

# Current drivers and future directions of global livestock disease dynamics

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Edited by Philip Thornton, Consultative Group on International Agricultural Research, Edinburgh, United Kingdom, and accepted by the Editorial Board March 25, 2011 (received for review September 2, 2010)

We review the global dynamics of livestock disease over the last two decades. Our imperfect ability to detect and report disease hinders assessment of trends, but we suggest that, although endemic diseases continue their historic decline in wealthy countries, poor countries experience static or deteriorating animal health and epidemic diseases show both regression and expansion. At a mesolevel, disease is changing in terms of space and host, which is illustrated by bluetongue, Lyme disease, and West Nile virus, and it is also emerging, as illustrated by highly pathogenic avian influenza and others. Major proximate drivers of change in disease dynamics include ecosystem change, ecosystem incursion, and movements of people and animals; underlying these are demographic change and an increasing demand for livestock products. We identify three trajectories of global disease dynamics: (i) the worried well in developed countries (demanding less risk while broadening the circle of moral concern), (ii) the intensifying and market-orientated systems of many developing countries, where highly complex disease patterns create hot spots for disease shifts, and (iii) the neglected cold spots in poor countries, where rapid change in disease dynamics is less likely but smallholders and pastoralists continue to struggle with largely preventable and curable livestock diseases.

disease drivers | spatial and host dynamics | diversity of disease trajectories

The current era of globalization is seeing unprecedented movements of people, products, capital and information. Although this has obvious implications for economies and ecosystems, globalization also affects the health of people and animals (1). This paper reviews changing patterns of livestock disease over the last two decades, discusses the drivers of these patterns, and plots future trajectories of livestock disease risk in an effort to capitalize on our understanding of the recent past and provide a guide to the uncertain future.

## Changing Capacity to Detect and Report Livestock Diseases

Is the world becoming sicker, or are we just better able to detect disease? This rhetorical question is best answered by reviewing recent developments. The last decades have seen dramatic improvements in disease detection, with dozens of new potential pathogens anticipated by 2020 (2). Metagenomics allows us to study microorganisms by extracting DNA, bypassing the need for culture, and it is revealing novel microbes, some of which may be responsible for diseases whose etiology is currently unknown. Technological advancement has, for example, (i) revealed mimiviruses and mamaviruses [scarcely known a decade ago and now considered the most complex viruses (larger than some bacteria) and among the most common], (ii) found a virus that parasitizes other viruses in a hitherto unknown biological relationship, and (iii) discovered aquatic viruses related to African swine fever, suggesting that this terrestrial plague of pigs may have oceanic origins (3, 4).

The ability to report and share information on livestock diseases is as crucial as the ability to generate it, and here, the trends are also to more and better, despite the persistence of large areas of terra incognita on disease maps. Peer-reviewed publications are still considered the gold standard knowledge source, and their range and ease of access is expanding fast (with some concerns about deteriorating quality and emergence of a scientific vanity press). Information published in peer-reviewed journals can now traverse the globe in hours. Additionally, emerging diseases such as severe acute respiratory syndrome (SARS), highly pathogenic avian influenza (HPAI), bovine spongiform encephalopathy (BSE), foot and mouth disease (FMD), and swine flu make headline news. However, inevitably, peer-reviewed papers are biased to diseases for which research funding is readily available (by no coincidence, these are often the diseases important to rich countries) (5).

National animal disease reporting systems vary dramatically in quality, representativeness, and timeliness. Reports based on passively derived data from underfunded public services in poor countries miss many disease events. Because international agencies generally rely on data submitted by member countries, they inevitably reflect the strengths and weaknesses of the national surveillance systems that inform them.

The last decades have seen more use of climate, remote-sensing, trade and production data as ancillaries to reporting, improving forecasts, and contributing to more powerful mathematical models of disease distribution and dynamics (6). However, decision makers may fully un-

derstand the implications of the models' underlying assumptions, and the precise outputs of models may create dangerous illusions of accuracy (7). Another development is in communication technologies, leading to a growing number of independent health information brokers; probably the best known of these is ProMED ([www.promed.org](http://www.promed.org)). The internet search engines Yahoo and Google detected onsets of seasonal flu epidemics, which not only matched official surveillance data but did so some weeks in advance (8). Additionally, as printed newspapers decline, there is a widening range of outlets for discussing disease. The internet is democratizing health information, but its many to many character facilitates misleading and being misled, contributing to an increased pathophobia or exaggerated dread of disease (9).

