ISSN 1466-2523

Animal Health Research Reviews **13**(2); 209–222
doi:10.1017/S1466252312000199

Climate change and animal diseases: making the case for adaptation

Sigfrido Burgos Cáceres

Center for Strategic Health Innovation, College of Medicine, University of South Alabama, 775 North University Boulevard, TRP II, Suite 250, Mobile, AL 36608, USA

Received 20 September 2012; Accepted 14 November 2012

Abstract

The exponential expansion of the human population has led to overexploitation of resources and overproduction of items that have caused a series of potentially devastating effects, including ocean acidification, ozone depletion, biodiversity loss, the spread of invasive flora and fauna and climatic changes – along with the emergence of new diseases in animals and humans. Climate change occurs as a result of imbalances between incoming and outgoing radiation in the atmosphere. This process generates heat. As concentrations of atmospheric gases reach record levels, global temperatures are expected to increase significantly. The hydrologic cycle will be altered, since warmer air can retain more moisture than cooler air. This means that some geographic areas will have more rainfall, whereas others have more drought and severe weather. The potential consequences of significant and permanent climatic changes are altered patterns of diseases in animal and human populations, including the emergence of new disease syndromes and changes in the prevalence of existing diseases. A wider geographic distribution of known vectors and the recruitment of new strains to the vector pool could result in infections spreading to more and potentially new species of hosts. If these predictions turn out to be accurate, there will be a need for policymakers to consider alternatives, such as adaptation. This review explores the linkages between climate change and animal diseases, and examines interrelated issues that arise from altered biological dynamics. Its aim is to consider various risks and vulnerabilities and to make the case for policies favoring adaptation.

Keywords: adaptation, animal diseases, climate change, policies

Introduction

Microbes that cause disease range from macro-parasites (e.g. worms), arthropods (e.g. lice, ticks and fleas), protozoa (e.g. coccidia) to fungi, bacteria and viruses. Most, if not all, require a living host on which to feed in order to perpetuate. In medical education, epidemiology is often depicted as a triangle that shows the relationship between microbe, its host and the environment. While it can be argued that this classical description is simplistic, it does highlight the importance of the environment (or the ecosystem), without which there would not be the right conditions for diseases to develop and spread.

Under a rapidly changing environment, pathogens can find new ecosystems in which to survive, thrive or expand. For instance, for a pathogen to survive, humidity outside the host is an important factor. This partially explains why diseases follow floods and rainfall. It is for this reason that humid tropical areas usually carry higher disease burdens than ecological zones that experience extreme cold or very hot and dry climates (Hay *et al.*, 2005; Singh *et al.*, 2011). In tropical and temperate climates, some diseases – particularly protozoan and viruses – are transmitted by arthropod vectors such as mosquitoes, midges and ticks. Should the trends of climate change depict a more humid Earth, the likelihood of disease emergence, incidence, spread and threats to human, animal and plant hosts will rise; and the existing evidence on climate change indicates that this is the case (De la Rocque *et al.*, 2008; IPPC, 2009).

Corresponding author. E-mail: sigfridoburgos@southalabama.edu

Other commentators have already noted that complex, rapid multivariable changes are increasing the magnitude, severity, dimensions and frequencies of classical and novel animal diseases, some of which have human health implications around the globe (Burgos and Otte, 2009). Many factors contribute to the emergence and intensification of infectious diseases including economic, social and cultural, human, and animal demographics, evolutionary and environmental factors (Burgos-Cáceres and Otte, 2009). The latter are of contemporary interest in view of the frequently cited facts by numerous media outlets regarding greenhouse gas (GHG) emissions and global warming that are said to profoundly influence the key drivers of disease emergence in a rapidly changing world (Burgos, 2010; Woolhouse, 2011).

Climatologists and other experts in atmospheric and biological sciences tell us that climatic changes are occurring as a result of imbalances between incoming and outgoing radiation in the atmosphere. This process generates heat. As concentrations of atmospheric gases reach record levels, global temperatures are expected to increase by 1.8–5.8°C by the end of this century. The hydrologic cycle will be altered, since warmer air can retain more moisture than cooler air. This means that some geographic areas will have more rainfall, while others more drought and severe weather (Lafferty, 2009; Shuman, 2010).

The potential consequences of significant and permanent climatic changes are altered patterns of diseases in animal and human populations including the emergence of new disease syndromes or changes in the prevalence of existing diseases, particularly those spread by biting insects (Mills *et al*., 2010). A wider geographic distribution of known vectors and/or the recruitment of new strains to the vector pool could result in infections spreading to more and potentially new species of hosts. For example, some diseases impacted may be endemic: more *Culicoides* midges to spread bluetongue, more snails to spread fluke infestations or more ticks to transmit Lyme disease (Summers, 2009). In Australia, veterinary epidemiologists strongly suspect that the huge escalation in outbreaks of Hendra has something to do with the heavy rainfall and big floods that drowned the northeast from November 2010 to February 2011 (Bazilchuk, 2011).

This review explores the linkages between climate change and animal diseases, and examines interrelated issues that arise from altered biological dynamics. Its aim is to consider various risks and vulnerabilities, and to make the case for policies favoring adaptation.

Characterization of risks and shocks

Climate change and animal diseases represent both a health security challenge and an economic opportunity. As a health security challenge, animal diseases affect animals and humans through mortality and morbidity. As an economic opportunity, any reduction in animal disease incidence can be translated into economic gains in terms of reduced health care costs, more animals and animal-based products for sale, or fewer expenses related to medications, treatments and downtime. Overall, climate change can be expected to impact the livestock sector by increasing the risk of heat stress – its intensity and frequency; modifying available water; modifying quantities and quality of available and accessible food; and modifying distribution, intensity and frequency of diseases and parasites (OECD, 2011). However, the risks and shocks go far beyond these.

The effects of climatic changes on animal diseases can be broadened, deepened or intensified during interactions with other powerful drivers of disease emergence. A 2010 study evaluated the evidence that reduced biodiversity affects the transmission of infectious diseases of humans, animals and plants. The authors found that, in principle, loss of biodiversity could either increase or decrease disease transmission; however, there is mounting evidence indicating that biodiversity loss frequently *increases* disease transmission. In contrast, areas of naturally high biodiversity may serve as a source pool for new pathogens (Keesing *et al*., 2010). This is critical because the scientific world already knows that there are linkages between climate change and biodiversity (IPPC, 2002).

Later, in 2008, a study analyzed a database of 335 emerging infectious disease (EID) events between 1940 and 2004. The study demonstrated non-random global patterns. These EID events are dominated by zoonoses (60.3%), with the majority of these (71.8%) originating in wildlife and increasing significantly over time. The authors found that a little over half (54.3%) of EID events are caused by bacteria or rickettsia, reflecting a large number of drug-resistant microbes. These study results confirm that EID origins are significantly correlated with socioeconomic, environmental and ecological factors. Also, the results reveal a substantial risk of wildlife zoonotic and vector-borne EID originating at lower latitudes where reporting is low (Jones *et al*., 2008; Bazilchuk, 2011).

Given that climatic changes will partly consist of rising temperatures and changing rainfall patterns, these will have a substantial effect on the burden of infectious diseases that are transmitted by insect vectors and through contaminated waters. Vector-borne diseases relevant to livestock production that could be affected include mosquito-transmitted Rift Valley fever, tsetse-transmitted trypanosomiasis and tick-transmitted Crimean–Congo hemorrhagic fever (Tabachnick, 2010). Also, water-borne infectious diseases could strongly contribute to the rapid emergence of botulism, campylobacteriosis, cholera, leptospirosis, salmonellosis and dysentery that not only affect animal health but also human health (Burgos-Cáceres, 2011). Climate change is also expected to affect the ecology of avian influenza viruses (Vandegrift *et al.*, 2010).

