The Value of the One Health Approach: Shifting from Emergency Response to Prevention of Zoonotic Disease Threats at Their Source

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ABSTRACT The majority of emerging infectious diseases have their source in animals, and emergence occurs at the human-animal interface, when infections in animals breach the species barrier to infect humans, the population in which they are often first identified. The response is often a series of emergency activities to contain and manage the infection in human populations, and at the same time to identify the source of the infection in nature. If an infection is found to have a source in animals, and if animals cause a continuous threat of human infection, culling is often recommended, with severe economic impact. Currently the animal and human medicine sectors are working toward interacting more closely at the animal-human interface through joint surveillance and risk assessment, and research is under way in geographic areas where emergence at the animal-human interface has occurred in the past. The goal of this research is to identify infectious organisms in tropical and other wild animals, to genetically sequence these organisms, and to attempt to predict which organisms have the potential to emerge in human populations. It may be more cost-effective, however, to learn from past emergence events and to shift the paradigm from disease surveillance, detection, and response in humans to prevention of emergence at the source by understanding and mitigating the factors, or determinants, that influence animal infection. These determinants are clearly understood from the study of previous emergence events and include human-induced changes in natural environments, urban areas, and agricultural systems; raising and processing of animal-based foods; and the roles of global trade, migration, and climate change. Better understanding of these factors gained from epidemiological investigation of past and present emergence events, and modeling and study of the cost-effectiveness of interventions that could result in their mitigation, could provide evidence necessary to better address the political and economic barriers to prevention of infections in animals. Such economically convincing arguments for change and mitigation are required because of the basic difference in animal health, driven by the need for profit, and human health, driven by the need to save lives.

EMERGENCY RESPONSE TO NEWLY IDENTIFIED HUMAN INFECTIONS

When an infectious disease organism from an animal breaches the species barrier to infect a human, it enters an immunologically naïve population. Depending on incompletely understood risk factors, which depend on both the organism and the infected human, there are several possible transmission pathways: (i) no further
transmission, with the human an endpoint as in rabies and variant Creutzfeldt-Jakob disease; (ii) nonsustained human-to-human transmission such as presently occurs in close human contact with persons with influenza A (H5N1) and human monkeypox (1–4); (iii) sustained human-to-human transmission following initial transmission from an animal source, as observed with influenza A (H1N1) that emerged as a pandemic in 2009; and (iv) sustained transmission that leads to endemicity (Fig. 1). HIV presents the most important recent example of the latter, but the pattern of animal infections becoming endemic in humans appears to have occurred throughout history, suggesting that most, if not all, endemic infections in humans have come from animals (5, 6).

The ecosystem in which microbes, humans, and animals exist is in delicate balance. Any changes to its equilibrium can afford increased opportunities for microbes to breach the species barrier. Opportunities occur through direct human contact with livestock and wild animals and/or their waste materials in shared ecosystems (7). They also occur through human-animal contact along the food production and marketing chain (8).

These opportunities are increasing because of greater levels of infringement of human populations on animal habitats through urbanization, logging, mineral extraction, and recreation; and increasing demand for animal-based foods and other shifting dietary preferences that require more intensive animal husbandry and are based on international trade.

While human behavior plays a role in the type and extent of animal contact, and therefore the risk that an infectious organism will cross the species barrier, the inherent biology and genetics of the infectious organism also play a fundamental role. Some microbes are genetically unstable—the genome may be prone to mutations, replication error, reassortment, or recombination during reproduction in the animal or human host. Such alterations in the genome can change the transmission properties and increase or decrease virulence. Modification of the microbial genome can thus equip a microbe with the ability to cause illness, to transmit, and/or to survive (9). RNA viruses in particular demonstrate a strong propensity to mutate and develop into human infections that emerge from animals and are transmissible from human to human (10).
The term “emerging infection” is often used to describe newly identified zoonotic infections at the animal-human interface. Often they are first identified many years after the breach in the species barrier has occurred (11). During the past 40 years newly identified zoonotic—or emerging—infections have been identified that range from Ebola and Marburg hemorrhagic fever viruses to HIV, the paramyxoviruses (Hendra and Ni-pah viruses), and certain food-borne bacterial infections (e.g., verocytotoxin-producing Escherichia coli O157) (12, 13). Most emerging infections have been first identified in humans, before the animal source was known, and many of them reemerge when the risk factors for cross-species transmission align.