## Major Trends in Disease Dynamics

Bearing in mind the biases introduced by partial and evolving disease detection and reporting, certain broad trends in animal disease dynamics may be tentatively deciphered. From a centuries-long and whole-world perspective, human wealth and health continue to improve (10), and animal health parallels this, showing an overall dramatic decline of infectious disease and shift to noncommunicable

Author contributions: B.D.P. designed the structure of the paper; and B.D.P., D.G., and K.S. wrote the paper.

The authors declare no conflict of interest.

This article is a PNAS Direct Submission. P.T. is a guest editor invited by the Editorial Board.

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diseases. (This has been called the second epidemiological transition; the first epidemiological transition was 10,000 y ago, when human settlement led to a surge in zoonoses and crowd-related diseases.) Radostits, an important veterinary educator of the last century, describes major improvements in health mediated by innovations in veterinary medicine; these include more effective drugs and vaccines, improvement in diagnostic technologies and services, and more recently, preventive medicine and herd- and flock-based monitoring (11–13). Undoubtedly, the last decades have seen improved control and management of a variety of endemic diseases in intensive dairy enterprises (notably mastitis, infectious causes of infertility, gastrointestinal parasitism, and calf mortality), intensive pig production (notably erysipelas and classical swine fever), and intensive poultry production (including Newcastle disease). For example, it has been estimated that, in the United Kingdom, the number of cases of clinical mastitis decreased by more than 70% between the 1960s and late 1990s (14).

In the developing world, it seems that there has been relatively little in the way of changes in the distribution, prevalence, and impacts of many epidemic and endemic diseases of livestock, especially in Africa. Key to this difference in dynamics is the stark contrast in the development context; we return to this later when we discuss likely future trajectories of disease dynamics. However, one undeniable achievement has been the progressive control of rinderpest, leading to anticipated global eradication by 2011 (15). Another less-heralded advance has been the adoption of veterinary drugs, now widely used in even the most remote communities (usually despite, rather than enabled by, official policy). Both common sense and evidence suggest that this results in significant benefits to animal health and human livelihoods, with the tradeoff of increased drug resistance, because more drugs are used less rationally (16).

Although control and management of many endemic diseases in rich countries have improved, new diseases such as BSE and HPAI have emerged (17). Some consider that we face a third epidemiological transition of disastrous consequence in which globalization and ecological disruption drive disease emergence and reemergence (18); as occurred in the first epidemiological transition (associated with neolithic sedentarization and the domestication of livestock), the worst of the emerging diseases are likely to be zoonotic (19).

If disease trends at the macro scale remain controversial (with some proclaiming

that we have never had it so good, whereas others warn of the impending perfect microbial storm), in the here and now, disease is demonstrably changing in spatial distribution and emerging (20). In the next section, we consider some of the drivers implicated: specifically, they are ecosystem change, ecosystem incursion, and movement of people and livestock.

### Changing Spatial and Host Dynamics of Animal Disease

Natural ecosystem changes, whether deforestation, infrastructure, irrigation, or urban sprawl, all alter natural ecosystems and affect disease dynamics but not necessarily in uniform directions. Although bush clearance reduced animal sleeping sickness in Nigeria, irrigation increased liver fluke in Mali (21, 22). Pig plagues in West Africa were linked to outbreaks of sleeping sickness as tsetse vectors changed host preferences, whereas in South Africa, the same plagues may have broken the cysticercosis transmission cycle, reducing human disease burden. A current hot topic is the impact of climate change on ecosystems. Climate partially determines the distribution of vector-borne diseases and free-living pathogens, and there is concern that a warmer, wetter world will also be sicker. Climate change is clearly implicated in some disease spread; bluetongue, a serious disease of sheep, has extended its range northwards into areas of Europe (23), and African horse sickness, caused by a related virus, looks set to follow it into Europe. However, climate change is predicted to decrease other diseases, such as trypanosomiasis in subhumid West Africa (24). Additionally, many diseases are not particularly climate sensitive (e.g., brucellosis and tuberculosis). Even for those that are sensitive, climate change is but one of many disease determinants, some of which may be orders of magnitude greater than climate (25). As Malaysia became steadily warmer over the last few decades, malaria—a highly climate-sensitive disease—steadily declined, because development and large-scale antimalarial interventions dwarfed the impact of temperature on disease dynamics.

