WWF-US
STRATEGIC
FRAMEWORK

STOP SPILLOVER AT THE SOURCE

Evidence-based Strategies for the Pandemic Era

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Authors
Annika Terrana, Rebecca Shaw

Systems Map Consultation & Design
Ryan Murphy, fulcra.design

Editors
Kimberley Marchant, Sheila McMillen

Design
Weirdesign

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Purpose
This overarching strategic framework defines the role conservation plays in reducing the risk of spillover now and in the future. This strategic framework is based on systems analysis, designed in consultation with WWF-US and WWF Network staff as well as external experts, and identifies the highest potential interventions to deliver on the aspirational vision for stopping spillover at the source.

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Contents

Summary

The devastating human and economic losses resulting from the COVID-19 pandemic have changed the lives of people throughout the world.

In building back better, we reimagine a new world in which we collaborate creatively with current and new partners and consider carefully the interacting drivers of emerging infectious diseases.

This overarching strategy frames a way forward for WWF and partners, prioritizing interventions that deliver the greatest potential leverage in the zoonoses system to prevent future pandemics by stopping spillover at its source. This framework is based on a systems analysis of zoonoses, engagement with experts, and draws on the WWF internal science brief, Beyond Boundaries. Systems analytics allow us to deeply understand the underlying, nonlinear dynamics that give rise to the spillovers of animal disease into human populations. We describe those dynamic feedback loops (Solution section and Figure 1) and identify the relevance of conservation in disrupting the primary drivers (Solution and Theory of Change sections), and we lay out a portfolio of interventions for conservation (Theory of Action subsections). The interventions are those with the highest potential to deliver on our aspirational vision for a better, more equitable world.

This systems analysis confirms that to decrease the likelihood of novel zoonotic disease outbreaks we need to prevent the pre-conditions enabling animal disease to spillover into human populations.

- Stop deforestation and the incursion into tropical forests that contribute to local disturbance of habitat, affect wildlife health, and increase wildlife-human and wildlife-domestic animal interaction, such as land clearing for commodity crops, animal agriculture, and linear infrastructure.
- Eliminate the luxury demand for live wildlife through targeted behavior change efforts.
- Promote changes toward more sustainable and efficient food systems accompanied by shifts to healthier diets.
- Support credible governance systems that earn trust in institutions and effectively regulate the harvest, transport, and sale of both live wild and domestic animals.
- Predict and mitigate zoonotic disease emergence through the combined surveillance of health, infrastructure, and environmental loss in a One Health Approach to prevention and preparedness.

WWF-US uses the Beyond Boundaries internal science brief and the actions named in this strategy to prioritize our interventions and work with partners globally and in-region. We are also nimble—adapting to emerging information, assessing dynamic opportunities for interventions and partnerships, and adjusting strategies. Our eye remains on the aspiring vision for a whole-planet shift to humans and nature living in harmony, through place-based solutions supported by systems acupuncture on global levers.

Compelling Context

The world has changed.

Originally intended to be a "super year" for nature, 2020 instead devolved into a confluence of an all-consuming pandemic, a series of climate catastrophes, ecological collapse in the form of runaway wildfires, disrupted value chains, volatile financial markets, free-falling economies, civil uprising, and the rise of autocratic authority across the globe. In place of a triumphant rallying cry for action on climate change mitigation and the reverse of biodiversity loss, the super year for nature served as a lesson in what happens when we neglect nature, ignore the environmental risks of unsustainable business practices, and tolerate inadequate governance policies—ultimately, we sacrifice our health and well-being.

Infectious diseases are on the rise.

Infectious diseases are the leading cause of death in low-income countries and in children under the age of five globally. Endemic infectious diseases—or those diseases that are persistent within a region year after year—account for the majority of this burden, while emerging infectious diseases (EIDs)—or diseases novel to humans within a region or globally—are on the rise, with the majority zoonotic in origin. Endemic disease burden exacerbates mortality rates from EIDs, and vector-borne endemic zoonoses are on the rise in the same places where pandemic-prone zoonoses are at greatest risk of emergence, largely from the same underlying drivers. The World Health Organization (WHO) estimates there are roughly 40 infectious diseases present now that were not present one generation ago (e.g., SARS, avian influenza, Ebola, Nipah, MERS) with more predicted to be on the way. Further, we have no way of predicting future spillover events or whether pathogens in circulation in wildlife have the potential to produce a pandemic upon spillover. The unfettered growth of inexpensive domestic and international travel delivers a high degree of connectivity that ensures that once a spillover occurs, its rapid spread is imminent making the ensuing disease extremely difficult to control—a reality reinforced by COVID-19. The current pandemic is negatively affecting global economic growth beyond anything experienced in nearly a century, at a magnitude yet untold.

Risks of zoonotic disease emergence and spread can be mitigated, slowed, and stopped.

The science behind zoonoses is complex but preventative solutions are consistent, with benefits that cascade. The global population grows larger and wealthier as our economies become more connected through global trade and travel, facilitated by the expansion of linear infrastructure worldwide. By 2050, livestock production is expected to double—growing faster than any other agricultural subsector—increasing the amount of land required to grow the commodity crops that feed livestock. Today, when land used for grazing and feed crops is combined, existing livestock production accounts for around 70% of agricultural land, about five times more land than needed to produce the nutritional value of its plant-based equivalents (Steinfeld et al. 2006; UNEP 2009). Yet not all sources of nutrition are of equal quality or equally accessible, and people who are malnourished are more susceptible to the impacts of disease. Increasing consumption of commodity crops and livestock is driving tropical deforestation and allowing encroachment into highly biodiverse, intact landscapes and increasing access to wildlife. As wildlife are hunted and trapped, housed, and transported with domestic livestock in close proximity to people, zoonotic pathogens have greater opportunity to jump between animal species and to humans through the exchange of respiratory droplets or bodily fluids. This sustained, close proximity increases the probability of a spillover. As live wild animals are transported regionally and globally, they become increasingly stressed and shed viruses as they interact with immunologically naive populations of people—populations of people whose immune systems have not yet been exposed to such pathogens—in densely-populated urban markets. This spiral of connectedness requires that we take a systems approach to identifying the points of intervention that have the highest likelihood of significantly decreasing the probability of a future spillover while supporting equitable access to culturally meaningful and quality nutrition.

The root cause of outbreaks and predeterminants of spillover remain unaddressed in public health agendas.

The global health community has focused on infectious disease through conventional public health interventions of diagnosis, treatment and containment of disease to limit its spread. Early detection systems focus on monitoring human populations for novel viruses, but such programs can only mitigate the spread of viruses that have already spilled over from wildlife, not reduce the probability of a spillover in the first place. In recent years, the health sector received over twelve times the amount of private philanthropic investment than the environment sector, yet it is increasingly clear that how we manage and interact with land and wildlife is a primary driver of health risks including the risk for spillover of diseases that have the potential to become pandemic. Thus, investments in issues typically viewed as conservation (e.g., combating deforestation and illegal wildlife trade) would yield significant health benefits and a significant return on investment, particularly if these investments were planned in what has been recognized as a One Health framework.

Renewed interest for One Health opens the doors to new and bold commitments.

Studies reflect three barriers to effective integration of ecological and health solutions: insufficient evidence base, weak integration of research into practice, and well-recognized lack of collaboration between disciplines. Until now, One Health practitioners unfamiliar with conservation approaches have overlooked or dismissed the opportunity for achieving health outcomes through the prevention of spillover. As a number of governments, businesses, and multilateral institutions have called for a renewed commitment to a One Health paradigm that fully integrates management of land and wildlife into public health programs, we have a discrete opportunity to align conservation strategies with public health outcomes where appropriate. If designed in a One Health framework, such interventions will reap benefits for both human health and nature.

We are at an inflection point for change and now is the time to influence a sustainable global recovery.

Cultural norms can be slow to shift except in times of sudden shock, should we choose—if we choose—to innovate and co-evolve beyond the status quo (Kolodny et al. 2016). Global events such as wars, disasters, and pandemics have the potential to unite at a scale needed to galvanize meaningful change. Punctuated Equilibrium Theory holds that when conditions are right, policy change can happen in sudden leaps forward that significantly alter the status quo, rather than the typical small incremental changes (Baumgartner 1993). Those conditions—including intense media, public interest, and new approaches offered to policymakers—make this moment ripe for change. As the world is hit by a multi-trillion dollar invoice from the impacts of COVID-19 (Park et al. 2020), recovery presents an unprecedented invitation to change how we eat, live, grow, and engage one another, and thus reduce the probability of spillover at its very source.