In some situations, an infection with the putative zoonotic organism is asymptomatic or causes mild human illness. At other times it causes severe human illness and there is need for an immediate and potentially emergency response in the infected human population to save lives and contain the infection through treatment and/or disease management.

The clinical response to zoonotic infections is often costly, an economic burden that can be particularly difficult in low-income countries where health budgets are already heavily restricted. Postexposure prophylaxis for rabies, for example, has been estimated (conservatively) to cost $40 in sub-Saharan Africa and $49 in Asia, a cost that equals 5.8 and 3.9%, respectively, of the annual per capita gross national income (14). But zoonotic infections can also be costly in industrialized countries. Health services utilization, work absenteeism, and direct costs for hospitalization of persons with H1N1 in Spain have been estimated at €6,236 per inpatient (15).

Following an outbreak caused by an emerging infection, an epidemiological investigation helps to assess the risk to humans—and to determine the source, and if the source is an animal, to understand whether there is continued risk of transmission to humans. A range of emergency response measures must then be implemented, including surveillance, contact tracing, isolation, social distancing, vaccination or prophylaxis (if vaccines and/or medicines are available), and in some instances culling of the animal source. The revised International Health Regulations (IHR 2005) (16) require World Health Organization (WHO) member states to rapidly assess an emerging infectious disease outbreak and notify the WHO, and through WHO the global community, if the outbreak fits the criteria established for a public health emergency of international concern and causes a risk of international spread (17).

Intensive culling of cattle after research had identified causal links between bovine spongiform encephalopathy (BSE) in cattle and variant Creutzfeldt-Jakob disease in humans, for example, was estimated to have cost the United Kingdom government $5.75 billion, including $2 billion in lost exports (18); culling of flocks of H5N1-infected chickens, coupled with inadequate compensation in Asian countries, cost an average of $210 per farmer, a high cost in a population whose average monthly income is $120 (19) (Fig. 2). If an emerging infection becomes endemic in human populations, the disease burden and cost can have a major and prolonged economic impact. The impact of AIDS in terms of lost economic output is significant, particularly in the poorest countries; reductions of 2 to 4% in the national gross domestic product have been calculated, for example, across a range of African countries (20).

Severe acute respiratory syndrome (SARS) was the first major emerging infection identified in the 21st century. A close examination of its origins, the outbreak and human sickness and death that it caused, the international response, and the effect it had on Asian economies provides a clear lesson of the impact of emerging infections and the reasons they must be assessed and managed with urgency to ensure a rapid and effective response.

First detected because it caused a severe atypical pneumonia, SARS soon became a burden in hospitals in the Guangdong Province of China, where many patients required respiratory support and broad-spectrum antibiotics had no effect. Hospital workers caring for these patients became infected as well, and one of them—a medical doctor who had treated patients in the Guangdong Province—traveled to Hong Kong, where he stayed in a hotel on the same floor as both Chinese and international guests. Some of these other hotel guests became infected, but it is not clearly understood how—hypotheses ranged from transmission through the hotel ventilation system to transmission in a shared closed environment such as occurs when people use the same elevator (21).

Those who became infected at the hotel were admitted to Hong Kong hospitals when they became ill or traveled to other countries, many times while still in the incubation period, to become seriously ill at their next destination. Hospitalized, they too became sources of infection of hospital workers, who in turn unintentionally infected other patients and family members.

Molecular and epidemiological investigation suggested that the infection of the index case (never identified) was a onetime event. As more information became
available, it was further hypothesized that this initial infection was due to close contact with an infected animal, probably a civet cat, thought to have been a carrier of a coronavirus that mutated, either in the animal or an infected human, in such a way as to cause severe human illness (22).

The world’s interconnectivity through air transport facilitated the international spread of SARS. Its electronic connections also permitted a virtual collaborative effort for surveillance, and for an emergency outbreak investigation, management, and containment: the most favorable patient management regimens and modes of transmission were rapidly identified; the causative organism was identified and characterized; international travel advisories were recommended to stop international spread; and after human-to-human transmission had been interrupted, the scientific evidence that was collected during the outbreak was used for guidelines in preparation for another outbreak should it occur (23).

SARS resulted in 8,422 probable infections and 916 (11%) deaths; in addition, the economic impact of the outbreak on gross domestic product was estimated at $30 billion to $100 billion from decreased commerce, travel, and tourism (24). Unlike HIV, the SARS coronavirus did not become endemic, and economic recovery was rapid.

