ZOONOTIC DISEASES: CLASSIFICATION, GLOBAL BURDEN AND THE ONE HEALTH IMPERATIVE

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Abstract

Zoonotic diseases infections that pass naturally between vertebrate animals and humans are among the most pervasive and consequential of all health threats, accounting for roughly six in ten human infectious diseases and the great majority of those that have emerged in recent decades. This review provides a structured overview of zoonoses for a veterinary and allied-sciences readership. We begin with definitions and terminology, then classify zoonoses by causative agent (viral, bacterial, parasitic, fungal and prion), by route of transmission (direct contact, food- and water-borne, vector-borne and airborne), and by epidemiological pattern (endemic, epidemic and emerging). We summarise the staggering global and Indian burden, noting that a small group of zoonoses cause billions of human illnesses and millions of deaths each year, concentrated among the rural poor, and that India ranks among the world's principal hotspots. Representative diseases are reviewed across the major agent groups rabies, avian influenza, Nipah, Ebola and COVID-19 among the viruses; brucellosis, leptospirosis, anthrax and bovine tuberculosis among the bacteria; toxoplasmosis, echinococcosis and cysticercosis among the parasites—alongside the food-borne and vector-borne dimensions of the problem. We then examine the ecological and socio-economic drivers of emergence, the principles of diagnosis, surveillance, prevention and control, and the central role of the One Health approach and of veterinarians within it. The recurring message is that animal, human and environmental health are inseparable, and that managing zoonoses is therefore a shared, cross-sectoral responsibility.

Keywords: Zoonoses; classification; global burden; One Health; emerging infectious diseases; foodborne disease; surveillance; veterinary public health

Introduction

Every year on 6 July the world observes World Zoonoses Day, marking the anniversary of Louis Pasteur's first rabies vaccination in 1885 and serving as an annual reminder that the boundary between animal and human health is, in reality, porous. The word "zoonosis", derived from the Greek for animal and disease, describes any infection that is transmitted naturally between vertebrate animals and people. Far from being a marginal category, zoonoses dominate the landscape of human infectious disease. Foundational analyses have repeatedly shown that more than sixty per cent of the pathogens known to infect humans are shared with animals, and that the proportion is higher still—around three-quarters—among pathogens that have emerged or re-emerged in recent decades, the majority of which originate in wildlife (Taylor et al., 2001; Jones et al., 2008; Karesh et al., 2012).

The practical importance of this fact is difficult to overstate. Zoonoses span the full diversity of infectious agents and the full range of human activity, from the dog bite that transmits rabies in a village street to the contaminated food that causes salmonellosis in a city, the mosquito that carries a virus from livestock, and the wildlife market that launches a pandemic. They impose an enormous and inequitably distributed burden, falling hardest on the rural poor and on livestock-keeping communities in low- and middle-income countries, and they are a recurring source of the epidemics and pandemics that periodically destabilise global health and economies. This review sets out to provide a coherent, broad overview of zoonotic diseases—their definitions and terminology, their classification, their burden, their major representatives across each class of pathogen, the forces that drive their emergence, and the principles of their diagnosis, prevention and control—before arguing that the unifying response to all of them is the One Health approach, within which the veterinary profession occupies a pivotal position.

Definitions, terminology and historical perspective

A zoonosis, in the classical definition adopted by the World Health Organization, is a disease or infection naturally transmissible between vertebrate animals and humans. Several related terms refine this idea. Anthropozoonoses are infections transmitted from animals to humans, while zooanthroponoses (sometimes called reverse zoonoses) move in the opposite direction, from humans to animals—a phenomenon documented, for example, when human respiratory viruses infect great apes or when SARS-CoV-2 spread from people to mink and other animals. Where a pathogen is maintained within an animal population with frequent spillover to people, it is described as enzootic in the reservoir; sapronoses, by contrast, are acquired from an environmental rather than an animal source, with the boundary occasionally blurred for organisms such as those causing leptospirosis or anthrax that persist in soil and water.

Awareness of disease passing from animals to people is ancient: rabies was described in antiquity, and the link between cattle and human tuberculosis, or between rodents and plague, was recognised long before the responsible organisms were identified. The modern, systematic understanding of zoonoses, however, grew from the germ theory of the nineteenth century and from the recognition during the twentieth and twenty-first centuries—through HIV/AIDS, severe acute respiratory syndrome, pandemic influenza and COVID-19—that the animal–human interface is the wellspring of many of humanity's gravest infectious threats (Karesh et al., 2012). It is this realisation that has propelled zoonoses from a veterinary curiosity to the centre of global health policy.