In relation to avian influenza and climate change, it is known that wild water birds form the natural reservoir of all influenza A viruses. The distribution of avian influenza viruses among wild birds is uneven, as it is influenced by both bird species and eco-geography. Climate change is reported to affect wild bird distribution in a variety of ways. Northward shifts in distributions have been reported in many species and have been attributed to climate change. Climate change is also considered to influence species composition, with increased diversity expected in northern latitudes. Declines in the number of species undertaking long-distance migrations have been observed in many instances. All these changes in population, distribution and movement patterns can affect the redistribution of avian influenza viruses among birds of different age classes, species and flyways (Gilbert *et al.*, 2008).

Furthermore, extreme climatic events may trigger abnormal population movements. In general, predictions about how changes in viral persistence in the environment, together with the various alterations in host migratory patterns, may affect the epidemiology of avian influenza are complex. However, with wild bird migration patterns and avian influenza evolution being intertwined, and climate change acting on both wild bird behavior and virus survival outside the host, the seasonal and geographic patterns of the virus cycles in wild birds are very likely to change in the future (Gilbert *et al.*, 2008; Lafferty, 2009). This justifies continued attention to climate change and diseases by international, regional and national organizations.

Some diseases are transmitted by vectors, such as arthropods (e.g. mosquitoes, lice and ticks) or rodents, which are sensitive to changes in climatic conditions, especially temperature and humidity (Zhang *et al.*, 2008). One of these diseases is Rift Valley fever (RVF), a mosquito-borne viral disease. Historical information has shown that pronounced periods of RVF virus activity in East Africa occur during periods of heavy, widespread and persistent rainfall, now associated with El Niño events, triggered by large-scale changes in sea surface temperature in the Pacific Ocean and the western Equatorial Indian Ocean, leading to climate anomalies at regional levels. Specifically, climate changes may affect the three fundamental components of the epidemiological cycle of RVF: vectors, hosts and virus. Increased temperature may have an impact on vector capacity; thus expanding the possibility that arthropod species in neighboring countries could also become competent vectors for RVF viruses, if initial infection occurs. Finally, climate changes may induce modifications in host distribution and density, as well as host migratory pathways (Martin *et al.*, 2008).

Helminth diseases (e.g. cestodiases, nematodiases and trematodiases) may also be affected by climatic changes. All evidence indicates that the effects of temperature and water-related variables on helminths are more pronounced in temperate and colder northern latitudes as well as in high altitude areas, where modifications of these variables appear to be more pronounced (Mas-Coma *et al.*, 2008; van Dijk *et al.*, 2010; Jenkins *et al.*, 2011).

The direct effects and/or impacts of heat waves, flood-related waterborne diseases and allergic diseases have not been mentioned, as the focus is placed on infectious and parasitic diseases of animals on which the direct and indirect effects and/or impacts of climate change are a little less difficult to ascertain. Broadly speaking, there is a concatenation of causes and effects that spill over from one domain to the other. What follows is a characterization of animal and human health risks, economic and market shocks, and livelihood disruptions.

Animal and human health risks

The health risks to animals and humans arise from direct stresses (e.g. weather disasters, drastic climatic modulations and heat waves), altered ecological processes (e.g. changes in infectious disease patterns, impaired food yields and pathogen adaptation to hosts), resource conflict over depleted resources (e.g. water, fertile land and fisheries) and population displacement due to rapidly evolving socio-economic forces, among others. It is believed that low-income and geographically vulnerable populations are at greatest risk (McMichael, 2010).

Economic and market shocks

The economic impacts of outbreaks of zoonotic animal diseases are enormous, even when human morbidity and mortality remain comparatively low. For example, in 2003, the severe acute respiratory syndrome (SARS) involved some 8500 cases and killed less than 1000 people, yet it represented an economic loss of approximately 2% of East Asia regional gross domestic product (GDP) for the second quarter of that year. Moreover, during outbreaks of SARS, infection minimization efforts resulted in a dramatic supply shock due to workplace absenteeism, disruption of production processes and shifts to more costly procedures, as well as severe demand shocks for service sectors such as restaurants, hotels, stores, supermarkets, tourism and mass transportation (Brahmbhatt, 2005). The precise quantification of the full costs of zoonotic diseases on livestock industries is complicated by the fact that there are upstream and downstream impacts through supply and distribution networks, and short-term reactions are likely to be followed by longer-term adjustments. However, some estimates indicating the order of magnitude of losses can be found. It has been estimated that Mad Cow disease resulted in losses amounting to US$10–US$13 billion in the UK alone. In Canada, the discovery of 1 case of Mad Cow disease in cattle (and not a single human case) in May 2003 was sufficient to cause losses in the order of US$1.5 billion. For 2009, Mexican authorities estimate that pandemic influenza H1N1 cost their economy over US$2 billion, much of which comes from foregone revenues in trade and tourism (Burgos and Burgos, 2007; Burgos and Otte, 2010). It is estimated that for the USA, a severe influenza pandemic might cause economic losses between US$71 and US$167 billion, excluding disruptions to commerce and society. Other predictions are that a highly fatal HPAI pandemic could cost the world economy as much as US$800 billion a year (Meltzer *et al.*, 1999; Baumuller and Heymann, 2010).

Livelihood disruptions

The animal production sector plays a significant role in the economic development of nations. The production of meat, eggs, milk, leather goods, fibers, feathers and other animal-based commodities generates valuable income, employment and foreign exchange to over a billion people. Animals also provide other benefits in preparing the soil for cultivation, power to irrigate fields, manure and fuel, and have important roles in the community for religious or ceremonial purposes. Globally, some 40% of agriculture GDP is provided by the livestock sector, and in some countries this exceeds 70% (FAO, 2009). As noted earlier, animal diseases cripple animal production efficiencies and trade, and some diseases directly affect human health. When a disease kills, animals that have been reared for months or years before they are fully productive or express their full genetic potential lose their entire economic potential and also wipe out the safety nets (or savings) of households and communities. Other animal diseases reduce efficiencies in production by eroding profit margins through reduced weight gains or poor quality of products, all of which disrupt livelihoods. Diseases such as HPAI, African swine fever, foot-and-mouth disease, bluetongue, the pest of small ruminants, highly virulent porcine reproductive and respiratory syndrome, RVF, and Hendra and Nipah viruses have been known to cause the rapid loss of productive, income-generating assets that have substantial and immediate financial implications to livestock owners and livestock-dependent communities.

As long as animals produce food to feed more people and generate income to buy food items, animal health will be one of the fundamental underlying activities supporting the basic human right to food. Hence, animal health services provided by national, regional and international agencies help maintain healthy and productive animals that make important contributions to food production, income generation, job creation, economic growth and poverty alleviation. The precipitous descent of some of the world's poorest countries into food insecurity, instability and poverty raises the risks of potentially detrimental spill-over effects, ranging from a rise in illegal migration to organized crime. It is important to underscore that the promotion of comprehensive animal health has long been used by regional bodies, civil society organizations, foreign countries and multilateral institutions as a strategic tool when dealing with countries whose economies and societies are deeply intertwined with agriculture and livestock (Burgos and Otte, 2011).

This section makes the point that climatic changes and the emergence or intensification of animal diseases are inescapable realities. Many of the climatologic disruptions arise from industrialization since the 1800s, and these disruptions are going to be exacerbated by the vibrant rise of few emerging market economies. For example, Asia's economic growth and development of infrastructure are permitting more people to buy cars, that burn more fuel, requiring the exploitation of more natural resources: all of these factors further contribute to climate change and will ultimately continue to influence animal diseases. Given that livestock contributes 40% of the global value of agricultural output and supports the livelihoods and food security of almost a billion people, there is an urgent need for strengthened governance of environmental and livestock linkages, as well as more institutional collaborations. Finally, in making the case for policies favoring adaptation, the argument is that decision-makers will find out soon enough that policy instruments (e.g. bills, codes, edicts, laws and regulations) will not be able to significantly reverse the deeply entrenched habits and practices of citizens and farmers, and that adaptation measures represent the surest way to deal with climate changes in agriculture.

