AGRICULTURE AND ENVIRONMENTAL SERVICES DISCUSSION PAPER 07

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REDUCING CLIMATE-SENSITIVE DISEASE RISKS

WORLD BANK REPORT NUMBER 84956-GLB

THE WORLD BANK

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Note: All dollars are U.S. dollars unless otherwise noted.

ACKNOWLEDGMENTS

This report was written by Timothy Bouley (World Bank) and Caroline Planté (World Bank). The team was under the leadership of Pai-Yei Whung and Francois Le Gall. Important contributions were made by Marius Gilbert (Université Libre de Bruxelles), Mimako Kobayashi, Anne Maryse Pierre-Louis, Norman Piccioni, Dipti Thapa, Cory Belden, Jim Cantrell, Angie Wahi (World Bank), and William Wint (University of Oxford). Communications were handled by Elisabeth Mealey. Editing was done by Linda Starke. Peer-review was performed by Ademola Braimoh, Shiyong Wang, Laurent Msellati (World Bank), Stephane de la Rocque (WHO-OIE), Judy Omumbo (independent consultant), and Joy Guillemot (WHO consultant). Special efforts were made by a team of international experts assembled to advise the development of this work, including Matthew Baylis (University of Liverpool), Diarmid Campbell-Lendrum (WHO), Cyril Caminade (University of Liverpool), Pietro Ceccato (Columbia University), Nicoline DeHaan (FAO), Stephane de la Rocque (WHO-OIE), Stephane Forman (World Bank), Marius Gilbert (Université Libre de Bruxelles), Peter Ithondeka (Department of Veterinary Services, Kenya), Bhoj Joshi (Nepal Agricultural Research Council), Steve Kemp (ILRI), Mark Nanyingi (Department of Veterinary Services, Kenya), Judy Omumbo (Independent Consultant), Madeleine Thomson (Columbia University), Joep Van Mierlo (Vétérinaires Sans Frontiéres, Belgium), Bill Wilson (US Department of Agriculture).

The final product remains the responsibility of the authors. Much gratitude is owed to Juergen Voegele, Mark Cackler, and Valerie Hickey of the World Bank's Department of Agriculture and Environmental Services and Rachel Kyte of the Climate Change Group for their leadership and guidance. Special thanks is due to the Rockefeller Foundation and the staff of the Rockefeller Bellagio Center for their support.

ABBREVIATIONS AND ACRONYMS

BT	Bluetongue
DPCF	Disaster-preparedness and contingency fund
DPSIP	Disaster-preparedness strategy and investment program
ECF	East Coast fever
EID	emerging infectious disease
ENSO	El Niño–Southern Oscillation
EWS	early warning system
FAO	Food and Agriculture Organization
GCM	global climate model
GDP	gross domestic product
GIS	geographic information system
GLEWS	Global Early Warning System for Major Animal Diseases
HPAI	highly pathogenic avian influenza
ICT	information and communication technology
IFAD	International Fund for Agricultural Development
ILRI	International Livestock Research Institute
IPCC	Intergovernmental Panel on Climate Change
NDVI	Normalized Difference Vegetation Index
OIE	World Organisation for Animal Health
PVS	Performance of Veterinary Services
RVF	Rift Valley fever
SST	sea surface temperature
TTL	Task Team Leader
WHO	World Health Organization
WMO	World Meteorological Organization

FOREWORD

It is clear that climate change is increasingly affecting life on the planet. Average temperatures are rising, rainfall patterns are changing, and weather is becoming highly volatile.

At the World Bank Group, we consider climate change a fundamental threat to sustainable economic development and the fight against poverty. We are concerned that without bold action now, the warming planet threatens to put prosperity out of reach of millions and to roll back decades of development. It is our hope that shedding light on the various links between climate change and development will help practitioners and governments to better respond to the challenges posed by global warming.

This study focuses on livestock diseases that are "sensitive" to climate change, with a view to help practitioners reduce the risks of key climate-sensitive infectious diseases by strengthening risk management systems for disease outbreaks.

The three diseases chosen for the study—Rift Valley fever, Bluetongue, and East Coast fever—spread through "vectors" such as insects and parasites, the prevalence of which fluctuates depending on key weather and climate variables such as temperature and humidity. As the symptoms of climate change continue, the frequency and extent of these diseases are expected to escalate.