Classification of zoonoses

Because zoonoses are so numerous and varied, they are most usefully approached through complementary systems of classification. The three most common schemes group them by the type of causative agent, by the route of transmission, and by their epidemiological pattern (Karesh et al., 2012).

By causative agent

The most fundamental classification is by the kind of pathogen involved. Viral zoonoses include rabies, the avian and swine influenzas, Nipah and Hendra, the filoviruses Ebola and Marburg, and the coronaviruses responsible for severe acute respiratory syndrome, Middle East respiratory syndrome and COVID-19 (Figure 1). Bacterial zoonoses encompass brucellosis, leptospirosis, anthrax, bovine tuberculosis, salmonellosis and other food-borne infections, plague and Q fever. Parasitic zoonoses divide into those caused by protozoa, such as toxoplasmosis, leishmaniasis and trypanosomiasis, and those caused by helminths, such as echinococcosis (hydatid disease), taeniasis and cysticercosis, and trichinellosis. Fungal zoonoses, though less prominent, include the dermatophytoses such as ringworm transmitted from companion animals. Finally, the prion diseases—most notably bovine spongiform encephalopathy and its human counterpart, variant Creutzfeldt–Jakob disease—represent a distinctive class of transmissible protein-only agents (Karesh et al., 2012; Torgerson and Macpherson, 2011). These groupings are summarised in Table 1.

Table 1. Classification of zoonoses by type of causative agent, with representative examples.

Agent group	Representative zoonoses	Typical reservoir / source
Viruses	Rabies; avian and swine influenza; Nipah; Ebola; COVID-19; mpox	Dogs, birds, pigs, bats, wildlife
Bacteria	Brucellosis; leptospirosis; anthrax; bovine tuberculosis; salmonellosis; plague; Q fever	Cattle, rodents, poultry, livestock
Protozoan parasites	Toxoplasmosis; leishmaniasis; trypanosomiasis; cryptosporidiosis	Cats, sandflies, tsetse flies, livestock
Helminth parasites	Echinococcosis; taeniasis/cysticercosis; trichinellosis	Dogs, pigs, cattle
Fungi	Dermatophytosis (ringworm); sporotrichosis	Companion animals, soil
Prions	Bovine spongiform encephalopathy / variant CJD	Cattle

By route of transmission

A second, highly practical classification rests on how the pathogen actually reaches people, because the route of transmission dictates the means of prevention (Figure 1). Direct-contact zoonoses are acquired through bites, scratches, or contact with the saliva, blood, urine or tissues of an infected animal, as in rabies, brucellosis and anthrax. Food-borne and water-borne zoonoses are acquired by ingesting contaminated animal products or water, as in much salmonellosis, brucellosis from unpasteurised dairy, taeniasis from undercooked pork or beef, and many causes of diarrhoeal disease. Vector-borne zoonoses depend on an arthropod intermediary—mosquitoes, ticks, fleas or sandflies—as in Japanese encephalitis, Crimean–Congo haemorrhagic fever, plague and leishmaniasis. Airborne or aerosol zoonoses, such as Q fever and certain influenzas, spread through inhalation of infectious particles. These routes, with examples, are set out in Table 2.

Table 2. Principal routes of zoonotic transmission, with examples.

Route	Mechanism	Example zoonoses
Direct contact	Bites, scratches, contact with saliva, blood, urine or tissues	Rabies, brucellosis, anthrax, leptospirosis
Food- and water-borne	Ingestion of contaminated animal products or water	Salmonellosis, taeniasis, brucellosis, toxoplasmosis
Vector-borne	Transmission by mosquitoes, ticks, fleas or sandflies	Japanese encephalitis, plague, leishmaniasis, CCHF
Airborne / aerosol	Inhalation of infectious droplets or dust	Q fever, avian influenza
Environmental / fomite	Contact with contaminated soil, surfaces or fomites	Anthrax, ringworm

By epidemiological pattern

A third scheme, particularly useful for prioritisation, distinguishes zoonoses by their behaviour in populations. Endemic (or enzootic) zoonoses are persistently present across wide areas and affect large numbers of people and animals year after year; rabies, brucellosis and the food-borne bacterial infections are classic examples, and it is this endemic group that imposes the greatest steady burden on human health and livelihoods. Epidemic or outbreak zoonoses, such as anthrax and Rift Valley fever, occur sporadically as clusters in time and space. Emerging zoonoses are those newly recognised in a population, or previously known but rapidly increasing in incidence or geographic range; many, like avian influenza, Nipah and SARS-CoV-2 (Figure 1), first announce themselves as outbreaks and carry the potential to ignite epidemics or pandemics (Grace et al., 2012; Karesh et al., 2012).