Change to agricultural ecosystems, although less eye-catching than change to natural ecosystems, also alters disease dynamics. The emergence and spread of certain food-borne pathogens, notably *Cryptosporidium parvum*, diarrheagenic *Escherichia coli*, *Listeria monocytogenes*, and *Campylobacter jejuni*, have been linked to intensive farming systems. These allow pathogens to enter the food chain at its source, and because they cause few visible ill effects on animal hosts or visible changes to meat, they are able to flourish without detection along the farm to fork pathway. At the same time, market concentration in

food processing and distribution facilitates widespread outbreaks, which are often well-removed from the source (26). However, from a disease perspective, intensification is not all bad news, and moving from intensive indoor production to extensive outdoor production can increase the risk of some diseases, such as HPAI in range turkeys and zoonotic diseases in outdoor pigs (27).

Ecosystem incursion, when people and their livestock invade natural ecosystems encountering long-standing ecological climaxes, can also affect disease dynamics. A notorious example is Lyme disease, first identified in 1975 after a mysterious outbreak of arthritis among the residents of Lyme, Connecticut in the United States; in the next few decades, clinical disease was recognized in dogs, horses, and cattle (28). The increasing importance of this disease in the United States as well as in continental Europe is linked to changing recreational use of the habitats where the tick vector abounds (29).

Movement, whether of people, livestock, or livestock products, is the third major cause of changed spatial dynamics. It is of particular importance in FMD, one of the most infectious diseases known to date; new outbreaks are often associated with the movement of infected animals (30). There is current debate as to whether the ongoing pandemic of HPAI is spread mainly by highways or flyways (that is, by movements of poultry and poultry products or migratory movement of wild bird reservoir hosts) (31). After introduction, it seems that poultry and poultry products are the primary pathway.

Disease dynamics are complex and not always reducible to single drivers. Many useful conceptual frameworks have been developed to illustrate generic drivers of diseases and their interactions (32–34). However, the complexity (sometimes counterintuitive) may best be understood through concrete examples; we use the case of tick-borne encephalitis (TBE) in the Baltics (35, 36). As well as being a disease of domestic animals, TBE is an important zoonosis, and recent insights into its epidemiology have broader relevance to other diseases. Estonia, Latvia, and Lithuania suffered an abrupt upsurge of TBE in the early 1990s, and it was first suspected that climate change was the culprit. However, climate change was a general phenomenon, whereas increased incidences of TBE were more localized. Deeper investigation implicated a complex mixture of factors, including reduction in air pollution after the fall of communism led to collapse of industry, collapse of collective farming (both agricultural and livestock production) led to changes in land cover that favored the abundance of the rodent hosts of TBE infections, and decreased demand