This research highlights the need for better understanding of the evolving interactions between the environment and emerging and re-emerging disease pathogens. It also points to the inseparable interactions between animal health and human health, which climate change appears to be reinforcing and even diversifying. In this context, the burgeoning concept and approach of "one health"—defined as "the collaborative effort of multiple disciplines—working locally, nationally, and globally—to attain optimal health for people, animals and the environment"—becomes increasingly relevant.

Going forward, it is clear that partnerships are essential to implementing the interventions recommended in this report (and those beyond) and to facilitating the mobilization of information and knowledge, technical capacity, and financial resources. The Global Livestock Agenda under development at the World Bank and the Livestock Global Alliance, with health, environment, and livelihoods at its core, envisages accelerating and scaling up systematic and coordinated interventions, including those for climate-sensitive diseases.

Dr. Juergen Voegele
Director
Agriculture and Environmental Services Department
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EXECUTIVE SUMMARY

Disease risks to humans, animals, and plants are determined by interconnected environmental variables that affect incidence, transmission, and outbreak. Climate change affects many of the environmental variables that lead to disease. Regardless of the species involved, the impacts can ultimately affect the health, livelihood, and economic security of humans.

The objective of this World Bank Economic and Sector Work is to build on scientific and operational knowledge of early action tools to help practitioners reduce the risks of key climate-sensitive infectious diseases by strengthening risk management systems for disease outbreaks. The report includes an assessment of known interventions such as the establishment of surveillance systems, the development of region- and nation-specific disease outlooks, the creation of climate-sensitive disease risk maps, and the construction and implementation of early warning advisory systems. The assessment then looks at proposed investments that can lead to the development of these tools, working toward reducing global climate-sensitive disease risk.

Because of the breadth of species affected by climate-sensitive disease, it has been helpful to select a model through which the specific impact of climate change and disease can be traced. In this instance, livestock has been chosen, given its significant global presence, economic importance, and susceptibility to disease outbreak. The livestock sector plays a vital role in the economies of many developing countries. Globally it accounts for 40 percent of agricultural gross domestic product (GDP). It employs 1.3 billion people and creates livelihoods for 1 billion of the world's poor. Livestock products provide one-third of human protein intake and are a potential remedy for undernourishment. Climate-sensitive diseases pose a permanent threat to this important sector, and disease outbreaks have major economic implications—both through private and public costs of the outbreak and through the costs of the measures taken at individual, collective, and international levels to prevent or control infection and disease outbreaks. Yet despite increasing evidence, including the Intergovernmental Panel on Climate Change's Fourth Assessment Report that linked climate variability and change to the emergence and re-emergence of infectious disease, concrete actions to address the climate impacts on disease outbreaks and livelihoods remain lagging. The World Bank's *World Development Report 2010* estimated the costs associated with climate-sensitive health impacts to be as high as 9 percent of GDP in some countries. Investments to reduce climate-associated diseases and health risks are only about 1–2 percent of overall climate sector investments.

There are many climate-sensitive livestock diseases; virtually any that are dependent on vectors or are waterborne could be included on this list. To narrow the scope, three of particular economic and health importance were chosen: Rift Valley fever (RVF), Bluetongue (BT), and East Coast fever (ECF). Rift Valley fever is a vector-borne viral disease transmitted by several species of mosquitoes that have facilitated epidemics in Africa and in the Arabian Peninsula, with dramatic impact on animal and human health due to its zoonotic dimension. Bluetongue is a vector-borne viral disease transmitted by several species of *Culicoides* midges. The disease is endemic to many tropical climates, though it has invaded Europe in the last decades with a massive economic impact, mainly through disruption of trade. East Coast fever is a vector-borne parasitic disease transmitted by ticks that is endemic in many southeast African countries, where it has a continuous and significant economic impact. The vector-borne nature of each implies climate sensitivity.

Livestock diseases can be classified and ranked according to various criteria, such as overall economic impact, impact on livelihood, potential to adapt and invade a new host and become zoonotic, potential to spread into new geographical areas, or a combination of these. The relative impact of each of these diseases is highly specific to the region and the capacity of agricultural and health systems to mitigate the effects. Furthermore, global data on each of these three, which can be taken as a sample of other climate-sensitive diseases, are incomplete and variable in quality and by type of disease, making it difficult to assess comprehensive economic impact. The data for health impacts on humans are even less robust, highlighting the need for individual case studies to clarify total costs.