Aspirational Vision

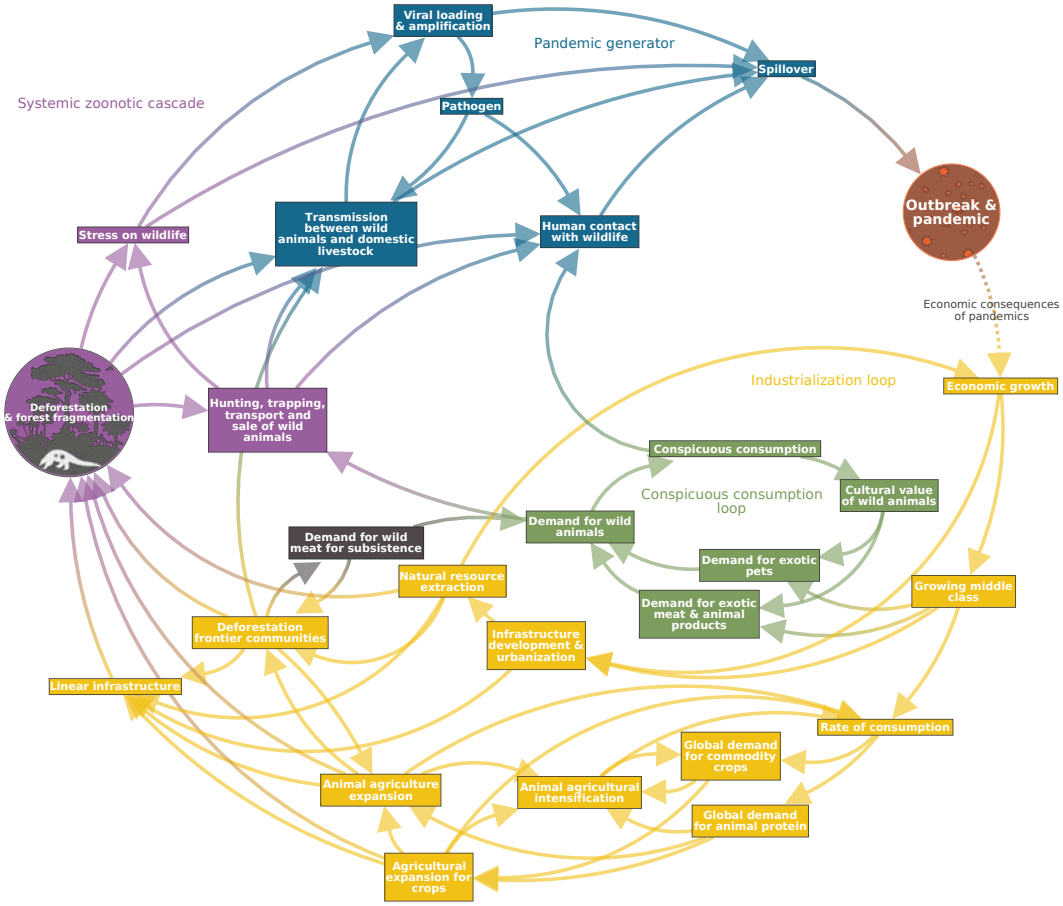
Rebalancing our relationship with nature sits at the heart of a sustainable global recovery from the impacts of COVID-19. To do so, there will need to be a broad-based understanding that human health is an essential benefit of sustaining the health of nature. Fully embracing this understanding will transform our relationship with nature from one of triggering cascading harms to generating cascading benefits for current and future generations.

Solution

A Systems Approach for Impact

A complex system is a system with behavior that can be extremely difficult to predict. Complex systems are dynamic, behave in nonlinear ways, and are made up of components that respond and adapt to each other. As with many of today's wicked problems, understanding the system dynamics that give rise to spillover is a necessary precursor to identifying and augmenting interventions that can reduce the risk of spillover over the long term. This type of analysis is an intentional departure from traditional conservation planning that uses linear causal diagrams to identify points of intervention. In this case, we are probing the dynamic zoonoses system to identify leverage points with the highest potential for reducing the risk of spillover over the long term, not simply naming static land use change and wildlife exploitation factors relevant to pandemic risk. We assembled internal and external experts across many disciplines to elucidate the well-known and hidden dynamics that lead to spillover, across the globe and region by region. The resulting systems map helped us define a set of interventions to reduce the risk of spillover, which changes the strongest feedback dynamics of the system. During implementation, the systems map continues to support discussion of the interventions, their dynamics, and the potential trade-offs.

Figure 1. Zoonoses Systems Diagram with Four Prominent Feedback Loops



Systems Map Consultation & Design: Ryan Murphy, fulcra.design

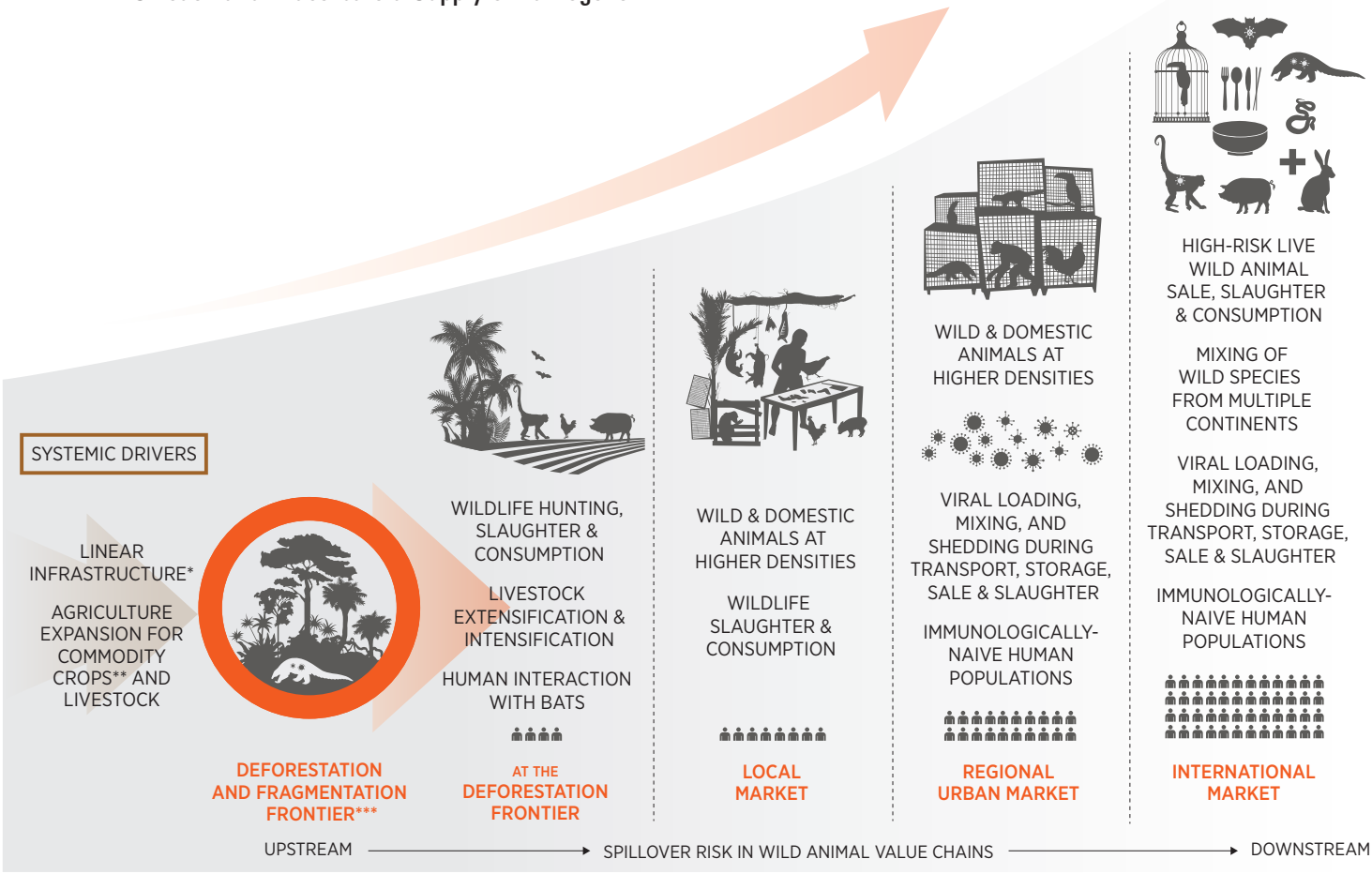
At the center in green, is the **Conspicuous Consumption Loop** which addresses the demand dynamics for live wild animals for pets, medicine, and exotic meat consumption. The **Industrialization Loop** in gold represents the increasing demand for live wild animals, livestock and commodity consumption from nations of high and growing overall wealth. As industrialization grows, so does commodity demand. The **Systemic Zoonotic Cascade Loop** in purple reveals how the wild animal value chain amplifies the risk of spillover as live wild animals are impacted by habitat loss, harvested, caged, transported, sold, and consumed—often alongside domestic livestock—increasing pathogen transmission among animals, wild animal shedding of pathogens and viral mutations creating novel combinations of pathogens. It is this dynamic that increases the probability of spillover and, when the conditions are right, the rapid spread of a new infectious disease in human populations as depicted in the **Pandemic Generator Loop** in blue.

In the systems map, **demand** for live wild animals is driven by cultural preferences for exotic pets, meat, medicine, and other uses. This demand can be amplified by social media and/or high or increasing **industrialization** within sub-populations. As the land use changes to accommodate food production to feed a growing global population and infrastructure development encroaches on intact tropical forests, more wild animals and the pathogens they host are disrupted and then exposed to human and domestic animal populations. When domestic animal production intensifies along the deforestation frontier, there is increased opportunity for the transmission of wild animal pathogens to domestic animals. As live wild animals are transported from the deforestation frontier to go to local or regional markets for sale, they often do so alongside domestic livestock, which facilitates more opportunity for interspecies transfer of pathogens. This is an increasingly stressful environment for all animals. When animals are stressed, they more readily shed their pathogens, again increasing the likelihood of transmission. The longer the animals remain confined together during transport and sale, the more time pathogens have to develop a mutation that would allow for a spillover event—as humans are ever present in these value chains. This is the **systemic cascade** that facilitates the improbable and increasingly common **spillover event**. Unless these relationships are disrupted, the economic recessions that result from a pandemic can accelerate new pressures to industrialize as a means to recreate wealth, thus repeating the cycle.