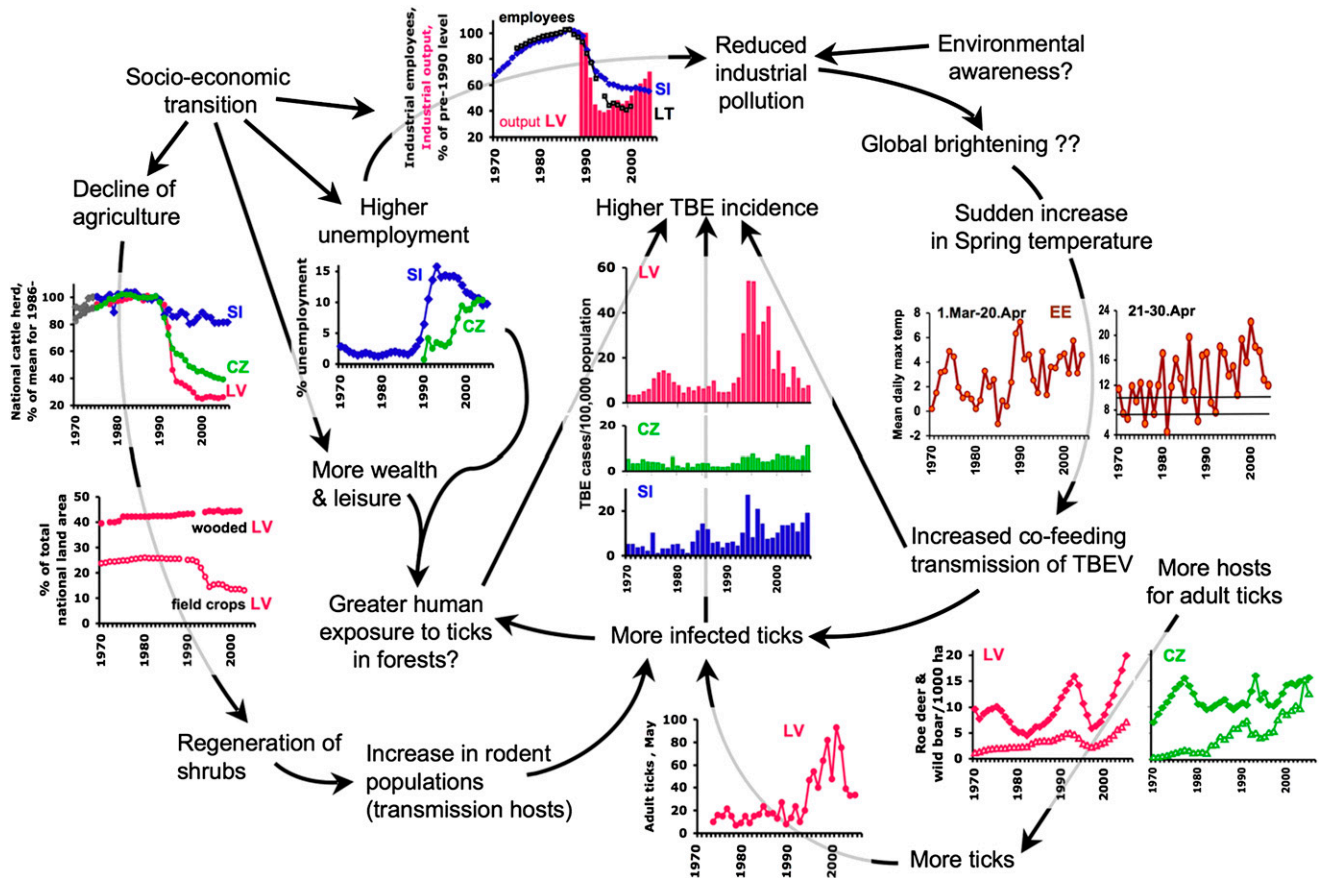


Fig. 1. Complex drivers of tick-borne encephalitis incidence in the Baltic states. [Reproduced with permission from S. Randolph (Copyright 2008, Elsevier).]

for labor in both industry and agriculture precipitated certain lifestyle changes, resulting in an increased interaction with forest habitats inhabited by rodents and ticks. The possible association of these different factors is illustrated in Fig. 1.

Disease emergence can be seen as a special case of dynamics in which disease agents increase their host range, which is often followed by geographic expansion. The largest threat in this category is from RNA viruses, such as SARS, the Heninipah viruses, HPAI viruses, and emerging lyssa viruses (37). One possible explanation for their susceptibility to change is that high nucleotide substitution rates for RNA viruses permit rapid adaptation, greatly increasing the chances of successfully invading a new host population (38).

**Drivers of Changing Disease Dynamics**

Ecosystem change, ecosystem incursion, and mass movement of people and animals are themselves manifestations of deeper drivers or causes of causes. Concern over climate change has sparked a plethora of futures studies. Although most do not address livestock diseases (a notable exception being the Foresight publications produced by the UK government; [www.foresight.gov.uk](http://www.foresight.gov.uk)), there is consensus that

infectious diseases are important and will remain so. For example, in a recent expert review of the top 100 priorities for agriculture, 12 were health-related (39).

Futures studies are based on the identification and extrapolation of drivers of change. Here, we consider the drivers with greatest influence on livestock disease dynamics, namely increasing human population size and prosperity and the related demand-driven Livestock Revolution.