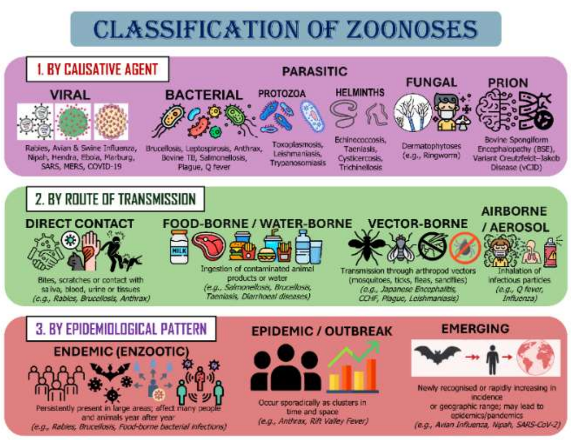

Fig. 1. Classification of zoonoses based on causative agent, route of transmission, and epidemiological pattern

Zoonotic diseases can be classified according to the type of etiological agent (viral, bacterial, parasitic, fungal, and prion), the principal route of transmission to humans (direct contact, food- and water-borne, vector-borne, and airborne/aerosol), and their epidemiological behaviour (endemic/enzootic, epidemic/outbreak, and emerging). This multidimensional classification facilitates the understanding of pathogen diversity, transmission dynamics, disease surveillance, prevention strategies, and public health prioritization within the One Health framework.

The global and Indian burden

The scale of the zoonotic burden becomes clear only when the many individual diseases are considered together. A landmark mapping study that reviewed fifty-six zoonoses estimated that, collectively, they cause on the order of two and a half billion cases of human illness and around two point seven million human deaths every year, with a top tier of thirteen diseases accounting for the bulk of this toll; crucially, the study found that the burden is concentrated overwhelmingly in low- and middle-income countries and among the world's roughly one billion poor livestock keepers (Grace et al., 2012). A complementary analysis emphasised that endemic and enzootic zoonoses alone—the persistent, everyday infections rather than the headline-grabbing outbreaks—cause about a billion cases of illness and millions of deaths annually, making them the single greatest zoonotic burden on human health (Karesh et al., 2012).

Food-borne disease, much of it zoonotic in origin, adds enormously to this total. The World Health Organization's first global estimates concluded that, in a single reference year, foodborne hazards caused around six hundred million illnesses and four hundred and twenty thousand deaths worldwide, with a disease burden comparable to that of malaria, HIV or tuberculosis (Havelaar et al., 2015). A substantial fraction of the world's diarrhoeal disease has a zoonotic component, and bacterial food-borne infection is widespread in livestock in poor countries (Grace et al., 2012).

India sits at the epicentre of this burden. The same global mapping placed India among the small handful of countries—alongside Ethiopia, Nigeria and Tanzania—that together carry the heaviest zoonotic disease load, by virtue of their large populations of poor livestock keepers, high levels of malnutrition and intense human–animal contact (Grace et al., 2012). India bears a major share of the world's rabies deaths, experiences recurrent outbreaks of Nipah virus, and contends with a heavy load of brucellosis, leptospirosis, Japanese encephalitis and food-borne and parasitic zoonoses. For a country with a vast livestock economy and dense rural and peri-urban populations, zoonoses are simultaneously a public-health challenge, an economic drag on animal production and a matter of food safety and rural livelihoods.

Major viral zoonoses

Viruses account for many of the most lethal and most feared zoonoses. Rabies, caused by a lyssavirus and transmitted overwhelmingly by the bite of an infected dog, remains the archetype: it is almost invariably fatal once symptoms appear and still causes an estimated fifty-nine thousand human deaths each year, predominantly in Africa and Asia, despite being entirely vaccine-preventable (Hampson et al., 2015; World Health Organization, 2024). The influenza A viruses constitute a second major group; highly pathogenic avian influenza of the H5N1 subtype circulates in wild birds and poultry and has repeatedly spilled into mammals, including a striking outbreak in dairy cattle in the United States in 2024 with infection of farm workers, an event that sharpened concern about the pandemic potential of the virus (Caserta et al., 2024).