Consideration of vulnerabilities

The Intergovernmental Panel on Climate Change (IPCC) has noted that a large body of research findings shows a clear increase in the temperature of the Earth's surface and of the oceans, a reduction in the land snow cover, and melting of the sea ice and glaciers. Quantitative modeling combined with statistical analysis has shown that this global warming trend is very likely the signature of increasing emissions of GHG linked to human activities (Delecluse, 2008). On 18 November 2011, the IPCC issued a special report on global warming and extreme weather after meeting in Kampala, Uganda. This was the first time the group of scientists had focused on the dangers of extreme weather events such as heat waves, floods, droughts and storms: with these being more dangerous than gradual increases in the world's average temperature. Science has progressed so much in the last several years that scientists can now attribute the increase in many of these types of extreme weather events to global warming with increased confidence (Borenstein, 2011).

The effects of climate change and animal diseases are particularly disruptive for the vast majority of the 4 billion people living at the bottom of the economic pyramid – who are living in aching poverty – because when the health of their surrounding ecosystems is damaged it severely affects their livelihoods. For instance, Africa is likely to be one of the continents worst affected by climate change through drought, spread of diseases, and desertification. And while this is known with a certain degree of accuracy, little substantive agreement on adaptation and mitigation measures has been reached. One of the most pressing problems is that when it comes to agreeing on climate change adaptation and mitigation measures, the ambition levels are low and the policy differences between industrialized and emerging economies remain acute.

Vulnerabilities at various scales

At farm level, climate change can have multiple effects on food animals. First, as temperature and humidity rise, animals are subjected to heat stress, which increases the levels of corticosteroids that reallocate available energy away from productive metabolic processes (i.e. protein build-up, milk production, egg lay). Second, as temperatures increase, animals tend to move less to generate less metabolic heat, which in turn reduces food and water consumption that is directly related to weight gain and positive production parameters. Third, as noted earlier, modulation of climatic variables may influence the emergence, spread and intensity of animal diseases, which are detrimental to the health of animals and impair their ability to produce draught power, eggs, meat, milk and other animal-based products. Climate change can also impact farm costs and operational expenses as it may bring about extreme weather events that require farms to strengthen or rebuild houses, buildings and structures, as well as the associated cost of insurance and repairs and equipment upgrades such as fans, ventilators, sprayers and dehumidifiers. Lastly, in case of animal mortality, the impact extends beyond the immediate loss of the productive asset and includes the loss of the income-generating potential all through the remaining life of the animal.

At the local level, climate change and animal diseases can have the same effects as in households (i.e. backyard livestock keeping) and farms of varying sizes with the difference being that the impact is collective and not individual. A livestock dependent community that does not have a diversified productive portfolio to spread risks and threats will be particularly vulnerable to these factors, and, ultimately, will experience the full brunt of the effects and the subsequent exposure to secondary and tertiary ripples such as unemployment, bankruptcy, social disruption, market shocks, human health deterioration, dissatisfaction and a general incapacity to cope with incoming challenges. This is not true for all local settings; it applies to those where animal agriculture plays a pivotal role in the economic activity of the area, and in particular to those sub-sectors that are invested in animals species that are susceptible to harm by the diseases that emerge and spread or to the ensuing heat stress.

At national and regional levels, the problems of climate change and animal diseases can be acute and lengthy, especially if the pathogen in question thrives under new climatic conditions or its spread is facilitated through multiple factors related to vector, host and ecologic milieus. For instance, it is known that when diseases arise in food animals – especially those that can also infect humans – government authorities undertake a number of measures to control their spread. Countries experiencing disease outbreaks suddenly face measures by neighboring countries to protect their citizenry and their productive assets. Common measures that countries impose on others to reduce the risk of disease introduction are import bans, revoked export licenses, temporary restrictions of import quotas, extended quarantine periods, stricter inspections of shipments, firmer application of standard sanitary and phytosanitary measures, public awareness campaigns, and media-based advertisements dissuading people from purchasing and consuming certain animal food products or advising on ways to deal with suspicious animal or human illnesses. With the aid of the Internet, blogs, chat rooms, mobile telecommunication, instant messaging and information exchange platforms, panic has sometimes been disseminated to misinformed audiences, thereby modulating animal product consumption patterns that have an economic impact on nations and regions.

At a global level, the vulnerabilities to climate change and animal diseases become significant given the scale or magnitude of the potential situation. Animal diseases raise concerns and fears within populations around the world because human fatalities from unusual contagious diseases are readily associated with severe epidemics and large death tolls that in the past accompanied the plague and the Spanish flu, among others. Nowadays, mass reaching communication technologies can create and facilitate hysteria by the widespread dissemination of information and misinformation regarding unusual diseases or sporadic outbreaks. Additionally, large-scale food-animal mortality and morbidity carry short, medium and long-term implications for food security, and its impacts, while largely experienced by currently living populations, can extend to future generations in terms of neonatal deformities, learning disabilities, neurological problems, in-born genetic errors, underweight at birth, nutritional insufficiencies and other disastrous consequences. In relation to animals, the vulnerabilities lie in the risks of biodiversity losses from diseases and climate change, as well as the persistent deterioration of health that could suppress the immune competence of species, placing them at the mercy of predators, hunters, or to diseases for which they are too weak to fight back.

Climate change could affect habitats, behaviors, coping mechanism, flight and migration patterns, metabolic and reproductive functions, productive outputs and health.

Animal and human health responses against climate change-influenced diseases carry an expenditure component that oftentimes is largely assumed by national governments (and ultimately taxpayers). The extent of fiscal obligations is normally aligned to the magnitude of responses implemented. Around most of the globe, responses to emerging infectious diseases have been clearly dominated by public fears of an epidemic, possibly reaching pandemic proportions. Defensive response measures against animal disease outbreaks include stockpiling of disinfectants, medications and vaccines, airport passenger scanning, increased import inspections, public awareness campaigns, among many others. In the case of avian influenza, for instance, it has been estimated that by the end of 2008 the US and European countries, including the European Commission, spent approximately US$2.8 billion 'at home' versus US$950 million 'abroad' for disease control at source (Jonas, 2008). The heavy budgetary burdens of alarmist and uncontrolled responses to disease outbreaks can result, in many cases, in unnecessary layouts that could be better allocated elsewhere (e.g. debt reduction, education, healthcare and infrastructure). The world is starting to witness an increasing number of animal diseases that are able to easily cross national borders; therefore, the economic, commercial, fiscal and political issues that arise may affect entire regions and even the world at large.

Vulnerabilities at various timeframes

The timeframes of consequences of GHG accumulation, global warming and other forms of climatic changes will vary according to the ways in which the ecologic and geographic setting responds to increases and/or decreases in temperature, humidity, rainfall, snow cover, wind patterns, cloud presence, etc. What is obvious is that changes in overall atmospheric circulation are already taking place, but predictions at a more local scale remain poor or ambiguous, mainly because of the 'unknowns' surrounding the roles of multivariable interactions, both in terms of generating exacerbated local effects and local susceptibilities. In the short term, given that these changes do have effects on biological systems, it is expected that there will be modulations to the transmission of pathogens. For long it has been generally accepted that climate restricts the range of infectious diseases, whereas weather affects the timing and intensity of disease outbreaks (Epstein, 2004). Thus, it can be ascertained with some confidence that changes in temperature and humidity affect the distribution or ecological range of infectious diseases, while the frequency and magnitude of outbreaks of diseases change with weather extremes such as flooding and droughts (Broglia and Kapel, 2011).