The world's population is growing, albeit more slowly (2.5 billion in 1950 to 6.9 billion in 2010); it is estimated to reach 9.2 billion by 2050 (40). Most growth is in the humid tropics, which have higher disease burdens than temperate or drier regions. Growth is accompanied by massive urbanization (41), which includes animals; more than one-half of the world's population now live in cities, and in poorer countries, livestock is kept in close proximity to people, often in cramped and unsanitary conditions (42). Livestock diseases and zoonoses associated with urbanization are becoming more important, and literate, media-aware, and connected urban populations are demanding more control of zoonotic and food-borne diseases. At the same time, the dramatic increase in the mobility of the world's population (for ex-

ample, the over sixfold increase in air passenger travel between 1990 and 2007) (43) is challenging for effective control of movement-associated diseases.

Our second main driver, the Livestock Revolution, is the term given to the enormous, demand-driven increase in consumption of livestock products (44), especially poultry meat, eggs, and pork driven by population and economic growth in developing countries (45). In countries where consumption has increased the most rapidly, particularly in Asia and Latin America, there has been a trend to larger-scale commercial livestock production enterprises and greater intensification, with a parallel exit from small-scale farming to more lucrative income-generating activities; for example, 70 million small-scale farmers in China ceased keeping poultry between 1996 and 2005 (46). We would expect this to lead to a gradual decline in those endemic and epidemic diseases that are both easier and more important to control in intensive systems, an increase in diseases associated with animal crowding and environmental degradation, and an increase in the food-borne diseases that often have few impacts on animal hosts and are associated with

poorly regulated intensive production (e.g., *Campylobacter* infections in poultry).

Parts of the developing world (notably sub-Saharan Africa) have been largely left behind in the Livestock Revolution, whereas others are adopting their own development path. For example, in many developing countries, there is a persistence of wet markets (selling live animals) and other informal sales channels (e.g., milk hawkers) and a strong preference for local meat and milk products (47). In some settings, the growing demand for livestock products is being partly met by upgrading smallholder production and traditional distribution channels.

The Livestock Revolution is associated with a large increase in global trade in livestock products. This can increase availability of livestock products and provide income for producers and other actors in the value chain, but it also increases the risk of infectious agent transmission. Some countries are unable to meet increased demand from local production; this is especially the case for milk. Most tropical developing countries are not well-suited to milk production based on high-yielding but heat-intolerant dairy breeds, and they rely instead on bulk imports of various dried milk powders. Between 1983 and 2003, the global trade in meat, by volume, increased by a factor of 2.6 and milk increased by a factor of 1.7 (48). This trade is dominated by a few actors; currently, just nine countries account for 96% of beef exports; Brazil went from a zero share in 1973 to more than one-fifth of the market by 2003 (48). When livestock trade is concentrated in the hands of a few large actors, we might expect the risks of disease transmission to be less than when dominated by many small, diverse players. However, if disease does break through, then the impacts will be wider and deeper. A particular area of concern is novel diseases, such as BSE, which was moved around the globe before its presence in meat, bone meal, and live animals was fully understood.

Linked to these deeper drivers are changes in human behavior, institutions, industries, policies, and technologies. In highlighting a few trends with potential to influence disease dynamics, we draw attention to the genetic revolution brought about by genome sequencing and fast, automated genetic manipulation (49); the acceleration of drug resistance (50, 51); the demise of paternalism and the growth of autonomy in healer–client relations; the consolidation of the pharmaceutical industry (52); the feminization of the veterinary profession (53); the growth of participation in livestock development [increased involvement of Nongovernmental Organizations (NGOs)] and promotion of Community Animal Health

Workers (CAHW) (54); the emergence of a global middle class with similar fears about food safety and disease; the emergence of global animal health standards under the aegis of the World Organization for Animal Health; the paradoxical predominance of private standards in retail of livestock and livestock products; the widening circle of moral concern from humans to the welfare of animals and ecosystems; and the current momentum to integrate human, animal, and even ecosystem health (Ecohealth and One Health; <http://www.onehealthinitiative.com>).

In summarizing the relative importance of different drivers of change, the most important issue here is the rapidly increasing demand for livestock products and marketing opportunities in developing countries, which is fueled by population growth, urbanization, and increasing incomes; another issue is the more fuzzy and poorly delineated impacts of climate change.