Research to examine various hypotheses of transmission and to develop medicines and vaccines was active during the outbreak, but it came to a standstill during the following year when there was no recurrence of human infection and resources were then shifted to other research priorities.

SARS and other emerging infections share a common theme: infection is often first detected in human populations, in which an emergency clinical response and hypothesis-generating outbreak investigation begin before the source of infection is understood. Initial recommendations for control are often precautionary—based on the evidence available from the current outbreak or previous outbreaks caused by similar organisms—and they can cause severe negative economic impact.

If it were possible to identify infectious organisms carried by wild and domestic animals and to predict if, when, and where they would emerge in humans, and if these animals could then be somehow removed from contact with humans or cleared of infection, human sickness and death could be prevented and economies protected.

A One Health approach to prevent human infection by enhanced detection and surveillance in both wild and domestic animals is actively being pursued, including identification of geographic areas where the greatest number of emergent infections have occurred historically (25). Such geographic localization is followed by prediction of which organisms might emerge based on an understanding of what infectious organisms are present in wild and domestic animal populations at those sites. Genetic sequencing of these infectious organisms and comparison of the sequence information to
that from other known infectious organisms is then done in an attempt to discern genetic changes that could lead to emergence (26, 27).

If the One Health approach could be expanded to understand and mitigate the determinants, or factors, that align to shape the risk of animal infection and breaches in the species barrier from animals to humans, both populations could be protected from sickness and death, and economies even better protected. The current paradigm of emergency response, and that of prediction and prevention, could then be shifted even further upstream to management and mitigation of the determinants of the risks that lead to emergence, thus preventing emergence at the source (Fig. 3).

UNDERSTANDING THE DETERMINANTS OF EMERGENCE AND THEIR MITIGATION

The determinants of emergence are risk factors that align in such a manner as to modify the equilibrium among and between three species: humans, animals, and the infectious organisms carried by those animals. The determinants cross many sectors, including human and animal health, animal husbandry, agriculture, community planning, water and sanitation, commerce, forestry, mining, food processing of animals, trade, and agriculture. Specific determinants must be identified in each instance of an emergence, understood, and then mitigated to prevent the same alignment and emergence in the future.

It is because of the cross-sectoral origin of these determinants that a One Health approach—defined as a collaborative effort of multiple disciplines to attain optimal health for people, animals, and the environment (28)—is of value. Figure 4 shows how this One Health approach builds on analyses of previous emergence events to (i) identify the determinants that have aligned in past or current emergence events in such a manner as to facilitate or permit emergence; (ii) engage partners and stakeholders outside of the traditional medical community to ensure that these determinants are understood; and (iii) with these partners and stakeholders, propose and implement strategies that will mitigate and decrease the negative impact of emergence events in the short term and contribute to prevention of emergence in the future.

Such a One Health approach over time could be used to change the existing paradigm of detection and emergency response to prevention, or to a decrease in the frequency of emergence, by mitigation of the determinants that have the potential to cause emergence. Mitigation requires observation and analysis of events that occur, or have occurred in the past, to identify the various government and other sectors involved and to develop the sector-specific strategies and policies that will prevent their occurrence. These strategies must then be put in place across all sectors involved through cross-sector—One Health—collaboration.

In the case of SARS, there was a flurry of field research activity in the Guangdong Province during and just after the outbreak, but over time funding decreased and research slowed. Among the research that was completed was a study of workers in some of the province’s wet markets that suggested that up to 22% (12/55) had...
antibody evidence of a coronavirus infection related to the SARS coronavirus, but that none had a history of severe respiratory symptoms such as were occurring in persons with SARS (29). Further field research might have helped better elucidate the risk factors for emergence, but it was not conducted, and the epidemiology remains unclear.

Determinants of emergence, in addition to working in a wet market, as suggested by the completed study, might also include hunting wild animals, killing and/or butchering/preparing wild animal meat for consumption in a restaurant, or living in a household that buys live or recently killed wild game meat from a wet market.

Even though evidence is available from just one epidemiological study of SARS, a series of actions outside the human and animal health sectors could be useful in preventing a future outbreak of another emerging pathogen in the Guangdong Province. These include education of all those who come into contact with wild game (and domestic animals) about how to protect themselves against infection; regulation with enforcement of wet markets and eating establishments that does

FIGURE 4 Flow chart showing steps for transforming evidence at the animal-human interface into policy. doi:10.1128/microbiolspec.OH-0011-2012.f4
not drive these activities underground, but rather ensures safe animal handling; and regulation and enforcement of trade between hunters and markets and between markets and those who purchase. Other activities might be research to determine whether any wild animals could be raised commercially under conditions that prevent their infection and risk to humans, or further downstream, more effective education of health workers about infection control. This latter activity would ensure that if other actions such as those above failed to prevent emergence, amplification of transmission of emergent organisms could be prevented.