In the long term, predictions on vulnerabilities to biological systems are difficult to make because of our lack of knowledge of how ecological systems are going to interact and respond as soon as short-term changes take place. It should be noted that although many of the responses of biological systems to changes in the environment are not linear, our understanding is limited to the linearity of events along time. This non-linearity applies also to climatic factors, and, as a result, chain-reactions with significant, abrupt changes are very likely to occur. Hughes has categorized evidence-based biological effects of climate changes on animal and plant life into: (a) effects on physiology, metabolism or development rate; (b) effects on distribution; (c) effects on the timing of life-cycle or life history events; (d) adaptation, particularly of species with short generation times and rapid population growth rates, which may undergo evolution (Hughes, 2000).

Vulnerabilities and the specificities of the risks

In relation to livestock, diseases and climate change, it is believed that if prolonged droughts occur as predicted, the likelihood for increased livestock movement in search of a more conducive environment could have a profound impact on the contact rate between hosts, and the spread and distribution of animal diseases. Also, climate change related disturbances such as deforestation – the impacts of deforestation and climatic volatility are a particularly potent combination creating conditions conducive to disease emergence and spread–, agricultural changes and loss of biodiversity could expose hosts to new pathogens for which they have not built resistance or immunity (Epstein, 1999). In fact, it is possible that the loss of biological diversity and a balanced sylvatic cycle between pathogen and host could trigger the emergence of new diseases as new hosts are sought. In relation to humans, diseases and climate change, the vulnerabilities extend from illness to death, which often carry a large financial impact in terms of professional healthcare, purveyance and application of medications and vaccines, costs related to research and development of drugs to combat new diseases or new strains (e.g. the common flu), expenses associated with health and life insurance, as well as macroeconomic burdens pegged to sickness-related downtime, operational inefficiencies, low productivity, reduced influx of tourism and forgone revenues owing to disease containment measures.

With this in mind, climatic changes constitute yet another large stress factor for African countries – piling on top of the classical burdens they have to endure. As the capacity to adapt is insufficient in Africa, this continent would appear to be one of the more vulnerable given its demographic growth, conflicts, shrinking natural ecosystems, water shortages and soil erosion.

Vulnerabilities and their interactions

Aside from the direct influence of climatologic variables, factors such as landscape changes that remove portions of host populations (e.g. habitat alteration or destruction), alteration of host migration patterns (e.g. habitat fragmentation) or increased host density are also likely to influence disease emergence (Daszak *et al*., 2000, 2001). There are also political and legal risks, especially since the evidence gathered so far in disease-infected countries suggests that diseases are able to cross borders regardless of the repertoire of direct and indirect measures enacted or levied. For example, wild bird migration, illegal animal trade, porous borders, international travel and rising urbanization – most of which fall outside the remit of legislative and regulatory frameworks – have been identified as contributors to disease spread.

Even if climate changes turned out not to have much of an influence on diseases affecting animal and human health, the aggregate of air pollution from burning fossil fuels and felling forests provides a relentless destabilizing force on the Earth's heat budget, and have been associated with extreme weather events that kill thousands. Examining the full life cycle of fossil fuels also exposes layers of damages: environmental damage from their mining, refining, and transport must be added to direct ecosystem health effects of air pollution and acid precipitation.

For way too long our economy has been based on erroneous beliefs that resource supplies are limitless and that the Earth can continually bounce back from abuse. We must continually remind ourselves that the measure of a civilization's growth is its ability to shift energy and attention from the material side to the aesthetic, artistic, cultural and spiritual side while at the same time caring for the surrounding environment. Our collective vulnerabilities can be minimized as long as we are aware of the proximity of risks.

Tendencies and potential changes in risks and vulnerabilities

According to a report from the International Energy Agency, global energy-related emissions of carbon dioxide jumped 5% in 2010 to record levels despite the 2008–2009 banking and economic crisis (Clark, 2011). The message is clear: the world must prepare for more frequent and more dangerous extreme weather events caused by climate change (e.g. super storm Sandy in the USA). Droughts, floods, storms and heat waves could wipe out billions of national economies' incomes and destroy lives of animals and humans alike. It is impossible to say exactly what the chances would be of a particular weather event happening in a world without climate change. Today, what can be said is how much the risk may have changed as a result of climate change.

By using daily satellite and surface measurements related to solar radiation and precipitation, it is known that, across the world, extremely sunny or cloudy days are more common now than in the early 1980s and that swings from thunderstorms to dry days have risen considerably since the late 1990s. These swings could affect the efficiency of solar energy production, have dire consequences for the control of diseases and pests, and, ultimately, inhibit the ability of crops and plants to remove carbon dioxide from the atmosphere (Twentyman, 2011). Moreover, we may be facing a third, protracted epidemiological transition of disastrous consequences in which *globalization* and *ecological disruption* drive disease emergence and reemergence, as occurred in the first epidemiological transition that was chiefly associated with Neolithic sedentarization and the domestication of livestock (Perry *et al*., 2011).

Let us give some perspective to these trends with an example. Researchers suggest that the biggest change in avian influenza epidemiology resulting from climate change will be brought about by changes in the distribution, composition, and migration behavior of wild bird populations that harbor the genetic pool of avian influenza viruses and in which natural avian influenza transmission cycles take place. In contrast, HPAI, which remains largely confined to domestic poultry, has been spreading worldwide successfully in a wide range of climatic conditions. Although the effect of the environment on HPAI transmission and persistence is poorly understood, emerging observations support the idea that climate change will have very little effect on HPAI epidemiology. Some indirect effects are anticipated, however, such as those occurring as a result of the influence of climate change on agro-ecosystems associating duck and crop production, and of changes in the distribution of domestic-wild waterfowl contact points (Gilbert *et al*., 2008).

In a trade study using spatially explicit mapping of land use patterns and GHG emissions, European researchers noted that further trade liberalization leads to higher economic benefits and lower global costs of food at the expense of environment and climate. Regions with comparative advantages like Latin America for cereals and cash crops, and China for livestock products will export more. In contrast, regions such as the Middle East, North Africa and South Asia face the highest increases in imports. The authors posit that deforestation, mainly in Latin America, leads to significant amounts of additional carbon emissions due to trade liberalization. Non-carbon dioxide emissions will mostly shift to China due to comparative advantages in livestock production and rising livestock demand in the region

(Schmitz *et al.*, 2011). All these signs seem to indicate that unimpeded economic activity worldwide will continue to take a toll on the environment (Broglia and Kapel, 2011).

Another major tendency in risks and vulnerability relates to population growth. The 2006 revision of the official United Nations Population Division estimates and projections revealed that the world population continues its path towards population ageing and is on track to surpass 9 billion persons by 2050. Most of this growth will be absorbed by the less developed regions, whose population is projected to rise from 5.4 billion in 2007 to 7.9 billion in 2050. In contrast, the population of the more developed regions is expected to remain largely unchanged at 1.2 billion, and would have declined, were it not for the projected net migration from developing to developed countries, which is expected to average 2.3 million persons annually (UNDPI, 2007).

A phenomenon very much related to population growth is urbanization – the rapid build up of an urban way of life (e.g. buildings, slums and favelas) at the peripheries of cities – that is putting pressures on healthcare systems given that closer human–human and animal–human contacts increase the risks of disease contraction and spread (McKinney, 2002). Continued rapid urbanization, together with risks posed by multi-host pathogens for humans and vulnerable animal populations, emphasize the need for better understanding of animal diseases and climate change in urban landscapes (Bradley and Altizer, 2007).