### Diversity of Disease Trajectories

Having synthesized the drivers of changing disease dynamics and the drivers of drivers, this last section looks at the evolving context of animal diseases and their control in different global settings, which we depict as three trajectories. Building on the arguments of the previous sections, we identify three overarching sets of animal diseases dynamics and associated control. Each system is facing different risks to livestock health, each has different determinants of disease status and capacity to respond, and each requires different approaches to resolve them. Underlying these trajectories is the determined and steady global trend to greater intensification of livestock systems and the benefits and challenges that it brings to animal health status. Threatening this trend is the risk of a third epidemiological transition and dramatic deterioration of animal and human health as the result of emerging and reemerging disease. Additionally, in the background is the significant component of the world's livestock enterprises in the hands of the very poor, for whom intensification is just not a realistic option and who are likely to be most vulnerable to disease resurgence.

The first trajectory is being traveled by the intensified and increasingly threatened worried well of the Western world. Their system is characterized by progressive disease control, progressively improving systems of disease management and disease preparedness, progressive public concern over animal welfare and environmental pollution, continuing intensification of production systems, and increasing availability of technological and methodological options for disease management and control combined with an

increasing awareness, even paranoia, about new emerging and invading disease threats: a sealed but threatened fortress first world.

Where animal production is progressively intensified, large-scale and industrial intellectuals and opinion setters seem more likely to hanker after small free-range/welfare-enhanced/organic niche production systems. Driven by welfare legislation, livestock enterprises are deintensifying in some places; tethered sows and veal crates have been banned in the European Union, and battery cages for chickens are to be outlawed by 2012 (55). However, although a minority argues that agriculture is on the verge of a post-industrial transition, it seems likely that the vast majority of the market will continue to be for low-cost meat and eggs produced in highly intensive systems that continue to adapt to stricter requirements for food safety, environmental sustainability, occupational safety, and animal welfare.

Among the worried well, the incidence of many diseases has reduced, but the concern over disease has grown. Innovation in the veterinary pharmaceutical sector has been largely driven by the highly profitable companion animal sector; the biotechnology revolution has yet to make its mark on the livestock health sector, and its major impacts will probably be through cheaper feeds and better use of genetic resources. The veterinary profession is becoming increasingly dominated by women practitioners and companion animal practices, specialists are starting to replace generalists, continuing professional development is becoming mandatory, and farm animal medicine is increasingly herd-based and preventive in approach. High-profile diseases such as BSE, FMD, and HPAI have led to a huge increase in public awareness and politicization of animal disease, and they served as wake-up calls to national and regional veterinary authorities that had, perhaps, become complacent as traditional diseases became better controlled. These diseases are now under control in wealthy countries. Climate change and mass global travel seem to be increasing the risk of certain tropical diseases becoming established or introduced, such as bluetongue and West Nile; however, in the past, wealth has trumped warmth, and there is no convincing evidence that climate change will inevitably bring worse health in the West, at least in the short term.

The animal health demands of this trajectory will be in understanding and managing the ever-widening set of risks, developing new more appropriate and more acceptable response and communications tools, and bringing public and private sectors, researchers, and civil society closer together in greater harmony.

There will also be substantial demands in research that will be increasingly targeted at the health threats to their societies. Close interaction is required between public and private sectors at the national level and beyond. Collaboration, preparedness, risk assessments, and response mechanisms will increasingly need to be at the level of the broader economic or political communities (such as at the level of the European Union, for example)—health and increasingly, animal welfare standards will likely be used in place of tariff barriers as protectionist measures.

Our second trajectory is the intensifying, increasingly market-orientated but high-

risk sectors of the developing world. This category, which will progressively include larger parts of South America and Asia (but also the few progressive livestock enterprises in most regions of the developing world, including Africa), is characterized by dramatic changes in the levels of intensification, increasing interest in gaining access to higher value national, regional, and global markets for livestock products, and increasing political pressure on livestock to make more demonstrable contributions to economic growth.