There are numerous other situations in which emergence occurs, and numerous reports in the medical literature that fully or partially analyze these events. People living and working in small rural farming communities carved out of tropical rain forests, savannas, mountains, and deserts often come in close proximity to wild animals, or to domestic animals they tend that in turn are in close proximity to wild animals. Exposures range from direct contact with wildlife and domestic animals to indirect contact through water, garden products, or other ecosystems in the environment that have been contaminated by animal waste materials. A 2004 serological survey demonstrated that 1% of inhabitants in rural villages who had reported exposure to primates presented with antibodies to simian foamy virus (30). Hantavirus outbreaks have occurred in rural American Indian communities when humans have become infected by inhaling dust particles contaminated by the urine of rats, and have occurred in other areas—recently in a national park in the United States—where humans and the waste products of rodents came in close contact (31). Human monkeypox—caused by an orthopoxvirus carried by rodents in tropical rain forests of sub-Saharan Africa—occasionally causes infection in hunters and others living in small rural communities who come in contact with forest animals they have killed or butchered (32).

In larger urban communities, human contact with animals may be limited to domestic pets, a few farm animals in close proximity to households, or rodents and other animals that have adapted to the environment and come in contact with humans or other animals as they range (e.g., cows and chickens in parts of Asia) or browse (e.g., urban foxes and rodents). The continued high rate of contact between humans and animals in both smaller backyard and larger market systems within these networks permits constant human exposure to and infection with the virus. Children and adults in Asia are thought to have been infected with the H5N1 influenza A virus by contact with living chickens in backyards, and adults have been shown to become infected at some point during the process of raising or slaughtering/butchering chickens (33). A recent multi-source outbreak of human monkeypox in the United States was associated with the importation of exotic animals for pets from West Africa, which served as a reservoir for infection of other animals in pet shops that then infected the children with whom they came in contact (34).

With increasing population density, particularly where rural-urban migration is a common trend, a breakdown in environmental sanitation/waste disposal from burgeoning population demands can create ecological niches for sustained transmission of animal pathogens through the environment, water, or food contaminated by animal waste (33). Major outbreaks of giardiasis—caused by an intestinal parasite that has a reservoir in livestock and wild animals—have occurred in the state of Wisconsin and in St. Petersburg (Russia), linked to contamination of drinking water systems (36).

Civil disturbance, destruction of community infrastructure, and resultant migration of human populations can likewise alter the interaction of humans and animals and lead to emergence. Lassa fever outbreaks in refugee camps following civil war in western Africa, for example, forced displaced human populations to migrate in mass numbers and relocate to camps with extremely poor housing and living conditions, an environment where the natural host for the Lassa fever virus, the rodent Mastomys natalensis, can thrive (37).

Determinants of emergence in these settings are poor or inadequate urban planning, lack of understanding by populations about risks associated with animal contact, failure to adopt and adhere to safe farming practices, and failure to maintain sanitation and water infrastructure. A One Health approach must work across all these sectors, assisting communities to develop a safer living environment through urban planning, developing and maintaining robust water and sanitation infrastructure, controlling rodent and other animal populations in near-proximity urban areas, ensuring safe animal husbandry, and providing understanding of risks through community-based education.

In addition to workers who have contact with domestic animals, other occupations are risk factors for human infection from wild animals. The 1998 Nipah virus outbreak in Malaysia was attributed to initial transmission of the virus at the livestock-wildlife interface (from bats to pigs, which served as the amplifying host) and then to pig farmers and slaughterhouse
workers (38). In Malaysia, the Nipah virus is thought to have been transmitted to humans who collected or drank palm wine that was contaminated with guano of Nipah-infected bats (39).

Outbreaks of Ebola hemorrhagic fever have also been linked to occupation: the index case of the Ebola outbreak in the Democratic Republic of the Congo is thought to have been a local inhabitant whose occupation was preparing charcoal in the tropical rain forest (40) and who was exposed to an Ebola-infected animal or to the guano of the bat reservoir.