Globalization, understood as the development of an increasingly integrated global economy marked especially by liberalized trade, free flow of capital and the tapping of cheaper foreign labor markets, has been noted as a major driver of animal disease emergence. Animals exported and imported for commercial trade represent a substantial risk to human health. For example, in 2003, monkey pox was introduced into the USA when a shipment of African Gambian giant rats was sold to dealers, one of whom housed the rats with prairie dogs intended for the pet trade in a US distribution facility. The prairie dogs subsequently became ill and transmitted the infection to 71 humans, including prairie dog owners and veterinary staff caring for the sick animals. In addition to monkey pox, human tularemia and salmonellosis outbreaks have been traced back to contact with prairie dogs and hedgehogs (Marano *et al.*, 2007).

Another fact that is becoming widely accepted is that of water scarcity. More than a quarter of the world's population or a third of the population in developing countries resides in regions that will experience severe water scarcity. Globally, there are now numerous signs that human water use exceeds sustainable levels: groundwater depletion, low or non-existent river flows and worsening water pollution levels are among the more obvious signs.

Lastly, the continued human encroachment into forests and natural reserves along with the concomitant alterations of natural ecosystems will likely result in more frequent encounters with animal reservoirs of recognized pathogens, as well as encounters with previously unknown infectious agents. This phenomenon has broadened the interface between wildlife and humans, thus increasing opportunities for the emergence of novel infectious diseases in both species.

Pitching adaptation: the appeal of risk management strategies

In the context of climate change, adaptation refers to the adjustments in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities. On the other hand, mitigation refers to the lessening or limitation of the adverse impacts of hazards and related disasters. These being clarified, let us move on to risk management, which comprises risk assessments and risk analyses, and the implementation of strategies and specific actions to control, reduce, and transfer risks (i.e. adaptation and/or mitigation). Risk management is widely practiced by states and organizations to minimize risk in investment decisions and to address operational risks such as those of business disruption, production failure, environmental damage, social impacts and damage from fire and natural hazards. In this section, I use all these terms to address animal disease control.

Monitoring, surveillance, prevention, early warning and early response

Disease *monitoring* describes the ongoing efforts directed at assessing the health and disease status of a population. Sampling of individuals from the population to assess disease or health status may be ongoing or repeated, and is undertaken to obtain the correct classification of the true health status of herds given that it is an important component of epidemiologic studies and animal disease control and prevention programs (Salman, 2003). In the context of climate change influencing disease emergence and spread, monitoring is a function to continuously survey the disease landscape and find out what ecology-pathogen dynamics are taking place early on.

Epidemiological *surveillance* for known pathogens and to identify previously unknown infectious agents is required, and should include the monitoring of weather variables in order to forecast and mitigate disease impact and spread. However, active surveillance for animal diseases in many regions of the world, particularly for vector-borne diseases, is very poor (Rogers and Randolph, 1993). Commentators note that disease reporting is often lacking, which affects knowledge of disease distribution and impact, and preparedness for early response. They ascertain that improved reporting for animal diseases that may be affected by climate change is needed for better prevention and intervention measures in susceptible livestock, wildlife and vectors in South America. This requires contributions from multidisciplinary experts, including meteorologists, epidemiologists, biologists and ecologists, and from growers and farmers at local communities (Pinto *et al.*, 2008).

Disease *prevention* expresses the concept, intention and practice to completely avoid potentially adverse impacts through action taken in advance. Actions encompassed within animal disease prevention include farm bio-security and vaccination schemes. In relation to climate change, preventive approaches might mean adjustments to farm infrastructure to provide aeration, humidification and ventilation, as well as bio-security enhancements to reduce the chances of pathogen entry into animal production systems. Although prevention on a global scale may ultimately be more cost-effective than a strategy of focusing limited resources on particular disease control measures, veterinarians cannot rest easy when effective solutions exist but remain unavailable to farmers.

Early warning of disease events (and the capacity for prediction of spread to new areas) is a prerequisite for the effective containment and control of epidemic animal diseases. Weaknesses of disease surveillance systems and the inability to control major diseases at their source have contributed to their spread across geographical borders of diseases confined to livestock. Early warning of disease events with a known zoonotic potential will enable control measures that can prevent human morbidity and mortality. Several initiatives, at national and regional levels, have already been developed in the field of early warning. Internationally, leading animal health agencies have developed early warning systems that systematically collect, tabulate, verify, analyze and respond to information from a variety of sources, including unofficial media reports and informal networks.

Early response is based on the concept that dealing with an animal disease epidemic in its early stages is easier and more economical than having to deal with it once it is widespread. Local, national, regional and intergovernmental efforts should aim to assist member countries with planning and implementation of measures to prevent and mitigate the spread of animal disease events of national and international concern. Initiatives should be directed to require legislation for early intervention based on contingency plans and emergency reserves, trained personnel across disciplines and ministries, and private sector responsibilities and obligations. These actions should include the purveyance of core human-resource capacity and ensure rapid access to contingency emergency funds in order to be able to respond to animal disease events of national and international concern quickly, effectively and resolutely.

Regional cooperation and professional education

The thrust behind *regional cooperation* lies in the collective agreement on actions or instances for working together for a common goal, purpose or benefit. While a high level of cooperation and synergy among key stakeholders characterizes emergency responses to transboundary animal disease events, it also needs to be demonstrated for other risks and threats from emerging diseases, including outside ‘periods of crises’. This applies in particular to cooperation between the animal and human health sectors at all levels, which led to improved early detection of diseases in animals and streamlined responses during SARS and the avian influenza crisis. In the context of climate change, multiregional cooperation is critical given that there is a need for carbon intensity cuts of at least 5% every year until 2050 if global temperature increases are to be kept to no more than 2°C above pre-industrial levels. This requires serious, sustained commitments from leading developed countries, especially to garner support and cooperation for initiatives that are already working well and that should be strengthened, such as the Clean Development Mechanism – the Kyoto protocol scheme that allows companies in wealthy countries to offset emissions by buying credits generated from carbon reduction projects in poorer nations.

Professional education is a long-term, cost-effective avenue for training the animal health actors of the future with the appropriate abilities and skills to address classical and novel animal diseases that emerge and spread as a result of climatic changes. Over the years, veterinary professionals have played significant roles in animal and human health and welfare, biomedical research, food safety, food security, ecology, development of vaccines and as educators, trainers, and policymakers, and also interlinked with wildlife conservation efforts and the protection of the environment and biodiversity. As challenges have risen, animal health professionals have found ways to adapt given that their abilities, skills, knowledge and training make them multifunctional professionals. Moreover, the veterinarians of the future will have to be trained alongside biologists, climatologists and in multidisciplinary educational centers that combine climatic, epidemiological, medical and veterinary domains.

Networks and simulations

Laboratory and epidemiology *networks* at national and regional levels aim to support the activities of monitoring, surveillance and early warning by issuing quick diagnostic results on samples sent by animal and human health authorities. The successful establishment, consolidation, and sustainability of regional laboratories and epidemiology networks are intrinsically linked to their recognition and support by intergovernmental organizations, national governments and regional economic bodies. There is a need to assist national laboratories in strengthening their quality assurance systems with objective, measurable indicators such as those provided by inter-laboratories proficiency tests. Other core areas of technical support include the need for sharing and updating information on laboratory diagnostic techniques, periodic maintenance and calibration of equipment and instruments, ensuring a regular supply of reagents, and continuous training of technical staff.

Other tools at our disposal are tabletop and field *simulation exercises* to preemptively identify the strengths and weaknesses of a country's contingency plans. They also serve to examine the communication, coordination and cooperation between different actors involved in disease prevention, detection and control in animal and human populations. The tool is applicable for the participation of local, national, regional and international institutions to address concerns of high-impact diseases which could be introduced into countries with potentially devastating consequences on food security, animal and human health, national stability, economic progress, social development and rural and urban livelihoods. These exercises also include mock press conferences to practice risk communication and addressing difficult questions often asked during emergency situations.