The henipaviruses Nipah and Hendra, harboured by fruit bats of the genus *Pteropus*, cause severe encephalitis with very high case-fatality; Nipah has produced recurrent and lethal outbreaks in India, beginning in West Bengal in 2001 and recurring in Kerala from 2018, and there is as yet no licensed vaccine or specific treatment (Chadha et al., 2006; Arunkumar et al., 2019). The filoviruses Ebola and Marburg, associated with bats as reservoir hosts, cause explosive haemorrhagic-fever outbreaks in Africa with international reach (Leroy et al., 2005). Above all, the COVID-19 pandemic—whose weight of evidence points to a zoonotic emergence linked to the wildlife trade at a market in Wuhan—demonstrated with devastating clarity how a single spillover of a novel coronavirus can reshape the world (Worobey et al., 2022; Holmes, 2024). Mpox, an orthopoxvirus disease of African wildlife, similarly moved from obscurity to a declared global health emergency in 2022 (Bunge et al., 2022).

Major bacterial zoonoses

Bacterial zoonoses, though often less dramatic than viral outbreaks, impose a heavy and chronic burden, particularly on livestock-keeping communities. Brucellosis, caused by *Brucella* species and acquired from infected animals or unpasteurised dairy products, is one of the most widespread zoonoses worldwide, causing debilitating undulant fever in people and substantial reproductive losses in cattle, sheep, goats and pigs; its global distribution and persistence make it a model neglected zoonosis (Pappas et al., 2006). Leptospirosis, caused by *Leptospira* spirochaetes shed in the urine of rodents and livestock and transmitted through contaminated water, is estimated to cause on the order of a million severe human cases and tens of thousands of deaths each year, with a burden that rises after flooding and in occupational and slum settings (Costa et al., 2015).

Anthrax, caused by the spore-forming *Bacillus anthracis*, persists in soil for decades and infects people who handle diseased livestock or contaminated animal products. Bovine tuberculosis, caused by *Mycobacterium bovis*, passes to humans chiefly through unpasteurised milk and remains an under-recognised contributor to human tuberculosis in many regions. Salmonellosis and related food-borne bacterial infections are leading causes of diarrhoeal disease acquired from contaminated meat, eggs and dairy. Plague, caused by *Yersinia pestis* and transmitted from rodents by fleas, and

Q fever, caused by *Coxiella burnetii* and acquired by inhalation from livestock, complete a picture in which bacterial zoonoses straddle direct contact, food, water, vectors and aerosols (Karesh et al., 2012; Grace et al., 2012).

Parasitic, fungal and prion zoonoses

Parasitic zoonoses are among the most prevalent yet most neglected infections of the rural poor, and they carry a substantial socioeconomic cost through chronic ill health and lost livestock productivity (Torgerson and Macpherson, 2011). Among the protozoa, toxoplasmosis—caused by *Toxoplasma gondii*, whose definitive hosts are cats—is extraordinarily common and of particular danger in pregnancy and immunosuppression; the leishmaniases, transmitted by sandflies from animal reservoirs, and the trypanosomiases, spread by tsetse flies and triatomine bugs, cause major disease across the tropics. Among the helminths, cystic echinococcosis (hydatid disease), caused by the dog tapeworm *Echinococcus granulosus*, and taeniasis with its serious sequel neurocysticercosis, caused by the pork tapeworm *Taenia solium*, are leading causes of preventable epilepsy and chronic disease in endemic regions, while trichinellosis is acquired from undercooked pork.

Fungal zoonoses are comparatively minor in mortality but common in practice; the dermatophytoses, the ringworm infections transmitted from companion animals and livestock, are a frequent reason for human and veterinary consultation. The prion diseases occupy a category of their own: bovine spongiform encephalopathy, the "mad cow disease" that emerged in cattle in the 1980s and 1990s, crossed to humans as variant Creutzfeldt–Jakob disease through the consumption of contaminated beef products, a sobering demonstration that even non-living, protein-only agents can move from animals to people and that food-chain integrity is a genuine public-health concern.