The origin of HIV emergence has been linked to both hunting and butchering of chimpanzees for consumption (41); the SARS infectious organism (coronavirus) spread to humans in China through either close contact with wild animals in wet markets or preparation of wild animals for consumption; and recurrent outbreaks of Ebola hemorrhagic fever are linked to ongoing hunting and butchering of nonhuman primates (42).

Extractive industries such as logging and mining open previously uninhabited parts of forests or other terrain to human settlement. Moving humans for work purposes to such naïve ecosystems increases the opportunity for their exposure, and that of their domestic animals, to infections present in the wildlife population (30). Though reports of outbreaks associated with the extractive industries have not yet been published, such events are thought to be of real but low potential. Such events are likely to have high impact, and it is known that habitat modification and fragmentation after deforestation or other extraction procedures can affect both animals and the vectors that transmit infections, as described for yellow fever or plague from wild animals to humans (43).

Determinants of emergence related to occupation include hunting and working in areas where either wild or domestic animals can transmit infection. Some of the determinants involve wild animals—contact with animals or indirectly with the vectors that carry infection from animals to humans such as mosquitoes. In addition to community education about occupational risks of infection, industry must be encouraged or legally required to ensure that workers are protected and safe from wild animal exposure whether they work in the slaughterhouse, mining, or forestry industry, and special attention must be paid to regulation of markets that sell wild animals and prevention of those that are clandestine.

Climate change may also be a factor in emergence of human infection. Rainfall associated with El Niño—Southern Oscillation in East Africa, for example, has contributed to frequent outbreaks of Rift Valley fever as a result of flooding that increases breeding sites of the mosquito vector (44). The frequency of *Leptospira* transmission from rodents to humans has been shown to increase following heavy rains and flooding in Latin America, Bangladesh, and India (45). Lassa fever has also emerged after severe drought in Sierra Leone, when rodents carrying the virus were forced to move closer to humans so that they could survive on agricultural products in cultivated fields or storage facilities, contaminating human food supplies (46).

Determinants related to climate change require (i) more robust civil engineering projects to prevent flooding and to channel water for irrigation, (ii) better rodent and wild animal control, and (iii) continued participation globally in the negotiation of the United Nations Framework Convention on Climate Change (47).

The 20th and 21st centuries have seen shifting dynamics across food and agricultural production systems, from rapidly intensifying systems throughout Southeast Asia to the rise of periurban farming practices in developing countries and the globalization of production and supply. Growing demand for animal-based food in many developing countries has led to more complex food chains. An increase in the numbers of animals has been followed by rapid expansion of both food and live-animal processing and trade networks, enabling food safety hazards and infectious organisms to travel with ease.

The emergence of Rift Valley fever in the Arabian Peninsula has been linked to the illegal importation of cattle from eastern Africa, where outbreaks are frequent (48). H5N1 influenza is endemic in poultry stock within a number of Southeast Asian countries where a multitude of live-animal trade networks exist. The rapid expansion of poultry production has led to increases in other food-borne zoonoses, particularly from eggs and egg products, which account for approximately 15% of food-borne infectious disease outbreaks across Europe (49). Changes in wide-scale, industrial processing of meat and animal by-products have been shown to also have the potential to lead to major large-scale zoonotic outbreaks. BSE emerged in cattle in the United Kingdom in the late 1980s, a result of reduction in the chemical solvent and temperature used for the rendering process for bone meal, ultimately enabling the infectious organism (a prion) to transfer back to livestock through feed made from bone meal (50). Outbreaks of *E. coli* O157 have consistently been shown to originate from meat and meat products, resulting in serious illness and death (51).
Overuse of antibiotics in livestock animals is thought to have led to an increase in antimicrobial-resistant bacteria in animals. This has been a primary consequence of extensive, often unregulated use of antibiotics for “growth promotion” in animal feed. Introducing antibiotics into the microbial gut flora of livestock animals alters evolutionary pressures on the microbes present, often increasing selection toward antibiotic resistance.

There is still much debate within the scientific community as to the contribution of antibiotics in farming systems to the rise of antibiotic resistance, and the implications for emerging antibiotic resistance in human populations are even less well understood. But there is general consensus that farming systems are likely to contribute to the flow of antibiotic-resistant microbes in the wider ecosystem and in humans by runoff into water used or consumed by humans, especially in economically poor settings where farming communities exist alongside densely populated human environments with poor sanitation/sewage systems.