Legislation, policies and institutions

As countries face increased number of risks and threats they have felt the need to counteract with flexible yet robust veterinary *legislation* that adapts to rapidly evolving situations. In the presence of legal frameworks, the national agencies tasked with delivery of veterinary services undertake their primary and secondary functions. The scope of these activities spans monitoring, detecting, reporting and controlling outbreaks of animal diseases, inspecting production systems before certifying live and processed products for export, overseeing food safety and quality and administering welfare practices. Also, with veterinary legislation in place, countries may seek to engage in animal trade and in certification processes of disease freedom, such as of avian influenza, rinderpest or foot-and-mouth disease.

In terms of *policies*, countries are becoming acutely aware that strong economic drivers acting on a more commercially driven world are more forcefully calling for the creation of basic agriculture and food policies. These policies are expected to encompass many interrelated activities but tailored to fit each country's legislative background, existing political system and unique identity. Importantly, the rationalization of these policies warrants an organized, multistage and participatory process. Countries may also seek guidance from other sources, which contain best practices, lessons learned or recommendations for regulatory issues.

As for *institutions*, whether these already exist or are in the process of being built, there is a need for interagency collaboration to address issues that overlap their mandates. For example, in the case of transboundary zoonotic diseases, the ministries expected to be involved can include, but are not limited to, agriculture/livestock, health, environment, interior and commerce. In addition to line ministries, boosting human capacity will require universities, veterinary schools, research hospitals, investigation centers, diagnostic laboratories and linkages to civil society organizations (e.g. NGOs, churches, charities and action groups).

Grassroots approaches

An approach that has been implemented with some success is *livestock farmers' field training*. These programs consist of education and awareness-raising. Trainers start by holding meetings with elders, farmers, growers and villagers to raise awareness of the pros and cons of irresponsible animal husbandry, bio-security and risks associated with poor hygiene, vaccinations and the role of communities in preventing and controlling animal diseases, as well as conducting demonstrations. Later, elders are requested to add this information to the agenda of village meetings, and to undertake community policing of sick animals. In similar fashion, authorities and communities can launch *climate change field schools* to include issues of cause and effect, animal–human health, diseases and adaptation and mitigation actions.

Lessons learned and the way forward

The eradication of rinderpest, the progressive control of foot-and-mouth disease and the management of HPAI in Southeast Asia contain many valuable *lessons to be learned*. One of these is that investments in early detection and response of disease events pay off. Another lesson is that collaboration of public and private sectors involved in human, animal and environmental health can contribute to greater effectiveness in the prevention, detection and response to animal diseases, thereby saving human lives, protecting animal health and preventing significant economic losses. Lastly, more comprehensive surveillance for infection and disease in occupational groups that work most closely with animals is a must for early disease detection. The benefits of having a national or regional disease surveillance capability may be readily apparent on a societal level, although not at a healthcare businesses level. Both understanding and articulating the 'value proposition' for healthcare providers are critical to forming productive collaborations in these key areas.

Some commentators believe that *the way forward* in dealing with animal diseases is to strengthen existing infrastructures and to reinforce human capital in regions denoted as hotspots. The reasoning is that countries must use the resources at their disposal to find creative solutions to local, context-based problems. Another route to moving ahead in dealing with climate change and animal disease emergence is to consolidate the in-country chain of command in preparation for rapidly infectious diseases events. This consolidation could bring about reduced ambivalence and ambiguity during crisis situations, and would tend to address priority issues as a classical case of triage. As noted above, a review of existing legislation and compensation strategies could shine light into deficiencies and gaps that could at some point rise up as real vulnerabilities during outbreaks. Finally, just as in natural disasters, keeping a strategic reserve of funds to deal with emergencies might be the best way to finance all activities under duress.

Now, let us turn our attention to climate change. A viable option is to shift to a true low-carbon economy. To this end, natural gas is a bridge fuel that can ease this transition. A renewed interest in gas is good news for efforts to tackle climate change because carbon dioxide emissions are far lower from burning gas than coal and it is a much more flexible fuel. However, its increased use could displace the trend in adopting non-carbon fuels, such as renewable sources and nuclear: particularly in the wake of the incident in Japan's Fukushima and the likelihood of a reduced role for nuclear energy in some countries. Gas and renewable sources could work well together, with gas plants that provide base-load power being able to switch to fill in the gaps when the wind is not blowing or the sun is not shining. However, an expansion of gas usage around the world is no panacea for climate change – a radical re-conceptualization of our consumption-oriented lifestyle is needed. Furthermore, individual countries can also decide to establish ambitious carbon and GHG emission targets that are far beyond those proposed in intergovernmental protocols. For example, China is the world's biggest emitter of carbon and it has pledged to reduce the amount emitted per unit of GDP by 40% by 2020, and also cut emissions of pollutants including sulfur dioxide and nitrogen oxides.

In the end, it is widely believed that climate change will enable the emergence of animal diseases around the globe, with human-to-human spread potential and multiple associated costs to societies and governments. These emerging threats can be addressed and reduced through the application of holistic and proactive disease risk management approaches that build on disease intelligence, multidisciplinary collaborations, public-private partnerships, international commitments and scientific progress (Burgos-Cáceres and Otte, 2010). All of this is critical given that, as the world population reaches the 7 billion mark and subpopulations in emerging market economies start to join the rank of middle-income households, livestock production systems will be pressed to supply the demand for meat that arises from adoption of the diverse and rich nutritional diets enjoyed in developed countries. Also, demands for grains to manufacture feedstuffs for animals in confinement will rise, and with it, the need for land and energy inputs (i.e. fuels, fertilizers). As a consequence of increased cropland requirements, encroachment into forests may continue eroding forestry resources and clearing plots of land that produce more polluting gases that further contribute to global warming. This is added to the extra methane that intensive animal production systems will generate, which are set to worsen already alarming climatic changes (Burgos, 2011).

Conclusion

Few would disagree that an exponential expansion of the human population has led to overexploitation of natural resources and overproduction of superfluous items that have caused a series of potentially devastating effects, including climate change, ocean acidification, ozone depletion, emergence of new diseases in animals and humans, biodiversity loss and the spread of invasive flora and fauna.

Present knowledge about climate change and its effects is sufficient to warrant taking action, but a stronger foundation is needed to ensure that pertinent and relevant long-term decisions and actions are made that will meet the demands for food for a rapidly growing human population. In the context of participatory actions and initiatives, implementing agencies should avoid cultural myopia, that is, an institution's failure to understand country cultural differences that require *different approaches* to disease control and prevention. Thus cross-cultural fluency must pervade discussions with stakeholders, especially those most affected by measures.

At the policymaking level, two of the most powerful tools are legislation and regulation. Strong and coherent legislation and regulation are needed to protect our remaining natural ecosystems and available farmland (i.e. by reducing deforestation that increases GHG emissions). For example, farmland can be improved by requiring the use of crop rotation and natural means of fixing nitrogen in soil. Moreover, developing countries need stricter regulations so natural resources cannot be pillaged with impunity.

Leading scientists and researchers around the world have been trying to understand the global temporal and spatial patterns of animal diseases through an array of instruments ranging from the use of satellite images to pin down geographical origins, to cutting-edge molecular technologies to track the genetic makeup of these insidious pathogens. The commonly shared outlook among experts is that animal diseases infecting humans will continue to rise, and that these will be modulated by impending climatic changes. Animal disease emergence can no longer be seen in isolation or in neatly defined compartments, but must now be viewed alongside an evolving continuum of climatic changes, natural resource management, agricultural intensification, land utilization patterns, trade globalization, changing consumer preferences, and shifting farming, marketing and food distribution systems (Burgos and Slingenbergh, 2010). This will require new paradigms, new technologies, new approaches, and much economic assistance from developed and transitioning economies. The problem, however, is that global economic resources to counter disease emergence are poorly allocated, with the majority of the research, scientific and surveillance efforts focused on countries and regions from which the next major EID is *least likely* to emerge or originate (Jones *et al*., 2008).