Conceptual Framework: The Wildlife Value Chain

The wildlife value chain is a framework for understanding the demand, supply, and the natural state of live wildlife. The wildlife value chain describes new and intensifying wildlife-livestock-human interactions that provide ample opportunity for transmission of pathogens and spillover. This value chain—a system of organizations, people, activities, information, and resources involved in supplying a product or service to a consumer—portrays what are illegal live wildlife "products" entwined with legal domestic livestock, together with human producers and consumers. Domestic livestock are often raised, captured, caged, transported, sold, slaughtered, and/or consumed alongside live wildlife, creating novel mixes of animals and their pathogens. Under certain socio-economic conditions, these human-animal interactions increase the risk for transmission of pathogens and the emergence of new zoonotic diseases, such as COVID-19. With these value chains spanning regions and continents, the amplified risk of animal disease spillover to humans has the potential for devastating impacts on global public health and economies.

Figure 2. Systemic Drivers of Tropical Deforestation and Forest Fragmentation Unleash and Exacerbate a Supply of Pathogens



*Includes infrastructure for mining, energy, logging, transporation, communication
**IIncludes primarily oil palm, rubber, pulpwood, soybeans, corn, and other feedstock crops
***See Figure 3 for illustrative detail of spillover risk along the wild animal value chain

Spillover risk begins at the tropical deforestation and forest fragmentation frontier (see Figure 2). In tropical forests, mammal diversity is very high and, therefore, pathogen diversity is also very high, particularly virus diversity. Global demand for natural resources and agricultural products, particularly livestock, are the largest systemic drivers of deforestation. Linear infrastructure, land use change to accommodate commodity crop and animal agriculture expansion, and natural resource extraction directly result in tropical deforestation and fragmentation worldwide. This encroachment can change individual wildlife health while favoring species more likely to circulate pathogens, and increase wildlife-livestock-human interactions at the frontier as wild animals are more accessible to be hunted, trapped, and transported for human use. Humans store, transport, and sell wild animals alongside domestic animals creating many opportunities for pathogen transmission, viral mutation, and spillover. In some regions, downstream demand for live wild animals leads to near-complete defaunation of the forest.

Using a **value chain framework**, we assessed the changing dynamics of the drivers of deforestation that might affect pathogen behavior among wildlife and open opportunities for human access to wildlife, transmission of pathogens and, ultimately, spillover at each node in the legal/illegal wildlife trade value chain. Using regionally specific information, we then identified the nodes along the value chain that exhibit the greatest risk and why. We explored those risky nodes in the context of the systems analysis to identify interventions that would have the highest chance of decreasing the risk of spillover over time. We then assessed the potential for unintended disruptions of those interventions in the context of the socio-economic system that might need to be mitigated. With a better understanding of the social, ecological, economic, and institutional conditions that increase the risk of spillover along each stage in the live wild animal value chain, including the enabling stage of deforestation at the value chain source, we created a theory of action that has the greatest leverage and likelihood of long-term success.

To explore the possible points of intervention, now and in the future, we developed a stylized value chain with general features (Figure 3). Not all features in this generalized value chain are present in every region. Although most disease surveillance and public health risk mitigating activities are implemented midstream and downstream in the value chain at the markets, it is there that a spillover can result in a catastrophic outcome—a pandemic. It is in these markets where wildlife-livestock-human interactions are intensified through close proximity, where pathogen transmission is unfettered and where animals of all kinds are most stressed and shedding pathogens. Upstream, identifying ways to restore or maintain ecological equilibrium, including equilibrium in pathogen behaviors, while keeping habitat intact and wildlife and livestock healthy entails a broader suite of interventions that target the drivers of encroachment into forest habitat while delivering a safe source of protein. Our strategy must balance risk, leverage, and influence according to each place-based context and seek targeted interventions that deliver the most significant impacts, opportunities for powerful partnership, and co-benefits to people.

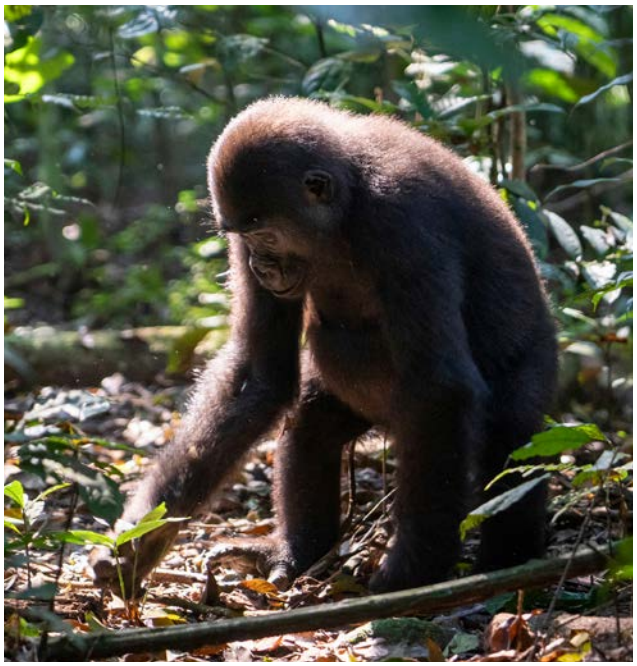
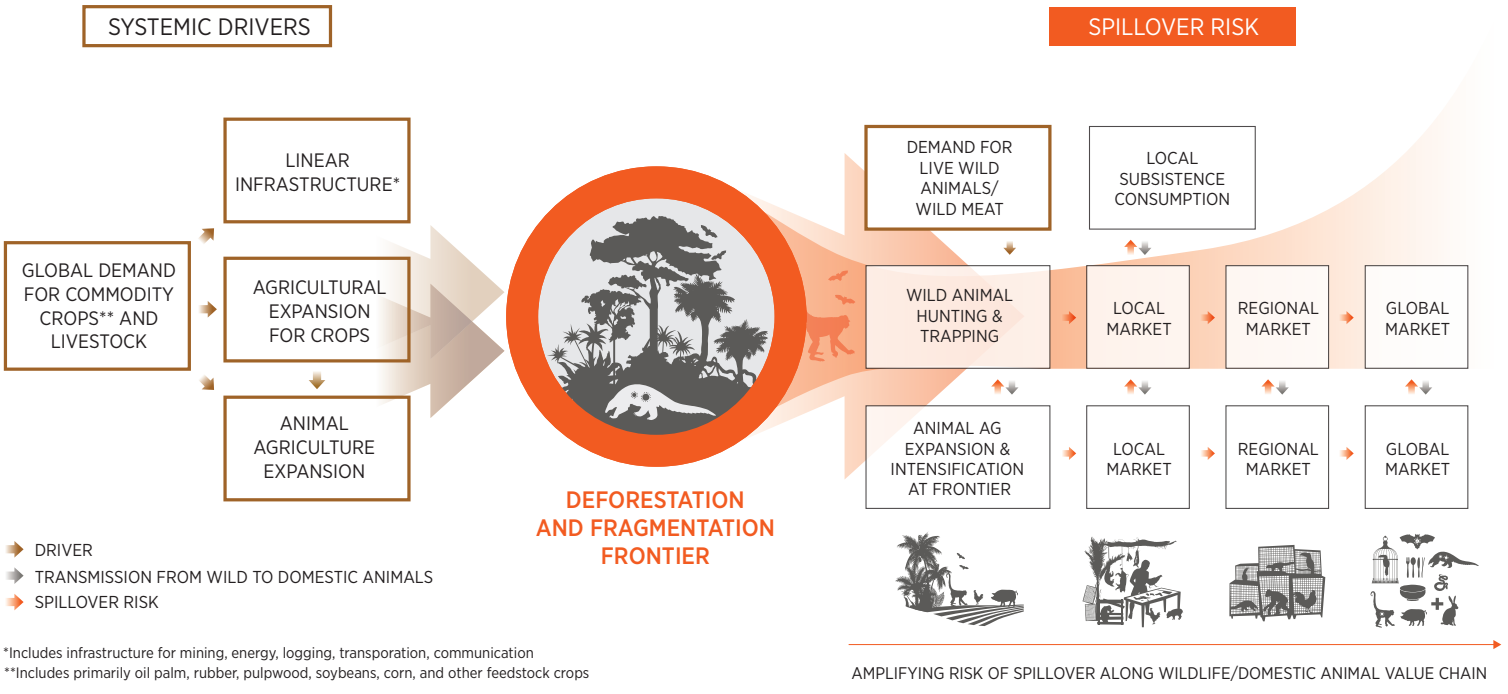


Figure 3. Amplifying Risk in the Wildlife Value Chain

The generalized wildlife value chain starts at the deforestation and forest fragmentation frontier. The drivers of deforestation and forest fragmentation vary by region though include linear infrastructure development for mining, logging, and energy development and the natural resource extraction that ensues; land use change for crop and animal agriculture; and growing demand for livestock products globally that drives both land use change for crop and animal agriculture. With human access to forest resources, wild animals can be hunted, trapped, and transported to local, regional, and/or international markets. At each stage in the value chain, viruses are shared through respiratory droplets, feces, or other bodily fluids among humans, live, or recently-slaughtered wild animals and, in many cases, live or recently slaughtered domestic livestock. As viruses move between species, they are constantly reproducing and mutating. If a mutation takes place that allows a virus to infect a human, spillover occurs.