The interaction between animals and the environment also plays an important role in other infections. Fecal contamination by feral swine, for example, is thought to have led to E. coli O157:H7 transmission to crops and resultant human outbreaks of hemolytic-uremic syndrome in both Europe and North America.

Though hunting and trade in wild animals may be negligible in terms of food products for consumption, they have been implicated in the emergence of highly significant infectious diseases such as a point source Ebola outbreak in the tropical rain forest of Gabon among a group of men who had killed and butchered a chimpanzee for food in the mid-1990s.

Determinants of infectious organisms in the food chain include breaches in personal protection during animal husbandry and slaughter, in quality control during food processing, and during storage and shipment. Other determinants include overuse of antibiotics and runoff from animal farms to water and the environment. Most of these breaches are accidental—and some are caused by attempts to economize to maximize profit.

Prevention of infectious disease emergence through the food chain and agricultural system must include intervention at each of the various steps along the pathway from the farm to the fork. If infectious organisms pass through the food chain and enter foods, their impact can be minimized at the final intervention point, where animal-derived foods can be prepared carefully in the factory, restaurant, and household either by cooking or other means to remove or mitigate the risk of infection. They could be controlled earlier—during the period animals are being raised, during slaughter, and during transport. Each known cause of emergence must be assessed for risk, and those that are considered risks must be mitigated. Mitigation plans must take into account the risks of wild animal exposure from land use and farming and must plan and implement strategies that mitigate risks of exposure that occur from activities such as deforestation and a reduction in biodiversity. They must also take into account human behavior and ensure that populations most at risk clearly understand the measures required to reduce high-risk behavior.

**TURNING EVIDENCE INTO POLICY THROUGH A ONE HEALTH APPROACH**

A great amount of scientific knowledge about the risk factors or determinants of emergence at the animal-human interface is already available from previous investigations and risk assessments of emergent events. More knowledge can be obtained from in-depth study of each new emergence event as it occurs. Research must also take into account human behavior and determine whether populations most at risk understand the measures that might be required to reduce or protect from high risk.

Translation of this knowledge into policy can help shift the paradigm from detection, assessment, and response further upstream to prevention of emerging infections at the source, thus better protecting animal and human health and protecting economies.

But many of these proposed evidence-based policies will encounter political barriers, especially when commercial benefits are at stake. The differences between the goals of the animal and human health sectors must be clearly understood. Agriculture is for profit—whether it is raising cattle for milk, poultry for eggs and meat, or pigs for meat and meat products. The mitigation strategies that are most easily accepted are therefore those that are shown to be cost-effective and have no negative impact on profit. For policy options that do not appear to be cost-effective, it is more difficult to achieve acceptance by all sectors of costly mitigation strategies, and enforceable legislation may be the only way they can be addressed. But it is clear that those preventive interventions that are cost-effective for the animal industry (and associated sectors such as trade, commerce, and the environment) will have a better chance of being accepted than others that could decrease profit, and barriers among the different sectors must be broken down by using clear and

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**The Value of the One Health Approach**
At the same time, stronger and joint surveillance and risk assessment are required at the animal-human interface to serve as a safety net for those emergence events that occur despite any mitigation policies that are in place. Monitoring of both livestock and wildlife animal populations is fundamental to identifying and assessing these emerging threats at an early stage and taking appropriate action. The United Kingdom fulfills this need through its Human Infections and Risk Surveillance group, which conducts monthly horizon scanning to identify emerging and potentially zoonotic infections that may pose a threat to the nation’s public health. Other countries have adopted joint animal-human surveillance and risk assessment activities as well, and this One Health perspective in surveillance—integrating animal and human surveillance with human activities (particularly in human populations at greatest risk)—will likely yield a cost-effective and sustainable approach to monitoring the flow of pathogens at the human-animal-environment interface (58). A recent World Bank report (59) concluded that there is significant merit in integrating surveillance activities that cover emerging zoonosis threats (which attract considerable funding) with persistent and endemic zoonotic disease monitoring.

In summary, it not enough to identify and understand the determinants that cause emergence of an infection at the animal-human interface if mitigation of these determinants is to lead to successful prevention of emergence. Various evidence-based mitigation strategies must be proposed, their cost-effectiveness assessed and understood, and scenarios developed that clearly provide the information needed by those responsible for the policies across sectors that deal with issues including animal and human health, trade, education, and urban planning. Working together to prevent infections at the human-animal interface requires a true One Health approach.

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