This brings a corresponding focus on quality, health, traceability, and safety of commodities emerging from countries that

sometimes have substantial animal health risks associated with tropical environments, weak and inadequate animal health services, and close proximity to smallholder and pastoralist systems in which disease surveillance and control are often extremely poor. Intensive sectors are growing fast in the rapidly emerging economies, especially in poultry and pork, driven by massive increases in demand for livestock products as incomes increase and populations become more urban (56). There is a trend to vertically integrated production, with services, including animal health, becoming predominantly private. The emergence of supermarkets is also

**Table 1. Animal health and service response needs by trajectory**

Trajectory	Animal health status and drivers summary	Animal health risks	Animal health service response needs	Key drivers
Intensified and worried well of the Western world	Well-controlled endemic disease	Increased drug resistance	Better surveillance, including for new diseases	Concerns over quality, safety, and animal welfare
	Changing and often stretched private health services to livestock enterprises	Expanded distribution of vector-borne and other pathogens	Appropriate and acceptable disease control measures	Climate change
	Heightened public awareness	Multisector economic impacts of disease incursions or scares	Incentives to develop new animal health products	
	Real/perceived threat from the rest of world			
Intensifying and increasingly market-orientated sectors of the developing world hot spots	Increasing intensification and widening of trading partnerships in an environment of endemic disease risk	Endemic disease outbreaks	Greater private sector response capacity through vertical integration and other models	Livestock Revolution (demand-driven intensification)
	Presence of several major infectious diseases	Inability to prevent and contain disease in the broader country and regional environment	Greater interface with public sector health authorities	Changing patterns of global trade
	Absence of effective veterinary infrastructure	Unachievable standards imposed by international authorities or trading partners	Greater understanding of returns that this sector can bring to national economies	Urbanization
	Limited voice in national animal health programs	Emergence of new disease		
Smallholder systems dependent on traditional livestock-derived livelihoods (cold spots)	Severely constrained economically	Multiple endemic diseases	Specific services targeted at smallholder and marginal producers	Population growth
	Limited livestock/feed/health resources	Limited or no movement controls	Well-coordinated national systems bringing in NGO, private, and donor-supported services	Climate variability
	Multiple endemic diseases	Provides source of infection to market-orientated trajectory	Particular attention to preparedness and response to shocks	
	Often in harsh environments Inadequate or total absence of animal health services	Highest vulnerability to zoonotic disease		

a factor driving standards. However, strong preferences for wet markets can persist even as socioeconomic conditions improve, presenting an incongruous interface between the old and the new. There is a substantial increase in the volume of global trade in livestock products, and a small number of emerging economies increasingly dominate. The rapidly growing market for veterinary pharmaceuticals in this sector will be served mostly by the expanding generic product sector. This presents a complex challenge: regulations, standards, and good practice are evolving much slower than in intensified systems, and there is a danger that, as drug use accelerates, the regulations and norms that support rational use will not be able to keep up.

These systems will have high demands of animal health services from all sectors of the value chains (not just producers, which historically is the case, but also marketers and consumers). Such services will likely be predominantly private but with potential to support public sector services in the less commercial production systems (the so-called sanitary mandate to perform acts prescribed by the state and thus, be partially subsidized by it). The public sector role will be to ensure good practices through enforcement of existing regulations but also to introduce new measures and endorse certification for domestic and international markets (57). The private sector role will be in developing herd and flock health management systems and recording and preventive medicine programs as well as clinical services; this will perhaps mimic the systems that emerged in wealthy countries some 30 y ago, but here, it is complicated by weaker institutions.

There will be a growing demand for health, feed, and genetic resource input services as small- and medium-scale producers gradually intensify, a demand that is unlikely to be met by current predominantly public sector service infrastructures. These small- and medium-sized emergent intensifiers are perhaps the hottest of the hot spots in terms of animal health risks, with high densities of animals in close association with people, often in periurban settings. The lack of knowledge and awareness of risks, coexistence of wet markets and backyard production, presence of regulatory vacuums, and inadequate services from public or private sector suppliers, among other weaknesses, will present major challenges for the development of effective services and perhaps, demand models other than those prevailing in the West.

Eventually, this trajectory is likely to converge with that of the worried well, which is already happening in certain parts of the newly emerging economies in countries such as Brazil and Thailand. On the way, there is a high risk of loss of

biodiversity and genetic resources and of emergence and spread of new animal and zoonotic disease; these systems are ones to watch or hot spots for risk-targeted surveillance.