Bearing in mind these limitations, rough estimates of costs can be assessed, providing a reference point for decision makers. For example, RVF epidemics in Somalia have prevented 8.2 million small ruminants, 110,000 camels, and 57,000 cattle from being exported, corresponding to economic losses for the livestock industry estimated at $109 million in 1998–99 and $326 million in 2000–02. For Bluetongue, in the Netherlands alone the 2006 and 2007 epidemics had net costs of 32.4 million and 164–175 million euros, respectively. The annual cost of ECF is estimated as $88.6 million in Kenya, $2.6 million in Malawi, $133.9 million in Tanzania, and $8.8 million in Zambia.

The impact of climate change on diseases is not unique to livestock. Human, plant, and other animal diseases are all affected by changing climatic conditions. Further, each affects the other and can lead to serious harm to economic and human well-being. Plant and animal diseases can lead to malnutrition and famine in humans, and many animal and human diseases can be exchanged via zoonotic (animal to human) or anthroponotic (human to animal) transmission.

One Health is a recognized framework that acknowledges the systemic connectedness of human, animal, and environmental health. These considerations have long been important to health care practitioners, as humans have historically lived intimately in the environment. As cities have emerged, as technology progressed, and as allopathic medicine become the predominant medical paradigm, this inherent understanding about disease and health has been displaced by disciplinary silos. In recent decades, however, renewed interest in jointly considering these different spheres of health has occurred. Global trends in environmental change, travel, population growth, and the livestock industry have resulted in a booming era of emerging infectious disease (EIDs). A total of 335 EIDs have been identified in humans since 1940, of which three-quarters are zoonotic, including HIV, Ebola, SARS, and avian influenza. Climate is thought to have a role in some of these emergent events; for example, recent work has suggested that variations in climate may have established environmental conditions ripe for avian influenza—a disease with catastrophic financial impacts that span sectors as diverse as livestock, tourism, trade, and health care.

The additional effect of climate change on health is difficult to calculate for one species, let alone for collaborative health systems that include humans, animals, and the environment. Nevertheless, in pairing what is known about the effect of climate change on the health of one species with what is known about how the health of one species affects another, logic can help us see how climate change is undeniably linked to health in many spheres of life. It is not necessary to establish clear causal links between climate change and environmental change before adaptation strategies can be developed and implemented.

In order to identify approaches to reducing these disease risks (and costs), it is important to understand the pressure points where climate affects disease. Climate may influence virtually all components of disease systems: the pathogen (for example, influencing the development rate or the survival outside the host or vector), the host (through the immune response or changes in host distribution), and the vectors (arthropod vector development is tightly linked to climatic parameters such as temperature and humidity). In addition, climate change and climate variability may strongly influence disease by indirect effects such as the movements of hosts resulting from floods or heat waves or climate-induced changes in land use or land cover.

People in developing regions are particularly vulnerable to negative economic, social, and health impacts resulting from climate change. Human vulnerability (inclusive of health, economics, livelihoods) is affected by the vulnerability of animals' health to climate change, but this has been the focus of few studies. Reducing climate-sensitive livestock disease risks overall can be aided by understanding how both animals and humans are vulnerable to climate change so that collaborative and comprehensive systems can be developed to increase resilience.

Through upstream disease prevention efforts, the health, livelihood, and economic security of downstream human populations can be protected. The tools identified and assessed in this report for upstream prevention include surveillance systems, disease outlooks, disease risk maps, and early warning systems (EWS).

- Surveillance systems are key to knowing where and when a disease will occur, providing baseline data for risk models. Both active and passive surveillance are important tools that can be used to generate most-accurate disease profiles. Geospatial and information technology is increasingly important for developing accurate surveillance methodologies.
- Risk maps rely heavily on the appropriate collection of disease data. They enable better prioritization of surveillance, prevention, and mitigation efforts. In many studies, risk maps have consisted of mapping the distribution of vectors; recent works enable modeling diseases themselves.
- Disease outlooks aim to provide long-term projection of disease trends so that disease control and mitigation efforts can be integrated into long-term planning. Unfortunately, few disease outlooks are yet available for any diseases.
- Early warning systems aim to provide short or midterm disease forecasting so that appropriate interventions and mitigation efforts can reduce the impact of an epidemic. Climate-based EWS have been developed for RVF in East Africa and have proved useful in predicting recent outbreaks.