*Includes infrastructure for mining, energy, logging, transporation, communication
**Includes primarily oil palm, rubber, pulpwood, soybeans, corn, and other feedstock crops

Conservation's existing interventions and their relevance to a wildlife value chain framework

Both wild and domestic live animals can be sources of zoonotic infectious diseases—often, it's both. The fast-paced and intensifying changes in human interactions with live wild and domestic animals across rural and urban landscapes are increasing the risk of spillover (Hassel et al. 2017). These interactions give rise to cross-species transmission and emergence of new pathogens. Identifying and understanding the form of these new and changing interactions is necessary to identify effective interventions that can mitigate the risk of disease emergence.

Without a doubt, the most conspicuous of these interactions for the conservation community are those that take place farthest upstream in the live wild animal value chain at the tropical deforestation frontier. Deforestation remains one of the most conclusive, though indirect, drivers of the emergence of disease through the way it can increase the hazard of pathogen concentration in remaining animal populations or the ecological release of more generalist species which tend to tolerate human activities and who carry more biologically similar virus species (Johnson et al. 2020). Linear infrastructure development, the expansion of extractive activities (e.g., logging, hunting, mining), and land use change to accommodate the expansion of crop and animal agriculture are all primary drivers of tropical deforestation and forest fragmentation. These activities and the rate at which intensification of animal agriculture are destroying tropical forest habitat are creating novel human-wildlife-livestock interactions at a mind-numbing pace. Indeed, recent research shows that the species mix typically found in anthropogenically dominated landscapes harbors more viruses that have the potential to cause emerging infectious diseases than do those in intact landscapes (Gibb et al. 2020). The conservation community has long worked at this interface with modest success, and these existing interventions can be augmented, supplemented, and scaled to help achieve the goal of reducing the risk of spillover. While sometimes recognized in general narrative, targeting spillover risk at this interface remains conspicuously absent in One Health approaches. An essential One Health strategic intervention is to stem deforestation through thoughtful planning, resulting in cost-effective benefits for people that abound.

Likewise, the conservation community works far downstream in the wild animal value chain at reducing demand for wildlife products using targeted consumer-facing behavior change campaigns (e.g., the campaign to reduce demand for ivory products in growing middle class cities in China). Lessons learned from this type of effort—from behavioral science to consumer research—can be readily deployed in reducing demand for live wild animals for pets, food, or medicine. Paired with policy and enforcement, coordinated interventions such as this could greatly reduce the risk of spillover inherent to wildlife consumption.

In aggregate, however, our current complement of interventions are insufficient to deliver the full potential of conservation to reduce the risk of spillover. In order to significantly reduce the risk of spillover, future interventions will need to consider the full suite of socio-ecological interactions that increase the frequency, proximity, density, and duration of contact between live wild animals, live domestic animals, and humans in the wild animal value chain (Bell et al. 2004), including:

- the exposure of wildlife species to humans in tropical forests, particularly loggers, hunters, trappers, and gatherers
- the exposure of wildlife species to live domestic animals and humans at the tropical deforestation frontier facilitated by the expansion and intensification of animal agriculture
- the change from subsistence wildlife hunting for local consumption to the sale of live or recently slaughtered wild animals in supply of an expanding domestic and international wildlife trade for food and pets, particularly in Asia and Africa
- the transport and storage of live wild and/or domestic animals at high densities in confined spaces (e.g., cages)
- the farming of wildlife species with or without biosecurity measures
- the sale and slaughter of live wild and/or domestic animals after storage
- the transport to cities, particularly to live animal markets and/or at restaurants

A complete value chain analysis requires we do an assessment of the spillover risk associated with the expanding regional and global live wildlife trade for the purpose of exotic/luxury foods, exotic pets, the expansion of animal agriculture in tropical zones and the concomitant tropical deforestation, fragmentation, and defaunation. This analysis takes into account the range of permutations of the value chain characteristics, organized as a set of "risky" nodes in the chain (see Annex 2 for more detail):

- the risky places (e.g., tropical deforestation frontiers, domestic animal rearing near deforestation fronts)
- local markets, transport vehicles with live animals, warehouses of live animals, ships transporting live animals
- urban markets in and out of the country of origin, restaurants, and homes) that concentrate wildlife, domestic animals, and people in confined space for periods of time
- the risky species and their interactions (e.g., bats, other mammals)
- the risky connections (e.g., local rural households to village, rural to urban, across nations, across continents) that link pathogens to new and immunologically naive hosts
- the risky behaviors which propel that value chain, including the expanding preferences for wild animal protein in urban areas and internationally
- the exotic foods and pets in Southeast Asia, China, North America, and the Middle East.

In addition, we must recognize bottlenecks in the value chain where there is a higher likelihood of return on investment for interventions. For example, there may be points along the value chain where there is a consolidation of wild species in which leverage is possible. These points may be places such as ports, livestock production centers, or demand markets at the wholesale level. There may also be points upstream where keeping forests standing provides multiple co-benefits to public health and wildlife, attracting a wide range of support while preempting the wildlife value chain. Strategic prioritization in these areas provides a high level of sustained impact based on level of investment.

Umbrella Theory of Change

Our Theory of Change is a set of strategic hypotheses that describe how we must transform the current system to a more sustainable future system. The demand, supply, and the infrastructure of the wildlife trade are changing rapidly. We project trends to mitigate future risks—in the drivers of infrastructure development; expansion of extractive activities, such as logging and mining; agriculture demand for domestic livestock, wildlife-derived status symbols, and demand for exotic pets, meat, and medicines, and the enabling conditions, which vary by geography, culture, economics, governance and by value chain node (Figure 1). And because the impact of a spillover is increasingly global and complicated by the impacts of climate change, we marry a global policy framework with ground-up norm setting to ensure that measures to mitigate risk are persistent and effective in the context of global planetary health.

This broad-based strategy covers:

1. Mitigating current risk of spillover;
2. Mitigating emerging risk of spillover; and
3. Global Action Plan for Planetary Health

To mitigate current and emerging risk, interventions are required at multiple nodes in the wildlife value chain, as are enabling policies and conditions that support the implementation of those interventions. Our Theory of Action identifies the interventions needed within each zoonotic regional hotspot along the wildlife value chain. And then we detail international policy opportunities for the necessary enabling conditions across regions that can prevent future spillover.

This Theory of Action prioritizes:

- Protecting & restoring tropical forests and their natural disease control;
- Identifying and intervening at system acupuncture points along that region's wildlife value chain to reduce wildlife use and consumption and to support sustainable food systems; and
- Designing and implementing targeted policies that provide the enabling conditions to support a planetary health approach to human well-being.

Theory of Action

1. Mitigating current risk of spillover

There are key dynamics in today's live wildlife value chains that provide us guidance on where and how best to intervene. We know there are pathogen source hotspots upstream in the wildlife value chain at the frontiers of tropical deforestation and defaunation. But not all deforestation fronts—or places where there is active deforestation—are hotspots for spillover. Intermediate levels of forest loss have been associated with higher probability for some spillover, while more extreme forest loss has been associated with bigger epidemics once a spillover event occurs. Hotspots for spillover at the tropical deforestation frontier are created by the combination of ecological and social factors, including forest fragmentation, high mammalian diversity, nutritional needs of local populations, demand for wild meats and medicines and/or wildlife pets, intensification of animal husbandry, and connectedness to urban trade infrastructure and populations. Defaunation of forests and high volumes of wildlife trade spread risk for spillover throughout trade hubs and markets (see Annex 2).

2. Mitigating emerging risk of spillover

We are in the middle of an era of accelerating zoonotic disease emergence that has the potential to continually undermine global public health. As both the legal and illegal global supply chains for live wild animals, including wild pets, become increasingly intercontinental, we are continuing to increase the diversity of wildlife-livestock-human interfaces from which spillover can occur and risking the probability of novel zoonotic disease mutation and emergence. To address emerging risk, we project trends that are changing risk at each stage in the value chain for live wild animals. The risk upstream in the value chain will change with climate migrations, changing rates of tropical deforestation and forest fragmentation due to shifting local livelihoods, crop and animal agriculture expansion, land use policies, and infrastructure development. The risk will change in response to shifts in production practices, investment decisions, and market preferences, as the demand for live wild animals increases both regionally and globally. As more wildlife are transported transcontinentally and the animals spend increasing amounts of time in tight enclosures along the value chain, the likelihood of pathogenic mutations, viral loads and viral shedding in response to stress increases.

Future work should account for trends in the drivers and enabling conditions for zoonotic spillover, project the increasing risk associated with these trends, and develop strategic, multi-disciplinary interventions to reduce risk.

3. Global Action Plan for Planetary Health

No single country is responsible for reducing the risk of zoonotic spillovers. To be successful in protecting the global public from the ravages of emerging zoonotic diseases, we are participating in the future of a One Health agenda, building it into global climate, nature, development, and food agendas, as well as into multilateral policy and financing, national policy, and corporate operations. Fortunately, the international framework for One Health is a collaborative, multisectoral, and transdisciplinary approach that works at local, regional, national, and global levels with the goal of achieving optimal health outcomes, recognizing the interconnection between people, animals, plants, and their shared environment. One Health's practical origins in the veterinary field has contributed to a narrow historical application focused on individual animal health, and this is likely to continue to be the approach's focus unless deliberate changes are made. One Health's collaborative mission, however, invites the nature conservation sector to play an essential role in decreasing the risk of emerging zoonotic diseases and to move toward a true One Health for Planetary Health Agenda.