The food-borne and vector-borne dimensions

Two cross-cutting themes deserve emphasis because they shape both the burden and the control of zoonoses. The first is food safety. A large share of zoonotic disease is acquired through the food chain—through meat, milk, eggs and produce contaminated at any point from farm to fork—and the global toll of food-borne disease, much of it of animal origin, runs to hundreds of millions of illnesses and hundreds of thousands of deaths each year (Havelaar et al., 2015). This places hygienic animal husbandry, meat inspection, pasteurisation, cold-chain integrity and consumer education squarely within the remit of zoonotic disease control, and it underlines the central role of veterinary public health in protecting the food supply.

The second theme is vector-borne transmission. A significant group of zoonoses depends on arthropod vectors that bridge animal reservoirs and human hosts: Japanese encephalitis, maintained in pigs and waterbirds and transmitted by mosquitoes, is a leading cause of childhood viral encephalitis in Asia; Crimean–Congo haemorrhagic fever and Kyasanur Forest disease are tick-borne; plague is flea-borne; and the leishmaniases are spread by sandflies. Because vector populations are exquisitely sensitive to temperature, rainfall and land use, vector-borne zoonoses are among the most responsive to climate and environmental change, a point with direct implications for the future distribution of disease.

Drivers of emergence and re-emergence

Why do zoonoses emerge and re-emerge as persistently as they do? The answer lies in a set of human-driven pressures that intensify contact between people and animals and disturb the ecological balances that ordinarily keep pathogens confined to their reservoirs. Deforestation and the conversion of habitat for agriculture, the encroachment of expanding settlements on wild areas, the intensification and crowding of livestock and poultry production, live-animal markets and the legal and illegal wildlife trade, the unprecedented volume and speed of global travel and commerce, and changing land and water use all enlarge the interface across which pathogens can spill into humans (Daszak et al., 2000; Jones et al., 2008; Karesh et al., 2012).

It is helpful to recognise that spillover is not a single event but the successful negotiation of a hierarchical series of barriers: a pathogen must be present and prevalent in its reservoir, be released, survive in the environment, reach a person in an adequate dose and by a suitable route, and then overcome the host's defences to establish infection (Plowright et al., 2017). Each barrier is also a point of intervention. Mapping of emerging zoonotic events has identified hotspots concentrated in biodiverse tropical regions undergoing rapid land-use change and overlapping with dense human populations—regions that prominently include South and Southeast Asia (Allen et al., 2017). Climate change adds a further, forward-looking dimension: modelling of mammalian range shifts predicts thousands of novel species encounters and new opportunities for viral spillover in the coming decades, concentrated in the very regions that are already most affected (Carlson et al., 2022). Taken together, these analyses argue for a strategic shift from reacting to outbreaks toward predicting and preventing emergence at its source (Morse et al., 2012).

Diagnosis and surveillance

Accurate diagnosis and robust surveillance are the foundations on which all zoonotic disease control rests, yet they are frequently the weakest links in endemic settings. Diagnosis draws on the full toolkit of modern microbiology: direct detection of the agent by microscopy, culture, antigen tests or, increasingly, molecular methods such as polymerase chain reaction and genome sequencing; and indirect detection through serology that measures the host's antibody response. Each zoonosis has its own diagnostic peculiarities—the post-mortem fluorescent antibody test for rabies, blood culture and serology for brucellosis, or stool and imaging studies for the helminthic infections—but the common requirement is laboratory capacity close to where cases occur.

Surveillance for zoonoses is distinctive in that it must span both animal and human populations, because outbreaks in people are very often preceded by, or coincide with, disease in animals. Integrated, cross-sectoral surveillance—linking veterinary and medical reporting, sharing data in real time, and investigating events jointly—allows threats to be detected earlier and resources to be targeted more efficiently. Where such systems are weak, cases go unreported and the true burden is chronically underestimated, which in turn undermines the case for investment. Strengthening surveillance, including genomic surveillance capable of characterising novel pathogens, is therefore a recurring priority of national and international strategies (Morse et al., 2012).

Prevention and control

The control of zoonoses operates at several complementary levels. At the level of the animal reservoir, vaccination of domestic animals (as in mass dog vaccination against rabies or livestock vaccination against brucellosis and anthrax), test-and-cull programmes for diseases such as bovine tuberculosis, vector control, and humane management of animal populations all act to reduce the pathogen at its source. At the interface, good animal husbandry, biosecurity on farms, hygienic slaughter and meat inspection, pasteurisation of milk, safe handling of animals and animal products, and the use of personal protective measures by those occupationally exposed all reduce the chance of transmission. At the level of the human host, vaccination where available, post-exposure prophylaxis (most importantly for rabies), prompt treatment, and public education complete the chain of defence.

