014) and for Australia (McFarlane et al 2013).
- The number of zoonotic diseases found in different wildlife species varies depending on a number of factors, including some which relate to threats to the ecosystems that they occupy. For example, more zoonotic diseases are found in threatened species facing declines in their habitat, or high pressure from exploitation, compared to those threatened for other reasons (Johnson et al 2020).

Following biodiversity loss, abundant species with no extinction risk and increasing populations (e.g. adaptable or 'weedy' species that thrive in heavily modified landscapes) are also significant carriers of zoonoses, indicating that degradation of intact ecosystems is not the only pathway to increasing the risk of wildlife-human transmission (Johnson et al 2020, Keesing 2010, Salkeld et al 2013).

c) Theoretical modelling

Several recent modelling studies provide theoretical support to the plausibility of increased spillover risk being linked to ecosystem degradation (e.g. Myers et al 2013, Gortazar et al 2014, Faust et al 2018, Wilkinson et al 2018, Borremans et al 2019).

d) Mechanisms

Across these various lines of evidence, several multiple interacting pathways are known or suspected to lead to increased risk of disease transmission. These include:

- Increased contact between humans, livestock and pathogens along newly created edges
 - These edges represent areas where newly arrived human and livestock populations without immunity mix with unfamiliar pathogens, with contacts sometimes further increased by the movement of host species in response to the disrupted ecology of their habitat (Bloomfield et al 2020, Brownstein et al 2005, Johnson et al 2020, da Silva-Nunes et al 2008). Fragmentation has placed over 70% of the world's forests within 1 km of an edge (Haddad et al 2015) and is worsening across the tropics (Taubert et al 2018).
- Increased contact with humans along wildlife trade chains.
 - Much wildlife trade originates from recently opened frontier areas where populations have not yet been significantly depleted by over-harvest. There is abundant evidence that large trade volumes, mixing of diverse species, and poor hygiene practices expose people all along these trade chains to increased risk of infection (Bloomfield et al 2020, Greatorex et al 2016, Pruvot et al 2019).
- Changes to pathogen abundance due to changes in host abundance, diversity and susceptibility.
 - Degradation can cause increases in the local populations of host or vector species, raising the chance of transmission. Habitat damage can also place individuals under increased stress, making them more susceptible to infections (Levi et al 2012, Civitello et al 2015, Rulli et al. 2017, Olson et al 2010, Vittor et al 2006, 2009).
- Rapid evolution/mutation of pathogens due to novel conditions and novel hosts is also suspected to be a contributory factor (Zohdy et al 2019).

It is also possible that changes in the biodiversity within ecosystems (eg extinctions of some species) can alter the likelihood of diseases being transmitted among the remaining species ('dilution' and 'amplification' effects), although there is insufficient evidence to confirm how common these alternative patterns are (Keesing et al 2009, Randolph & Dobson 2012). It is well known for Lyme disease (see above) but has been looked for in other disease systems (Hanta virus and West Nile virus) with mixed results (Suzan et al 2009; Luis et al 2018; Tran et al 2017; Koenig et al 2010)

Point 4. Degradation of ecosystems also has complex effects, often negative, on many other aspects of human health

Vector-borne and parasitic disease

There are several studies of the prevalence of vector-borne disease in relation to ecosystem change. Some show increases, others do not:

- **Malaria**
 - **The Amazon.** Deforestation has altered mosquito ecology, resulting in more larval breeding habitat and higher human biting rates of *Anopheles darlingi*, which is a highly competent vector for the more deadly falciparum malaria. This phenomenon is ephemeral and occurs at the frontier of deforestation events where new human migrants are also arriving. In one community, after adjusting for access to care, health district size, and spatial trends, a 4.3% increase in deforestation was associated with a 48% increase of malaria incidence (Olson et al 2010, Vittor et al 2009, 2006)
 - **Malaysia.** In Malaysian Borneo the main vector is *Anopheles leucosphyrus* and the malaria parasite is *Plasmodium knowlesi*, which primarily infects macaques. Since 2004 it appears deforestation has altered the dynamics of the entire system, impacting vector habitats as well as abundance and distribution of macaques and humans. Cleared land within 1 km and deforestation within 4-5 km of households influenced vector abundance and high historical forest loss is correlated with higher incidence of infections (Fornace et al 2016; Brock et al 2019).
 - **Africa.** Although data were too limited to take a longitudinal approach, the latest data-rich assessment at multiple scales and using a pre-registered hypothesis testing approach (which makes it less subject to selective interpretation) shows no relationship between deforestation and malaria in Africa. Differences between Africa and the Amazon are attributed to the fact that forest-human associations in Africa are long-standing, and do not involve migration to a deforestation frontier (Bauhoff & Busch 2020). There are a few local ecological studies from Kenya that suggest deforestation increases vectorial capacity of *Anopheles gambiae* through changes in microclimates that influence sporogonic development and mosquito reproductive fitness (Afrane et al 2006, 2008).
- **Lyme disease.** In this system, home of the ‘dilution effect’, one reservoir host, the white-footed mouse, is more competent at transmitting the bacteria that causes Lyme disease to biting *Ixodes* ticks than other small-mammal hosts (which therefore provide a dampening or ‘dilution’ effect). The larval and nymphal ticks feed non-selectively so changes in host composition end up impacting human disease risk. In the presence of fragmentation, the white-footed mice are more abundant for the larval and nymphal ticks to feed on (and white-tailed deer are also more abundant for the adult ticks to feed on). Hence when biodiversity is lost, resilient species like the mouse are more prevalent and more ticks wind up taking more blood meals from the mice and subsequently have higher prevalence of the bacteria that causes Lyme disease (Keesing et al 2009, Turney et al 2014).
- **Schistosomiasis.** Dam construction led to local extirpation of native prawns. Restoration of these prawns, which are ‘voracious predators of the snail intermediate hosts for schistosomiasis’, reduced snail host abundance and as a result, human schistosomiasis prevalence (Sokolow et al 2017; Sokolow et al 2015).

Water-borne disease

There are examples of water-borne bacterial disease increases associated with ecosystem degradation:

- **Diarrheal disease in children.** There is a significant association between tree cover in upstream watersheds and probability of diarrheal disease among rural children under age 5, as measured from a dataset from 35 developing countries. The effect of a 30%

increase in upstream tree cover is similar to the effect of improved sanitation (Herrera et al 2017).

- **Typhoid occurrence.** Fragmentation of riparian forests and density of roads crossing creeks within a watershed is significantly related to incidence of typhoid in Fiji (Jenkins et al 2016).

Other established connections between environmental degradation and human health effects include air quality, nutrition, pharmaceuticals and biomedical discoveries, mental health, access to traditional medicines, endemic zoonotic diseases, and indirect effects on human health through the impacts of climate change. More detailed coverage of these topics can be found in the broad reviews by ILRI (2012), Romanelli et al (2015), Rohr (2019), Kilpatrick (2017), and Whitmee et al (2015).



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SOLUTIONS AND RESPONSES

As described above, there are multiple clear lines of evidence pointing towards the conclusion that declines in the integrity of ecosystems increase the global risk of zoonotic disease spillovers, and hence pandemics such as the current COVID-19 pandemic. Enough is already known to identify the broad steps needed to ensure that our interactions with nature occur in a way that lowers pandemic risk. Nonetheless, it should be acknowledged that the science is not complete and there are important questions to answer before we know everything that we would ideally wish to know around the linkages between the integrity of ecosystems and emerging zoonotic diseases.

The One Health framework, adopted and championed by WHO, FAO, OIE, the Centers for Disease Control, the World Bank and many other organizations and institutions, is a widely applied approach to address zoonotic challenges (Waltner-Toews 2017). The core One Health principle is that ‘communicable and non-communicable diseases demand a truly comprehensive understanding of health and disease, and thereby a unity of approach that is achievable only through convergence of human, domestic animal, wildlife, plant, and

environmental health, on a planetary scale'. One Health should be used as an umbrella framework to find convergence among ecological and human health challenges. The Berlin Principles state, 'going forward...we must overcome sectoral and disciplinary silos; apply adaptive, forward reasoning, and implement multidisciplinary and multilateral solutions, while boldly integrating current uncertainties to address the opportunities and challenges ahead'.