Theory of Action

1. Mitigating current risk of spillover

Background

Even though international trade in live wild animals moves animals across continents, the viral source of recent spillovers has been within the region of the origin of the spilled over pathogen, including SARS (Asia), MERS (Middle East), Ebola (Africa), and COVID-19 (Asia). For example, the virus that was the precursor to the SARS-COV-2 virus had been circulating in horseshoe bats in Southeast Asia for 40–70 years and likely originated in Myanmar, Laos, or Vietnam (Boni et al. 2020). Because of the length of time the virus was in circulation, scientists hypothesize that there is generalized immunity to the virus in people throughout Southeast Asian countries and southern China (i.e., Kunming). For this reason, it is unclear when the SARS-COV-2 spillover occurred and what steps led to this bat virus initiating a global pandemic. It is clear that the person-to-person transmission began in earnest in Hubei Province, China, where the SARS-COV-2 virus reached a population that was largely immunologically naive. It is also clear that the spillover happened along the intricate live wild animal value chain that operates within the region to supply the growing demand in China for wild meat, live wild pets, and wild animal medicinal products. The growing demand in China that has caused vertebrate populations across Southeast Asia to decline as hunters, trappers, and traders worked to meet the demand for exotic wild pets, products, meats, and medicine, further increasing risk of spillover (Harrison et al. 2016). It follows that interventions to lower the risk of zoonotic spillovers in Asia should first focus on the live wild animal trade throughout the Southeast Asia region. Similarly, live wild animal pathogens of African origin are responsible for spillovers in Africa. No known novel spillovers have occurred in the tropical regions of the Americas for a variety of evolutionary, genomic, historical, demographic, cultural, institutional, and economic reasons, but those conditions are changing (see Emerging Risk section).

As access to tropical forests increases throughout the globe with the development of linear infrastructure for mining, logging, and transportation, land is opened up for agriculture, which creates deforestation and fragmentation frontiers, upsets the balance of biodiversity that can otherwise impede rampant disease, and directly exposes the wildlife within. With this development activity, comes hunting, trapping, transport, and sale of live wild animals. A small proportion of this activity is attributable to subsistence consumption by local communities and Indigenous people. A much larger proportion of the hunting and trapping of live wild animals is for sale to domestic or foreign markets for luxury consumption. Significant volumes of wildlife trafficking pass through Asia. For Southeast Asia and Indonesia, the terminal markets are largely in China, North America, and Europe. For Africa, the terminal markets are largely China, North America, Europe, and within Africa. This connectedness requires that we understand the challenge of eliminating spillover from a systems perspective with regionally specific context, and we design and implement a suite of coordinated interventions with a broad slate of stakeholders to prevent intercontinental spillover events in future—with an initial focus on where the conditions are ripe for spillover now.

Southeast Asia and China Action Plan

Targeted landscapes include Indonesia (30 Hills, Sumatra, Sebangau Katingan, Central Kalimantan Province), Malaysia (Sabah), Myanmar, and Thailand (Tanintharyi Forest).

Regional context: Deforestation in the tropics of Southeast Asia from the legal food and commodity supply chains facilitates the interaction of humans and wildlife species. However, because of the scarcity of large areas of empty land, large-scale economic land concessions for agricultural production are becoming less common. Focusing on avoiding fragmentation in the remaining blocks of primary forest would decrease spillover risk with the co-benefits of mediating additional endemic zoonotic disease risk. In addition, hunters, trappers, and traders work to support the demand for live wildlife in the wealthier urban markets throughout Southeast Asia and China. People living at tropical forest edges more typically consume common, less valuable wild species for subsistence. The result is the systematic defaunation of standing forests. In addition, the intensification of domestic animal agriculture alongside deforestation fronts to meet community nutritional requirements and the regional and the pressures of global demand for livestock and feed crops have created conditions for ongoing risk of spillover.

Augmented interventions at the deforestation frontier to protect & restore tropical forests include

Protect and restore tropical forests under the global 30X30 goal by

- using Earth for Life's project finance for permanence mechanism
- implementing nature-based solutions for climate mitigation and health portfolios, supported by the private sector
- strengthening forest monitoring, law enforcement, and reporting

Implement deforestation-free commodity production by

- engaging large companies with supply chain origins in the tropics to secure deforestation/conversion free (DCF) supply chain commitments and field investments
- establishing public-private partnerships on deforestation policies in high zoonoses-risk jurisdictions to establish jurisdiction-level sustainability goals and joint action plans—addressing health and climate co-benefits that sustain support
- providing supplier incentives to adopt best management practices (BMPs) for palm oil, rubber, and other deforestation-driving commodities at a jurisdictional scale

Decouple local livelihoods from deforestation and forest degradation by

- providing smallholder financing for forest protection, conservation, and restoration
- implementing community enterprise business development
- diversifying nutrition sources for local communities dependent on forests for basic needs
- facilitating culturally appropriate, diversified livelihoods, including community-led wildlife protection efforts community managed reserves, and community managed sustainable harvest programs

Support implementation of sustainable infrastructure to avoid remaining intact forests by

- encouraging zoning policies to protect contiguous forests, while promoting the spatial aggregation of deforested areas
- convening and connecting public health, environment, and infrastructure ministries following the global gold standards
- applying systems-scale analyses to incorporate human health, economy, and the SDGs into infrastructure plans
- incorporating zoonotic disease hotspot predictive models into forest protection and infrastructure planning
- providing predictive analytics on new infrastructure development risks to triggering spillover
- providing integrated training, surveillance, and monitoring systems on links between built environments and zoonoses risk
- partnering to implement cold chain technology to ensure the sanitary transport and sale of domesticated animal products, reducing pressure on wild animals and mixing while facilitating modular cold chain use for future vaccine dissemination

Interventions at the end of the wildlife value chain to reduce wildlife use and consumption and support sustainable food systems include

Reduce demand for wildlife use and consumption by changing social norms around consumption, changing behavior of diehard buyers, and transforming high-risk markets by

- launching a behavior change campaign to deliver sustained demand reduction for high-risk wildlife in the urban areas with riskiest practices for spillover and spread, using social science methods that quantify demand for wildlife and can help identify the appropriate socioeconomic drivers of demand to be targeted
- applying public pressure and policy advocacy efforts to secure meaningful enforcement and closure of high-risk wildlife markets and trade routes in key Asian countries
- establishing a regional collective of ecommerce, social media, and tech companies to detect, remove, and dissuade trade online in high-risk species and products in Asia

Targeted policies and conditions to support a Planetary Health Agenda throughout the value chain include

Policy

- leveraging policy changes to close, restrict, or better regulate wildlife markets in China, Greater Mekong countries, and Malaysia in response to national/local circumstances
- developing regionally specific policies to ban the transport, trade, and sale of high-risk species
- developing regionally specific policies to regulate the production, intensification, transport, sale of livestock in high-risk geographies, and to implement biosecurity policies
- increasing capacity for law enforcement and transport sector company detection at ports, airports, and border crossings for shipments of live high-risk wildlife and meat using technology innovations
- implementing anti-corruption campaigns to strengthen institutional trust and the enforcement of enabling policies

Central Africa Action Plan

Targeted landscapes include the Democratic Republic of Congo, the Central African Republic, Cameroon, and Gabon.

Regional context: Deforestation and forest fragmentation in the tropics of West and Central Africa facilitates the interaction of humans and wildlife species and tends to favor species that are more likely to transmit pathogens to people, such as primates. Small-scale agriculture drives deforestation while commercial agriculture and infrastructure increasingly result in deforestation in the Congo Basin. Fuelwood and charcoal—associated with expanding urban markets—cause degradation, while increasing risk for encounters with wildlife. The intensification of domestic animal farming alongside deforestation to meet local nutritional needs further increases the risk of spillover. Trappers and traders along the forest margins work to support the growing demand for live wildlife and wild meat in the burgeoning regional urban markets in Central and West Africa where Ebola is of high concern. The Ebola virus remains relevant in African animal populations due to (1) its large size that enables it to remain virulent for a week after animal slaughter and (2) sequential outbreaks. In addition, researchers positively associate land tenure security and the recognition of resource rights with a decrease in deforestation.