Because risks have already increased dramatically, intergovernmental organizations' responses need to anticipate disasters and reduce risks before they happen rather than wait until after they happen and clean up afterward. This is the operational imperative for what is now known as *active disease intelligence* – foresight capacity built on visioning exercises that systematically scans horizons to identify sources of pathogens as well as pathways and drivers of emergence, leading to the identification of geographic 'hotspots' and 'risky practices'. Also, a profound understanding of the demographic, cultural, economic, environmental, climatic, evolutionary and social factors that contribute to the emergence and spread of diseases is needed.

It is evident that the systems and mechanisms involved in climate change are extremely complex and intertwined, and that the impacts will differ considerably from one region of the world to another. In fact, the most serious consequences are just as likely to come from disruptions to the Earth's rhythms as from changing average temperatures. The effects of climate change will vary widely: depending not only on the fragility of ecosystems and the intensity of the changes, but also on a country's ability to prepare itself and adapt to such changes (De la Rocque, 2008). The predictions for the next few decades are reasonably robust, whereas predictions for later time-periods depend on uncertainties in climate model structures and on the unknown future course of GHG emissions. A major problem that remains is the gap between the spatial resolution of climate model outputs and the spatial scale of concern in animal health assessments. On a global average, it may not matter much, but health assessments are generally of much more local interest. Another issue is that the microclimate experienced by any particular animal or disease agent may not be identical to the overall climate of the area (Stone, 2008).

At a practical level, businesses and farmers worldwide need to consider the risks extreme weather events might pose to their enterprises. For example, growers and livestock keepers reliant on water should consider the impact of increasing water scarcity. Those with big farms and property investments should think about effects on asset life, valuations, and insurance costs, whereas those dependent on non-intensive agriculture, especially in poor developing countries, are more likely to suffer from droughts and/or flooding. Most importantly, and above all, the time to start preparing is now.

If the world continues to witness repeated climate change mitigation failures along the lines of Copenhagen, Cancun and Durban, then it might start falling into doubt as to whether the United Nations Framework Convention on Climate Change should remain the central process for finding a climate change mitigation agreement, and this could allow for *newer forums* and *novel initiatives* to emerge in the hope that alternatives and options might turn out better outcomes than the ones so far achieved under the current format. Lastly, it is worth noting that a majority of the countries of the world that embrace free-market capitalism under neoliberal agendas have for long-traded economic growth for environmental standards, but many countries are now slowly starting to try to change that equation by raising environmental standards and slowing growth.

It is now clear that adaptation measures to climate change will be far reaching.

References

Baumuller H and Heymann D (2010). Health Security and Animal Diseases: Hooves and Humans. *The World Today*, March Issue, 21–23. [Available online at: http://www.chathamhouse.org/publications/twt/archive/view/169073. Last accessed 14 November 2012].

Bazilchuk N (2011). Climate Change May Boost a Lethal Disease. *The Daily Climate*, issued 29 November. [Available online at: http://wwwp.dailyclimate.org/tdc-newsroom/2011/11/hendra-virus, Last accessed 14 November 2012].

Borenstein S (2011). Science Panel: Get Ready for Extreme Weather. *Associated Press*, issued 18 November. [Available online at: http://www.weather.com/outlook/weather-news/news/articles/science-panel-more-extreme-weather_2011-11-18. Last accessed 14 November 2012].

Bradley C and Altizer S (2007). Urbanization and the ecology of wildlife diseases. *Trends in Ecology & Evolution* **22**: 95–102.

Brahmbhatt M (2005). Avian and human pandemic influenza: economic and social impacts. *Paper Presented at the World Health Organization (WHO) Conference*, Geneva, Switzerland, WHO Headquarters, 7–9 November 2005. [Available online at: http://web.worldbank.org/WBSITE/EXTERNAL/NEWS/0,contentMDK:20715087~pagePK:34370~piPK:42770~theSitePK:4607,00.html. Last accessed 14 November 2012].

Broglia A and Kapel C (2011). Changing dietary habits in a changing world: emerging drivers for the transmission of foodborne parasitic zoonoses. *Veterinary Parasitology* **182**: 2–13.

Burgos-Cáceres S (2011). Climatic changes, infectious diseases and livestock production. *Livestock Research for Rural Development* **23**: epub183. [Available online at: http://www.lrrd.org/lrrd23/9/burg23183.htm. Last accessed 15 November 2012].

Burgos-Cáceres S and Otte J (2010). *Global Public Health and Transboundary Animal Diseases: Issues and Options, Approaches and Concerns*. Rome, Italy: Food and Agriculture of the United Nations, Pro-Poor Livestock Policy Initiative, Research Report No. 10–02, 1–10. [Available online at: http://www.fao.org/ag/againfo/programmes/en/pplpi/docarc/rep_1002_GlobalPublicHealth_100413.pdf. Last accessed 14 November 2012].

Burgos-Cáceres S and Otte MJ (2009). Blame apportioning and the emergence of zoonoses over the last 25 years. *Transboundary and Emerging Diseases* **56**: 375–379.

Burgos S (2010). Emerging zoonotic diseases in a changed world: strategic vision or firefighting? *Transboundary and Emerging Diseases* **57**: 465–467.

Burgos S (2011). Challenges for a growing world: meat for all? *International Journal of Rural Development* **45**: 40–41.

Burgos S and Burgos SA (2007). Avian influenza outbreaks in Southeast Asia affects prices, markets and trade. *International Journal of Poultry Science* **6**: 1006–1009.

Burgos S and Otte J (2009). *Animal Health in the 21st Century: Challenges and Opportunities*. Rome, Italy: Food and Agriculture of the United Nations, Pro-Poor Livestock Policy Initiative, Research Report Nr. 09–06, 1–11. [Available online at: http://www.fao.org/ag/againfo/programmes/en/pplpi/docarc/rep-0906_21stCenturyAnimalHealth.pdf. Last accessed 15 November 2012].

Burgos S and Otte J (2010). *Managing the Risks of Emerging Diseases: From Rhetoric To Action*. Rome, Italy: Food and Agriculture of the United Nations, Pro-Poor HPAI Risk Reduction, HPAI Research Brief No. 22, 1–4. [Available online at: http://www.dfid.gov.uk/r4d/PDF/Outputs/HPAI/FAO_2010HPAI_rbr22.pdf, Last accessed 15 November 2012].

Burgos S and Otte J (2011). Linking animal health and international affairs: trade, food, security, and global health. *Yale Journal of International Affairs* **6**: 108–109.

Burgos S and Slingenbergh J (2010). FAO in one health: business unusual. *One Health Newsletter* **3**: 17–19.

Clark P (2011). Kyoto protocol at risk in Durban. *Financial Times*, issued November 28. [Available online at: http://www.ft.com/intl/cms/s/0/aea9b710-1448-11e1-b07b-00144feabdc0.html. Last accessed 15 November 2012].

Daszak P, Cunningham AA and Hyatt AD (2000). Emerging infectious diseases of wildlife: threats to biodiversity and human health. *Science* **287**: 443–449.

Daszak P, Cunningham AA and Hyatt AD (2001). Anthropogenic environmental change and the emergence of infectious diseases in wildlife. *Acta Tropica* **78**: 103–116.

De La Rocque S (2008). Introduction–climate change: impact on the epidemiology and control of animal diseases. *Revue Scientifique et Technique – Office International des Epizooties* **27**: 303–304.

De la Rocque S, Hendrickx G and Morand S (2008). Climate change: impact on the epidemiology and control of animal diseases. *Revue Scientifique et Technique – Office International des Epizooties* **27**: 5–11.