Ecological changes are an important factor in driving disease outbreaks and as such need increased levels of attention at international, national and local levels. One Health approaches relating to the integrity of ecosystems must be placed in the context of how much land degradation has already occurred in an area, and the 'three conditions' described by Locke et al (2019) are one useful way to frame these solutions. This framing recognises that there have been diverse human influences on the Earth's surface and it is possible, at least broadly, to define landscapes by integrating nature-centric (what remains of nature) and human-centric (human land-use) assessments of drivers and pressures on biodiversity. Three broad conditions emerge:

- large, intact, mostly natural areas areas;
- 'shared', partially natural landscapes;
- farms and cities with very limited natural space remaining

According to each condition, broad suites of responses can be proposed to improve the state of ecosystem integrity, to secure nature's contributions to people, and minimise the risk of future pandemics. These responses are outlined below. To be achieved, they need to be placed in the appropriate policy, regulatory and legal frameworks, supported by finance, engage the full range of stakeholders in effective ways and be supported by additional science. It is beyond the scope of this paper to discuss these critical aspects of implementation in detail.

In large wild landscapes we need to retain ecosystem integrity to the greatest extent possible as by doing this we will minimize the various pathways that increase the risk of pandemics and other spillover events.

- Maintaining ecosystem integrity means not modifying ecosystems beyond their natural range of variation, which in practice means avoiding the expansion of large scale extractive uses (industrial logging, large-scale harvest of animal and plant products), not fragmenting areas with infrastructure, pastures and farmland, and not disrupting natural fire and flood regimes.
- Since many of these areas are inhabited by, and protected by, Indigenous Peoples and local communities, we must strengthen health care infrastructure to meet the needs of these populations, and enhance emerging infectious disease surveillance in collaboration with them (Munster et al 2018) as well as better understanding the patterns of exposure and immunity that they experience.

In shared landscapes we need to manage significant ongoing levels of contact between humans, wildlife and livestock, and be aware of factors (eg changing farm practices) that may increase these levels. In this context we should consider nature-based or 'One Health' solutions that support both human health and the restoration of ecosystem integrity to the fullest extent possible.⁴ Solutions that benefit both human health and environmental targets have the advantage of contributing to multiple Sustainable Development Goals. Broad recommendations for shared landscapes are:

⁴ see e.g. the [Berlin Principles](#) and IUCN's new [standards](#) for Nature-based Solutions

- Infectious disease interfaces and pathways that have been created must either be removed or mitigated.
 - Forest edges are an example of an interface that can be reduced in extent in some settings, e.g. through restoration that reduces fragmentation.
 - In other settings forest edge contact zones may be a part of the landscape that cannot be reduced, in which case the focus should be on mitigating the risks they present.⁵
 - The commercial wildlife trade is an example of a high-risk interface that can be removed in many cases, and whose risks should be mitigated in the remaining cases.
 - Where restoration is not attainable, management decisions should nonetheless avoid any further degradation of ecological systems

In the ‘third condition’ of the Locke et al (2019) framework - highly human-dominated, farmed and urban areas - the likelihood of zoonotic outbreaks spreading from any remaining wildlife populations is low, although it still exists (e.g. rabies from bats or skunks, or West Nile virus from birds via mosquito vectors). However, such areas are still risky areas for disease outbreaks from wildlife due to connections between remote source areas and urban centres of demand for the wildlife trade, particularly as regards consumption for food.

- In these areas, commercial wildlife trade should be halted and other forms of domestic animal trade should be improved to ensure excellent hygiene standards. Public health, biosecurity and disease surveillance and response systems tend to be more robust for known pathogens in these places, but defences are less robust for the new, emerging pathogens that also occur in commercial wildlife markets.



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⁵ For example, an intervention used after the discovery of Marburg, and Bombali and Zaire Ebolaviruses in West Africa was as simple as information and resources on how to exclude insectivorous bats from homes and cover food sources <https://www.ecohealthalliance.org/living-safely-with-bats>. In the case of Nipah virus in Bangladesh, a simple tree skirt can prevent bats from urinating in vessels that are used to collect tree sap (Khan et al 2012).

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