Augmented interventions at the deforestation frontier to protect and restore tropical forests include

Protect and restore tropical forests under the global 30X30 goal by

- elevating Indigenous peoples and local communities (IPLC) tenure and governance rights
- using Earth for Life's project finance for permanence mechanism
- implementing nature-based solutions for climate mitigation and health portfolios, supported by the private sector
- strengthening forest monitoring, law enforcement, and reporting

Protect threatened wildlife by

- establishing a standby protocol for rapid vaccination dissemination for great apes, ensuring preparedness for Ebola, Anthrax, or other virus outbreaks within endangered great ape populations and, subsequently, the people who encounter them
- incorporating disease monitoring of great apes into protected and conservation area management to inform early warning systems for potential outbreaks

Implement deforestation-free commodity production by

- engaging large companies with supply chain origins in West & Central Africa to secure deforestation/conversion free (DCF) supply chain commitments and field investments
- establishing public-private partnerships in high zoonoses-risk jurisdictions to establish jurisdiction-level sustainability goals and joint action plans—addressing health and climate co-benefits that can sustain support

Support implementation of sustainable infrastructure by

- applying systems-scale analyses incorporating human health, economy, and the SDGs to inform infrastructure plans
- incorporating zoonotic disease hotspot predictive models into forest protection and infrastructure planning
- integrating spillover risk into commercial agriculture and forestry infrastructure planning

Implement community-based natural resource management at deforestation frontiers by

- empowering communities, supporting ground-up visions for economic growth and sustainable development, and appropriately valuing natural resources
- facilitating training and other support for sustainable commodity production

Interventions at the end of the wildlife value chain to reduce wildlife use and consumption and support sustainable food systems by

- leveraging the influence of the private sector to elevate the connection between forest health, wildlife health, and human health in high risk regions
- implementing behavior change strategies to reduce demand for high-risk wildlife trade and consumption in urban areas in Coastal East Africa, Europe, North America, Southeast Asia and China
- implementing a ban on the transport, trade, and sale of higher risk wildlife meat in regional urban markets
- developing improved access to diversified sources of protein
- regulating the slaughter and sale of live domesticated animals in regional urban markets
- partnering to implement cold chain technology to ensure the sanitary transport and sale of domesticated animal products, reducing pressure on wild animals and mixing while facilitating modular cold chain use for future vaccine dissemination

Targeted policies and conditions to support a Planetary Health Agenda throughout the value chain by

Policy

- promoting biosecurity regulation markets that sell wildlife and domestic animals in Central Africa
- capacitating law enforcement and transport sector detection, including technology innovations, at ports, airports, and border crossings for high-risk shipments of live wildlife and meat.
- implementing anti-corruption campaigns to strengthen institutional trust and the enforcement of enabling policies

2. Mitigating Emerging Risk of Spillover

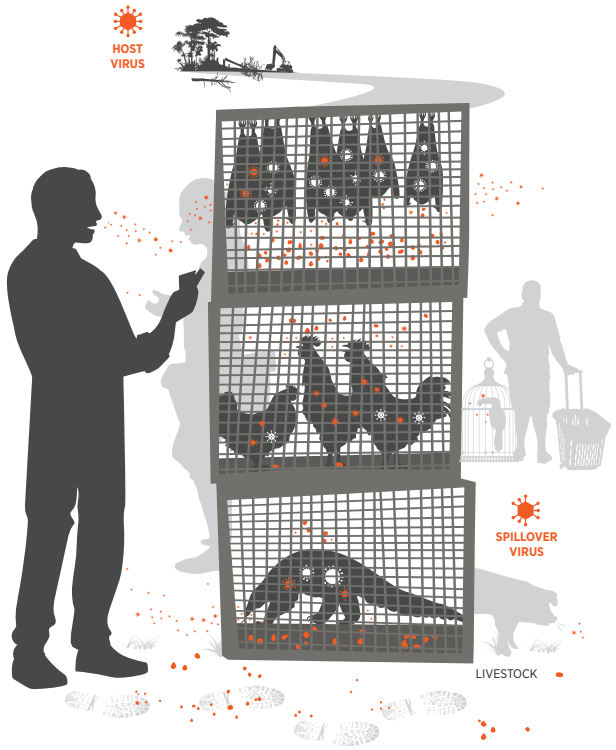
Background

Connectivity growth worldwide increases the risk of spillover. Some of these most important connections directly link wild animals in tropical forests to large populations of immunologically naive humans. Nowhere do we see this configuration more starkly than in the connections between China and countries that house and steward tropical forests. China and countries throughout Southeast Asia, West and Central Africa, and South America that contain tropical forests have extensive trade and development cooperation. China's interest is in developing fluid connectivity via supply routes for natural resources and agricultural products to support its growing population, currently at 1.43 billion with a growth rate of 0.37% per annum. Increased infrastructure development in once pristine, intact tropical forests and the harvesting of a vast suite of tropical forest products to meet the demand of China's burgeoning middle class are some of the results of the opening of these trade routes. With the opening of these trade routes, we see increased trade in live wildlife for luxury products such as exotic wild meat, fur, pets, and for medicinal products sourced from wild animals. We also see increased expansion and intensification of domestic animal and wild animal production in tropical zones to meet the increase in the global demand for animal protein in urban areas and internationally.

As North America and the EU continue to consume disproportionate volumes of deforestation-driving goods, and China and its development partners continue the implementation of the expansive Belt and Road Initiative (BRI), far reaches of the planet become intimately connected, creating new opportunities for novel viral mixing to occur and incubate. One of the inevitable outcomes of this viral mixing, mutation, and incubation is that new super viruses will find populations of people who are immunologically naive and unprepared. The fear, of course, is that a super virus will spillover, initiating a new disease that may exhibit the deadly combination of high infectiousness, a long period of asymptomatic spread, and high death rates that would be devastating. As we have seen with COVID-19, the devastation will be measured in significant loss of life, economic output, and social cohesion. This is not inevitable but probable without action. In order to avert the possibility of this future, we need to augment our existing interventions in areas of emerging spillover as conditions change, develop new interventions based on targeted research with priority for prevention, and develop new partnerships for full implementation. The Americas, the exotic pet trade, and wildlife trafficking trends must be targeted for future research to better understand what we can do to avert disaster. These interventions are detailed below.

Figure 4. Virus Mutation, Transmission, and Spillover

(via respiration, excrement, or bodily fluids)



LIVE WILD AND DOMESTIC ANIMAL MARKET

South America

Targeted landscapes include the Amazon Basin and surrounding lands.

Regional context: Tropical regions of the Americas have had no known spillovers with the potential to create a pandemic for a variety of evolutionary, genomic, historical, demographic, cultural, institutional, and economic reasons, but those conditions are changing. South America is set apart from the other regions and the spillover risk differences include (1) the potential biological difference in Old World versus New World pathogens and the duration of the co-evolution of animal and humans pathogens; (2) the role of Indigenous communities in modern South American societies in their cultures and their institutional rights that may play a role in biosecurity measures and forest intactness; and (3) the relatively low densities of people and domestic animals in the rural areas at deforestation fronts. While key questions in understanding novel spillover risk in South America should be investigated, there are no-regret interventions that can redirect the worrisome increase in enabling conditions for spillover, as deforestation and defaunation of the region's biodiverse forests are on the rise.

South America struggles with endemic and vector-borne zoonoses, including zika, dengue, and malaria, all of which share a root cause of forest loss. Focusing interventions on avoided fragmentation decreases the risk for spillover, while also providing the co-benefits of mediating additional endemic zoonotic disease risk. In Amazonian countries, pressures on forests originate from road expansion, including along development corridors for crop commodity production zones to reach external markets. As connectivity and access increases, so too does evidence of increased urban demand for wild meat.

Interventions at the deforestation frontier to protect and restore tropical forests include

Protect and restore tropical forests under the global 30X30 goal by

- elevating IPLC tenure and governance rights
- using Earth for Life's project finance for permanence mechanism to expand protected areas
- implementing nature-based solutions for climate mitigation portfolios in which the private sector could invest for carbon credits
- strengthening forest monitoring, law enforcement, and reporting

Implement deforestation-free commodity production by

- engaging large companies with supply chains origins in the tropics to secure deforestation/conversion free (DCF) supply chain commitments and field investments
- developing deforestation/conversion free (DCF) crop and animal agricultural systems

Support implementation of sustainable infrastructure by

- applying systems-scale analyses incorporating human health, economy, and Sustainable Development Goals (SDGs) to inform infrastructure plans
- incorporating zoonotic disease hotspot predictive models into forest protection and infrastructure planning and vice versa, connecting infrastructure-related forest encroachment into early warning surveillance for zoonoses

Interventions at the end of the wildlife value chain to reduce wildlife use and consumption and support sustainable food systems include

- establishing a regional collective of ecommerce, social media, and tech companies to detect, remove, and dissuade trade online in high-risk species and products in Latin America

Targeted policies and conditions to support a Planetary Health Agenda throughout the value chain by

Policy

- capacitating law enforcement and transport sector detection at ports, airports, and border crossings for high-risk shipments of live wildlife and meat, including technology innovations
- partnering with public health departments to integrate surveillance for the root causes in upward trends for endemic disease and emerging zoonoses, with deforestation surveillance integrated into public health planning and preparation systems

Research

- determining the risk potential of trade in wildlife in Latin America, particularly live mammal and bird trade for export to terminal markets in China and North America

North America, Europe, and the Middle East

Regional context: North America, the EU, and the Middle East remain sources of demand for wildlife products with potential for spillover into immunologically naive populations of people. North America and the EU are the largest importers of exotic live wild pets behind China. While fish, reptiles, and birds are imported in the greatest numbers, the sheer volume of imported mammals is high, with taxa more risky for spillover, including primates for biopharmaceutical research. Although well regulated, importation of live wildlife for pets into the US and Canada includes substantial illegal trade volumes in risky species including primates, rodents, and birds smuggled from the wild for captive breeding or direct sales. Legal controls and veterinary checks for smuggled animals are limited once past border control. The US, EU, and Middle East are a significant market for illicit diaspora demand for wild meat, particularly that smuggled from West and Central Africa. North America and the EU also remain some of the largest drivers of deforestation through demand for animal protein and other deforestation-driving commodity consumption (addressed in mitigating current and emerging risk).

Interventions at the end of the wildlife value chain to reduce wildlife use and consumption include

- establishing a regional collective of ecommerce, social media, and tech companies to detect, remove, and dissuade trade online in high-risk species and products in North America

Targeted policies and conditions to support a Planetary Health Agenda throughout the value chain by

Research

- determining the risk associated with housing exotic pets or farming exotic animals for fur
- identifying key species smuggled into North America and their origins to evaluate trade trends, wildlife demand behavior, and risk for potential spillover

3. Global Action Plan for Planetary Health

The Global Action Plan is designed to support the desired outcomes in each regional zoonotic hotspot and underpin a post-COVID-19 transition to true planetary health.