Delecluse P (2008). The origin of climate changes. *Revue Scientifique et Technique–Office International des Epizooties* **27**: 309–317.

Epstein PR (1999). Climate and health. *Science* **285**: 347–348.

Epstein PR (2004). Climate change and public health: emerging infectious diseases. *Encyclopedia of Energy* **I**: 381–392.

FAO – Food and Agriculture Organization of the United Nations (2009). *State of Food and Agriculture*. Rome, Italy: FAO Press. [Available at: www.fao.org/docrep/012/i0680e/i0680e.pdf. Last accessed 14 November 2012].

Gilbert M, Slingenbergh J and Xiao X (2008). Climate change and avian influenza. *Revue Scientifique et Technique – Office International des Epizooties* **27**: 459–466.

Hay S, Guerra C, Tatem A, Atkinson P and Snow R (2005). Tropical infectious diseases: urbanization, malaria transmission, and disease burden in Africa. *Nature Reviews Microbiology* **3**: 81–90.

Hughes L (2000). Biological consequences of global warming: is the signal already there? *Trends in Ecology & Evolution* **15**: 56–61.

IPPC – Intergovernmental Panel on Climate Change (2002). *Climate Change and Biodiversity*. Geneva, Switzerland: Technical Paper V. [Available online at: http://www.ipcc.ch/pdf/technical-papers/climate-changes-biodiversity-en.pdf, Last accessed 14 November 2012].

IPPC – Intergovernmental Panel on Climate Change (2009). *IPCC Expert Meeting on Detection and Attribution Related to Anthropogenic Climate Change*. Geneva, Switzerland: Meeting Report. [Available online at: www.ipcc-wg2.gov/meetings/.../EM_D&A_MeetingReport_Final.pdf. Last accessed 14 November 2012].

Jenkins EJ, Schurer JM and Gesy KM (2011). Old problems on a new playing field: helminth zoonoses transmitted among dogs, wildlife, and people in a changing northern climate. *Veterinary Parasitology* **182**: 54–69.

Jonas O (2008). Update on coordinated international assistance. *Paper Presented at the Sixth International Ministerial Conference on Avian and Pandemic Influenza*, October 24–26, Sharm-el-Sheikh, Egypt. [Available online at: www.fao.org/docs/eims/upload/250968/aj200e00.pdf. Last accessed 14 November 2012].

Jones KE, Patel NG, Levy MA, Storeygard A, Balk D, Gittleman JL and Daszak P (2008). Global trends in emerging infectious diseases. *Nature* **451**: 990–993.

Keesing F, Belden LK, Daszak P, Dobson A, Harvell CD, Holt RD, Hudson P, Jolles A, Jones KE, Mitchell CE, Myers SS, Bogich T and Ostfeld RS (2010). Impacts of biodiversity on the emergence and transmission of infectious diseases. *Nature* **468**: 647–652.

Lafferty K (2009). The ecology of climate change and infectious diseases. *Ecology* **90**: 888.

Marano N, Arguin PM and Pappaioanou M (2007). Impact of globalization and animal trade on infectious disease ecology. *Emerging Infectious Diseases* **13**: 1807–1809.

Martin V, Chevalier V, Ceccato P, Anyamba A, De Simone L, Lubroth J, De La Rocque D and Domenech J (2008). The impact of climate change on the epidemiology and control of rift valley fever. *Revue Scientifique et Technique – Office International des Epizooties* **27**: 413–426.

Mas-Coma S, Valero MA and Bargues MD (2008). Effects of climate change on animal and zoonotic helminthiases. *Revue Scientifique et Technique – Office International des Epizooties* **27**: 443–452.

McKinney ML (2002). Urbanization, biodiversity and conservation. *Bioscience* **52**: 883–890.

McMichael AJ (2010). Climate change and human health. *Health G20* **11**: 121–136.

Meltzer M, Cox N and Fukuda K (1999). The economic impact of pandemic influenza in the United States: priorities for intervention. *Emerging Infectious Diseases* **5**: 659–671.

Mills JN, Gage KL and Khan AS (2010). Potential influence of climate change on vector-borne and zoonotic diseases: a review and proposed research plan. *Environmental Health Perspectives* **118**: 1507–1514.

OECD – Organization for Economic Cooperation and Development (2011). *Building Resilience to Climate Change in the Agriculture Sector*. Paris, France: Reference Code COM/TAD/CA/ENV/EPOC, 13 pages. [Available online at: http://search.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=COM/TAD/CA/ENV/EPOC%282011%2930/FINAL&docLanguage=En. Last accessed 14 November 2012].

Perry BD, Grace D and Sones K (2011). Current drivers and future directions of global livestock disease dynamics. *Proceedings of the National Academy of Sciences USA*, Electronic Publication on May 16, 2011, ahead of print version. [Available online at: http://www.pnas.org/content/early/2011/05/10/1012953108.full.pdf. Last accessed 14 November 2012].

Pinto J, Bonacic C, Hamilton-West C, Romero J and Lubroth J (2008). Climate change and animal diseases in South America. *Revue Scientifique et Technique – Office International des Epizooties* **27**: 599–613.

Rogers DJ and Randolph SE (1993). Distribution of tsetse and ticks in Africa: past, present and future. *Parasitology Today* **9**: 266–271.

Salman M (2003). Surveillance and monitoring systems for animal health programs and disease survey. In: *Animal Disease Surveillance and Survey Systems: Methods and Applications*. Ames, Iowa: Iowa State University Press, pp. 3–13.

Schmitz C, Biewald A, Lotze-Campen H, Popp A, Dietrich JP, Bodirsky B, Krause M and Weindl I (2011). Trading more food: implications for land use, greenhouse gas emissions, and the food system. *Global Environmental Change* **22**: 189–209.

Shuman EK (2010). Global climate change and infectious diseases. *New England Journal of Medicine* **362**: 1061–1063.

Singh BB, Sharma R, Gill JP, Aulakh RS and Banga HS (2011). Climate change, zoonoses, and India. *Revue Scientifique et Technique – Office International des Epizooties* **30**: 779–788.

Stone DA (2008). Predicted climate changes for the years to come and implications for disease impact studies. *Revue Scientifique et Technique – Office International des Epizooties* **27**: 319–330.

Summers BA (2009). Climate change and animal diseases. *Veterinary Pathology* **46**: 1185–1186.

Tabachnick WJ (2010). Challenges in predicting climate and environmental effects on vector-borne disease epi-systems in a changing world. *Journal of Experimental Biology* **213**: 946–954.

Twentyman J (2011). Hard to pin down precise causes of the effects. *Financial Times*, issued November 28. [Available online at: http://www.ft.com/intl/cms/s/0/db22a0b8-1448-11e1-b07b-00144feabdc0.html. Last accessed 14 November 2012].

UNDPI – UN Department of Public Information (2007). *World population will increase by 2.5 billion by 2050; people over 60 to increase by more than 1 billion*. Press Release POP/952, News and Media Division. [Available online at: http://www.un.org/News/Press/docs//2007/pop952.doc.htm. Last accessed 14 November 2012].

Van Dijk J, Sargison ND, Kenyon F and Skuce PJ (2010). Climate change and infectious disease: helminthological challenges to farmed ruminants in temperate regions. *Animal* **4**: 377–392.

Vandegrift KJ, Sokolow SH, Daszak P and Kilpatrick AM (2010). Ecology of avian influenza viruses in a changing world. *Annals of the New York Academy of Science* **1195**: 113–128.

Woolhouse M (2011). How to make predictions about future infectious disease risks. *Philosophical Transactions of the Royal Society London B: Biological Sciences* **366**: 2045–2054.

Zhang Y, Bi P and Hiller JE (2008). Climate change and the transmission of vector-borne diseases: a review. *Asia Pacific Journal Public Health* **20**: 64–76.