The third trajectory is being traveled by traditional livestock-dependent small-holder and pastoralist systems of many developing countries. These constitute a high proportion of the bottom billion people in countries that are stuck in a poverty trap of conflict, poor governance, and low education as well as the billion people estimated by the World Health Organization to suffer from the neglected diseases that are a proxy for poverty and disempowerment. People in these systems, many of whom are subsistence farmers, will be less able to take advantage of the rising demand for livestock products because of lack of capital, knowledge, and access to input and output markets. In those parts of the developing world where economies are growing slowly and new employment opportunities in construction, manufacturing, and service industries are not emerging, the poor will continue to rely on small-scale livestock production to supplement their diets and incomes and for noneconomic uses such as cultural and social uses, status, and safety nets in times of crisis and crop failures. Livestock keeping may be as much a symptom of poverty as a pathway out of it (58). Although we call these systems cold spots for disease dynamics and emergence, they are inevitably hot spots for endemic diseases, periodic epidemics (such as Newcastle disease, which regularly wipes out village flocks), and neglected zoonoses, which significantly impact on human health. Because of the low densities of livestock, their remoteness, and the slow change in husbandry practices, these are probably not hot spots for emerging diseases. However, they are highly vulnerable to poorly designed disease control measures (often designed with the intensifying sector in mind), such as culling in response to FMD, hog cholera, and HPAI outbreaks or threats.

In cold spots, structural adjustment policies contributed to a reduction in public veterinary services, although the poor were badly served before this (59, 60). CAHW systems have emerged, but although now recognized by the World Organization for Animal Health as a valuable part of a surveillance system, there is still a long way to go before these are effectively exploited on a significant scale in all developing countries. There has been an explosion of the veterinary NGO sector, but this is often poorly coordinated, across both NGOs and host governments. Veterinary drugs are often administered by owners, and misuse is common; however, the level of drug use

is still very low compared with intensive systems.

What role will climate change bring to cold spots? Climate variability has been a key factor for centuries in regions such as the Horn of Africa (61). It seems likely that the variability will intensify but will differ by region, and our ability to predict changes is hobbled by the weaknesses of our climate change modeling systems (62).

The cold spots require substantial attention and public investment, which will be driven largely by the poverty reduction agenda. The challenges, however, will be (i) to ensure that public sector attention and resources are diverted to this group, which is often seen as presenting a burden or threat rather than an opportunity to national economies and (ii) to accommodate the very diverse needs of the emerging intensive/commercial sector situated in close apposition to the traditional/subsistence sector but under the aegis of a single national veterinary service. Additionally, all must happen in an environment in which effective collaboration between public and private sectors does not have a good track record.

The main features of each trajectory, in terms of animal health status, animal health risks, and service response needs, are summarized in Table 1.

## Conclusions

We have attempted to decipher the complex arena of global livestock disease dynamics over the last quarter century and have described the wide variety of influences on and responses to these evolving trends. There is considerable geographical diversity on the continuum of uncertain change, but we see three overarching sets of scenarios of animal disease dynamics and their control in the world: the already intensified (and now diversifying on the margins) worried well of rich countries, the intensifying but substantial numbers of traditional producers and sales channels in rapidly developing countries, and the poorest, mainly in Africa, who are the most dependent on livestock and the most at risk for being left behind.

This review is prognostic rather than therapeutic, presenting implications for livestock disease in the 21st century. In an increasingly globalized world, deepening of the existing balkanization of livestock health status will create inevitable instability. The main challenges are (i) to speed the convergence of livestock health between the intensifying and intensified regions through improved coordination, communication, and harmonization and (ii) to improve resilience of smallholder livestock systems, including the support of viable exits from livestock keeping.

**ACKNOWLEDGMENTS.** We thank Jeroen Dijkman, Eric Fèvre, Adrian Hill, Anni McLeod, Mary-Lou Penrith, Tom Randolph, and Jan Slingenbergh for their contributions and com-

ments on earlier versions of this manuscript. This paper emerged as a product of a background paper developed by the authors for the Food and Agriculture Organisation (FAO) of the United

Nations as a contribution to the FAO's State of Food and Agriculture Report 2010. We acknowledge, with gratitude, the support of the FAO.

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