Targeted policies and conditions to support a Planetary Health Agenda throughout the value chain include

Policy

- capitalizing on the high-profile private-sector partnership to obtain Nature Positive commitments with One Health
- campaigning for protecting and restoring tropical forests under the policies being negotiated under the Paris Agreement and the Convention on Biological Diversity
- integrating Nature and One Health into the Global Sustainable Development policy agenda
- integrating Nature into Global Health Security Agenda Action Packages and member states' commitments
- developing a close working partnership with CDC and WHO to
  - build environmental health and food safety into their Sustainable Diets platform to bolster their responsibility for global surveillance of food safety by taking a seat on the Open-ended Working Group
  - lobby countries to address emerging zoonotic diseases in global trade, medicinal health, and food policy
  - develop a One Health approach for all animal agriculture systems, including reductions in deforestation
  - integrate monitoring data of deforestation fronts and diseased wildlife into emerging and endemic zoonotic disease data for early warning AI systems to build political will for maintaining habitat intactness and connectivity
- strengthening international trade policies on trade, transport, and sale of exotic live wild animals by
  - adopting best practices for the prevention of zoonotic disease spillover into trade pacts
  - increasing regulation and enforcement of trade in high risk species, with a focus on exotic meats and pets
  - banning the sale and transport of wildlife for exotic wild meat and pets to restrict trade in high-risk species
  - ensuring transparent monitoring, analytics, and reporting of legal trade activities to identify and stop the associated illegal wildlife trade
- convening leading Environmental/Social/Governance (ESG) corporate sustainability rating systems to strengthen metrics related to nature into their methodologies
- developing policy recommendations to regulate livestock intensification and biosecurity measures in high-risk geographies to meet One Health goals
- applying systems-scale analyses incorporating human health, economy, and SDGs to inform infrastructure plans

Finance

- implementing a COVID-specific campaign for Multilateral Development Banks to develop guidance on zoonotic transmission for infrastructure projects, including avoiding avoiding intact areas of high mammal diversity, or integrating forest loss and signs of spillover into their surveillance
- mainstreaming pandemic risk in the insurance industry and investors' due diligence models
- establishing financial risk of deforestation with investors and companies; stacking physical and transitional risk issues on deforestation, including climate implications and material human health impacts supported by science in deforestation adjacent regions
- developing financing tools for capital investment in a clean, cold value chain in Asia and Africa

Research

Behavior change

- engaging top researchers in behavior change for application to efforts to prevent zoonotic spillover
- integrating zoonoses-relevant questions into the country-by-country food surveys that will take place as part of WWF's Planet-Based Diets report
- developing incentive schemes to shape the behaviors of farmers, hunters, and local traders while embracing culturally acceptable alternative livelihood
- determining costs and benefits (direct and indirect) of addressing risks, with implications for who pays the costs and who reaps the benefits
- understanding regional differences and contexts for wild meat harvest, consumption, transport, and sale in high-risk geographies
- identifying the differences in the regions in spillover and forecasting future spillover given changes in existing and emerging drivers of change
- understanding the potential for behavioral interventions
  - using evidence to both maintain or reinforce positive behaviors post-pandemic
  - co-designing with partners new health and conservation interventions to change risky behaviors in order to reduce zoonotic spillover
  - researching wildlife purchase and consumption to understand the attitudes, motivations, and norms driving the purchase and consumption of high-risk wildlife products
- identifying spillover hot spots, accelerating inclusion of disease regulation in natural capital, setting targets, and modeling econometrics that inform infrastructure and land use planning
- identifying high multiple benefit, high value natural capital areas (e.g., those that support climate risk reduction; extreme events like flooding) and reducing disease emergence to create more powerful arguments for addressing deforestation/fragmentation
- mapping high conservation value areas and disease emergence hotspots to identify habitats as no go zones to maintain habitat and promote natural disease regulation
- mapping areas for restoration to restore ecological integrity and limit vector borne disease spread
- mapping infrastructure and natural capital planning and development
- mapping overlapping trade routes for wildlife trade and domestic livestock supply chains at hotspots
- conducting a detailed analysis of regional differences and risk for spillover

Tools

- establishing new tools and technologies to rapidly identify high risk meat products in the market and at border points and detect smuggled live wildlife in baggage, parcels, and freight.
- developing predictive analytics on new infrastructure development risk to triggering spillover

Research

- understanding emotions around wildlife products (to go beyond motivations to understand consumer commitments and actions), as well as potential prosocial behaviors for reducing consumption
- identifying the most influential levers for demand reduction for wild animal and livestock products and the feasibility for intervention
- ensuring that interventions seek to sustain and measure preventive health and pro-environmental behaviors over the long term

Communication

- developing positive, clear stories about corporate-funded health and sustainability efforts taking place in landscapes/jurisdictions
- creating epidemiological education programs that unite pathology and conservation, in partnership with Planetary Health Alliance
- raising public awareness on the role of wildlife trade and livestock production on increasing the risk of spillover

STOP SPILLOVER AT THE SOURCE

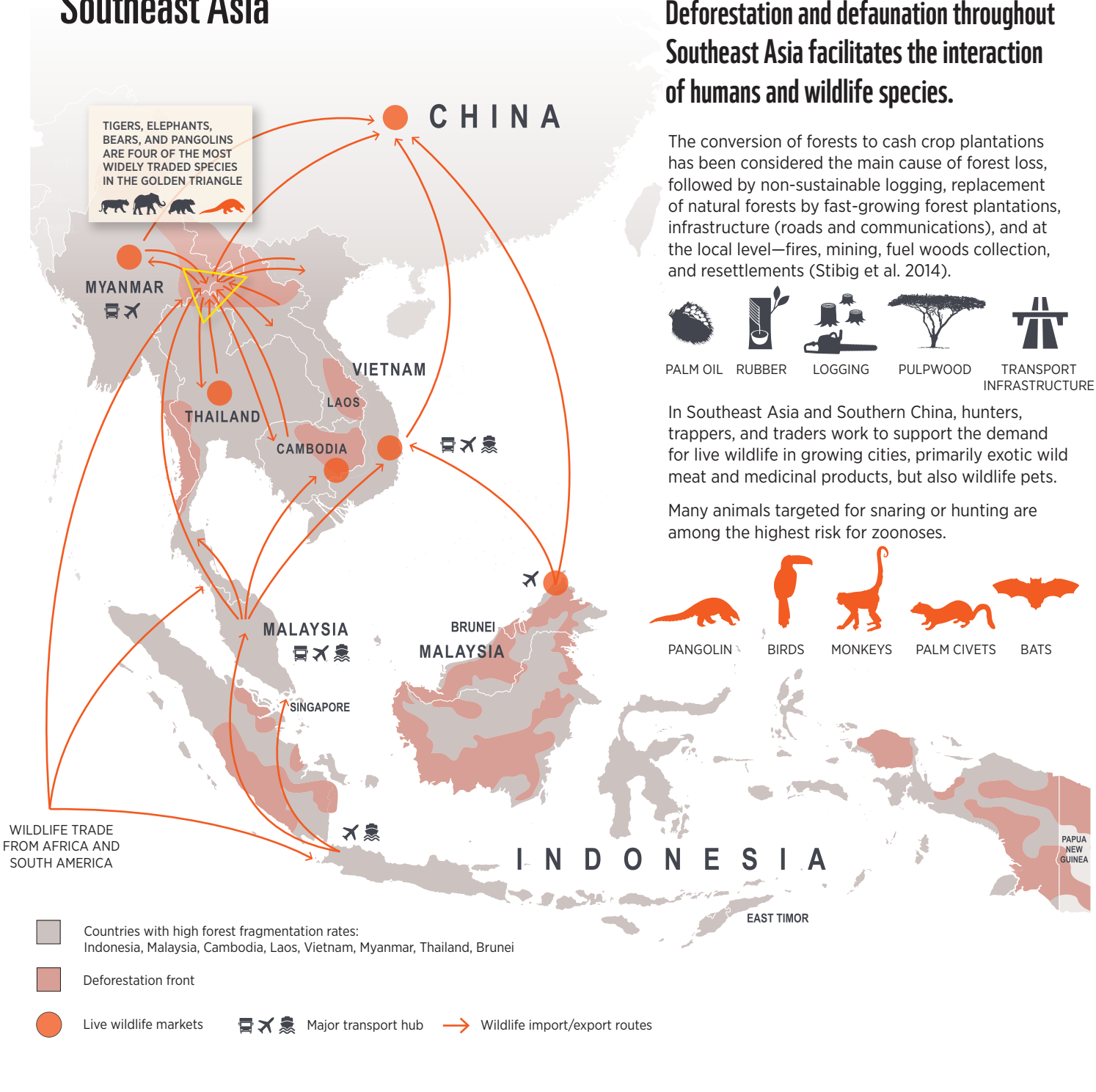
Evidence-based Strategies for the Pandemic Era

Annexes 1 & 2

Annex 1: Regional Hotspot Summaries

Hotspot visualizations: Southeast Asia, Central Africa, and South America

Southeast Asia



Deforestation and defaunation throughout Southeast Asia facilitates the interaction of humans and wildlife species.