Underpinning all of these is the principle that prevention at source is generally more effective and, over time, more economical than repeatedly treating human cases—a logic demonstrated clearly for rabies, where sustained dog vaccination is ultimately cost-saving compared with indefinite reliance on human prophylaxis. The same reasoning extends across the zoonotic spectrum and provides the economic rationale for investing in animal and environmental health as a means of protecting people. For emerging zoonoses specifically, reducing the upstream ecological drivers of spillover—protecting habitat, regulating the wildlife trade and improving the conditions of animal production—offers the prospect of preventing outbreaks before they begin (Plowright et al., 2017; Morse et al., 2012).

One Health and the role of the veterinarian

No single sector can control zoonoses, because zoonoses by definition straddle the divide between animal, human and environmental health. One Health is the formal expression of this insight: as articulated by the international expert panel that advises the global health agencies, it is an integrated, unifying approach that seeks to sustainably balance and optimise the health of people, animals and ecosystems, recognising their close interdependence and organised around communication, collaboration, coordination and capacity building (Adisasmito et al., 2022). Institutionally it is carried forward by the Quadripartite of the World Health Organization, the World Organisation for Animal Health, the Food and Agriculture Organization and the United Nations Environment Programme,

once outbreaks occur (Grace et al., 2012; Karesh et al., 2012).

The way forward follows from these gaps. It requires strengthening and integrating

which promote multisectoral action at the human–animal–ecosystem interface.

Within this framework, the One Health agenda extends beyond classical infections to encompass antimicrobial resistance, a slow-moving emergency in which the use of antimicrobials in human medicine, animal production and the environment together select for resistant organisms that move freely among all three compartments. Managing resistance, like managing zoonoses, demands precisely the coordinated, cross-sectoral stewardship that One Health is designed to deliver. Veterinarians are central to this entire enterprise. They are often the first to detect unusual disease in animals, they possess the skills for vaccination, herd-health management, diagnosis and food inspection, and they move routinely among farm, clinic, laboratory, market and wildlife. Investing in veterinary services and in the communication between the animal- and human-health sectors is therefore not a narrow professional concern but a direct investment in the protection of human health and in pandemic preparedness.

Challenges and the way forward

Several obstacles stand between current knowledge and effective control. Surveillance and diagnostic capacity remain inadequate in many high-burden settings, so that cases are missed and the true scale of the problem is underestimated. Many zoonoses—rabies, brucellosis, the helminthic infections and others—fall into the category of neglected zoonotic diseases that disproportionately affect the poor and struggle to command sustained funding and political attention. Coordination between the veterinary, medical and environmental sectors, though improving, is still too often improvised rather than institutionalised, and the resources devoted to prevention are dwarfed by the costs incurred

animal and human surveillance, expanding laboratory and genomic capacity in endemic districts, scaling up the proven interventions of animal vaccination, food-safety regulation and vector control, ensuring access to human vaccines and prophylaxis, and shifting investment upstream toward the prevention of spillover by protecting ecosystems and improving the conditions of animal production. For India in particular, which combines an enormous livestock economy, dense populations and a position within recognised emergence hotspots, building durable One Health capacity offers a double dividend: it reduces the heavy everyday burden of endemic zoonoses while also strengthening the nation's defences against the next emerging threat (Allen et al., 2017; Morse et al., 2012).

Conclusion

Zoonotic diseases are not a peripheral category of illness but a defining feature of the human infectious-disease landscape, responsible for the majority of known and emerging human pathogens and for billions of illnesses and millions of deaths each year. They span every class of agent and every route of transmission, from the ancient scourge of rabies to the novel coronavirus that recently halted the world, and they fall hardest on the poorest communities and on those who live closest to animals. Yet the diversity of zoonoses conceals a fundamental unity: all of them arise at the interface of animal, human and environmental health, and all of them yield to the same broad response—vigilant surveillance, prevention at the animal source, food and vector control, accessible human countermeasures, and, above all, the cross-sectoral collaboration embodied in the One Health approach. World Zoonoses Day is a fitting occasion to reaffirm that protecting human health is inseparable from protecting the health of animals and the environment, and that veterinarians stand at the very heart of that shared task.

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