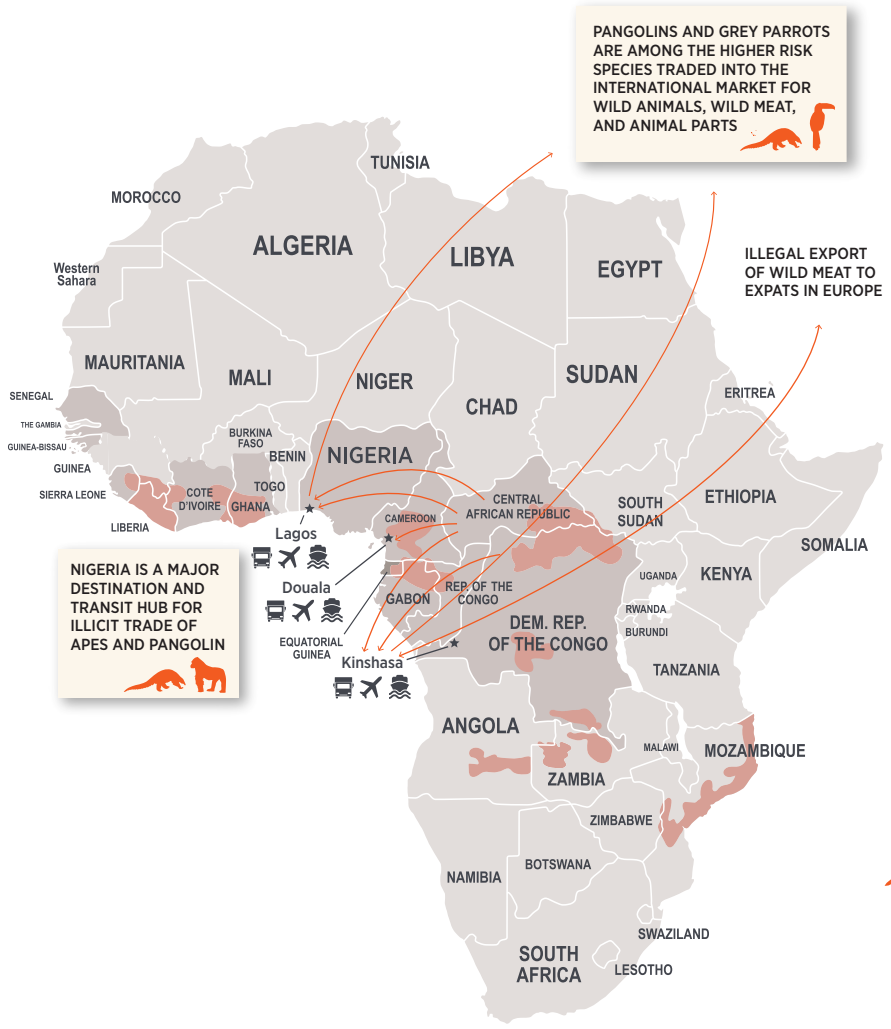
The conversion of forests to cash crop plantations has been considered the main cause of forest loss, followed by non-sustainable logging, replacement of natural forests by fast-growing forest plantations, infrastructure (roads and communications), and at the local level—fires, mining, fuel woods collection, and resettlements (Stibig et al. 2014).

In Southeast Asia and Southern China, hunters, trappers, and traders work to support the demand for live wildlife in growing cities, primarily exotic wild meat and medicinal products, but also wildlife pets.

Many animals targeted for snaring or hunting are among the highest risk for zoonoses.

Hotspot visualizations: Southeast Asia, Central Africa, and South America

Central Africa



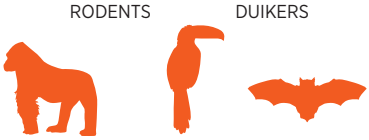
Deforestation and degradation of tropical and subtropical forests increase the interaction between humans and wildlife.

In Africa, small-scale agriculture remains the primary driver of deforestation with commercial agriculture increasing in the Congo Basin. While deforestation is growing in some parts of West Africa, most deforestation has already occurred relative to Central Africa. Logging occurs widely and is a major contributor of fragmentation through the establishment of forestry roads and associated infrastructure, allowing broad access to the forest interior and increasing likelihood of interactions with animals.

SMALLHOLDER FARMING | COMMERCIAL AGRICULTURE | LOGGING AND MINING ROADS | FUELWOOD

People consume wild meat locally, while encroachment opens up new access for hunters to meet demand for luxury bushmeat in growing urban centers across the region.

PANGOLIN | RODENTS | DUIKERS | MONKEYS



APES | BIRDS | BATS

Countries with high rates of deforestation and fragmentation: Central African Republic (CAR), Republic of Congo, Gabon, Ghana, Guinea-Bissau, Ivory Coast, Liberia, Nigeria, Senegal, Sierra Leone, Cameroon, Democratic Republic of the Congo (DRC), Equatorial Guinea

Deforestation front | Major transport hub | Wildlife import/export routes

Hotspot visualizations: Southeast Asia, Central Africa, and South America

South America

Deforestation, defaunation, and forest fragmentation is increasing interaction between humans and wildlife.

In the Amazon—including Brazil, Colombia, Peru, and Bolivia—pressures on forests originate from mining, roads, agricultural expansion and cattle pastures. Pasture expansion for cattle grazing is still the main driver leading to forest loss across the Amazon and is in part due to attempts to justify land ownership for speculative rather than productive purposes. Forest stewardship tends to be strongest where indigenous rights are upheld.

CATTLE | SMALLHOLDER FARMING | TRANSPORT INFRASTRUCTURE | LOGGING & MINING ROADS

Wildlife trafficking in the Americas primarily involves live animals for a growing international exotic pet trade. Domestic wildlife markets and trade routes play a role, especially in Brazil and Peru, and both enforcement and awareness of zoonotic spillover risk remain low.

RODENTS | BIRDS | MONKEYS | BATS | JAGUARS

Countries with high forest fragmentation rates: Brazil, Bolivia, Peru, Colombia

Deforestation front

Major transport hub

Wildlife import/export routes

Annex 2: Risk Framing

While more research is needed to better understand and predict risk for spillover of emerging zoonotic diseases, there are defining questions for what we already know to be risky and how risk amplifies through the value chain:

1. **What makes a risky space?** The density, frequency and novelty of human interaction with live and recently slaughtered risky taxa constitute risky spaces. Risky spaces can include

   - degraded tropical forests high in mammalian biodiversity
   - active tropical deforestation fronts high in mammalian biodiversity
   - pastures/domestic animal pens at or near deforestation fronts
   - high density wild and/or domestic animal production
   - live animal transport vehicles/vessels
   - markets selling live wild and/or live domestic animals
   - live animal warehouses
   - restaurants selling/serving live wild and/or live domestic animals
   - domestic houses with live wild animals, exotic and native
   - slaughterhouses/slaughter locations

2. **What makes a risky species?** All taxa carry some degree of risk; however, there are taxa that are either inherently more risky for spillover to humans (e.g., bats because of their high viral loads and high shedding; primates because of the high genome overlap with humans) or become risky because of their physical conditions and/or the length of time in a mixed animal value chain, which increases viral loads and shedding. Species-related risk to consider include

   - bats due to the combination of their high viral loads, novel viruses, rapidly mutating viruses, ability to transgress multiple human-dominated environments, and high shedding rates when stressed
   - primates due to their high genome overlap with humans
   - mammalian taxa, especially bats and primates that are confined in high density enclosures or high density enclosures for a long time; mixed with other wild live taxa and domestic animals while confined; and/or mixed with novel wild taxa or live native or domestic taxa
   - Old World taxa due to mammalian species with higher genome overlap and a longer time frame of domestication of animals and co-evolution of primate diseases (5M years in the Old World versus 14000 years in the New World)

3. **What makes a risky connection (value chain)?** Risk for spillover or spread grows in value chains of live wild animals. Risky connections can include

   - the number of nodes and subsequent mixing in a value chain increases
   - the value chain connects to urban populations
   - the value chain connects across geographical boundaries introducing live wild animals and humans to novel viruses and/or
   - the value chain connects Old World pathogens to New World pathogens

   Value chains should be considered separately for risk of spillover or risk of driving the conditions for it and include

   - commodity crop value chains driving tropical deforestation, including those supporting livestock production
   - live wild animals for food value chains
   - live wild animals for medicine value chains
   - live domestic animals for food value chains
   - live wild pet value chains

4. **What makes a risky behavior?** A risky practice or behavior is one that increases human exposure to the respiratory droplets and/or bodily fluids of risky species, including live and/or recently slaughtered wild animals and domestic animals and, in some cases, humans who are carriers but not susceptible to animal pathogens. These risky practices or behavior include

   - spending excessive time (i.e., hunting, working, living, etc.) in tropical forests or interacting with live or recently slaughtered wildlife
   - slaughtering wild or domestic animals without biosecurity measures and equipment in place
   - raising domestic livestock at or near deforestation fronts and/or within tropical forest fragments
   - farming wildlife species without biosecurity measures

- transporting live wild and/or domestic animals at high densities in confined spaces and/or for a prolonged period
- spending time at markets where live wild and/or domestic animal are sold and slaughtered
- eating live or recently slaughtered wild animals or domestic animals exposed to wild animals
- living and/or working in close proximity to live wild and/or domestic animals and/or hunters and traders

5. **How and where is risk amplified?** Risk is amplified when the above considerations for risk intersect or compound, across and within regions.

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