Preparing climate-sensitive disease risk-reduction tools requires basic levels of underlying infrastructure in a number of areas: knowledge, policy, human resources, information and communication technology, and physical building. Investment in individual project components in each of these infrastructure areas will help build the capacities of countries so that they can effectively implement and use risk management tools. Many of the actions and project components leading to the strengthening of this infrastructure are interrelated and co-dependent, necessitating investment packages that address a portfolio of needs. Further, the actions required to bolster underlying infrastructure are not necessarily specific to any one disease, and investment in project components that lead to improved infrastructure can have co-benefits for a variety of non-disease-related development needs. (See following page for detail.)

Building an investment package requires a chronological deployment of activities. A three-phased approach has been recommended.

Phase 1:

- Knowledge: Needs assessments and baseline surveys of basic capacities of institutions, individuals, and technical and physical infrastructures

Phase 2:

- Information and communication technology (ICT): Climate-sensitive disease web-portals inclusive of integrated EWS information, risk maps, disease outlooks
- ICT: Mapping, geographic information system (GIS), and modeling software
- ICT: New and/or integrated with current hydro-met information systems
- Human Resources: Workforce trainings (policy makers, veterinarians, physicians, environmental scientists, communication experts, others) through short courses, workshops, and sponsored advanced degree programs on general climate-sensitive disease information as well as specialized technical aspects of the work (for example, disease diagnostics, GIS, computer programming)
- Policy: Coordinated animal health–human health collaboration mechanisms through, for example, committees and cross-sectoral working groups at national/regional levels

Phase 3:

- ICT: EWS messages disseminated through new media of websites, mobile phones, social media

INFRASTRUCTURE REQUIREMENT	INVESTMENT FAMILY	PROJECT COMPONENTS REQUIRING INVESTMENT
Baseline Knowledge	Information Product and Knowledge Generation	• Needs assessments and baseline surveys of basic capacities of institutions, individuals, and technical/physical infrastructures • Climate-sensitive disease risk catalogues and impact assessments at national and regional level • Feasibility studies for risk management tools, such as EWS messaging
Policy and Human Resources	Institutional Strengthening and Professional Capacity Building	• Workforce trainings (policy makers, veterinarians, physicians, environmental scientists, communication experts, others) through short courses, workshops, and sponsored advanced degree programs on general climate-sensitive disease research as well as specialized technical aspects of the work (such as disease diagnostics, disease risk mapping (GIS and spatiotemporal modeling), computer programming) • Environment, disease, and ICT workforce recruitment • Coordinated animal–human health collaboration committees and cross-sectoral working groups at national/regional levels • Early warning protocols for specific climate-sensitive diseases
	Community Capacity Building	• Climate-sensitive disease and ICT user trainings at local and subnational levels • Community support groups and knowledge exchanges
Information and Communication	Information Dissemination	• Climate-sensitive disease publications disseminated to professional and lay audiences • Climate-sensitive disease and EWS messages to be disseminated through traditional media resources: print, television, radio, community theatre • EWS messages disseminated through new media: websites, mobile phones, social media
	ICT Capacity Building	• Digital climate-sensitive disease libraries at regional/national level • Climate-sensitive disease web-portals inclusive of integrated EWS information, risk maps, disease outlooks • Mapping, GIS, and modeling software • New and/or integrated with current hydro-met information systems • Innovative data collection approaches
Physical	Building and Construction	• New or retrofitting of current facilities to create coordinated animal-human health–environmental data collection and collaboration centers at national/regional levels; to include meeting facilities, high speed Internet, resource libraries, and computers equipped with mapping, modeling, climate, and disease monitoring software • Rapid diagnostic laboratories equipped to process climate-sensitive diseases • ICT networks

The real problems are setting up the delivery systems that can protect people not only from the diseases of today, but from the diseases of tomorrow, and there's enough money out there in the world that we can begin moving in that direction. That's how I would like to see the World Bank engage.

—Jim Yong Kim at Brookings Institution, July 19, 2012
President
The World Bank

SCOPE OF THIS REPORT

The risk of disease to humans, animals, and plants is determined by interconnected factors of political, structural, organizational and technical nature. Environmental variables affect incidence, transmission, and spread. In this Economic and Sector Work, we focus only on the additional risk posed by climate change, which affects many of the environmental variables that lead to disease. We further narrow the scope by focusing on livestock. Many of the lessons learned from this exercise are transferrable to other diseases, including those that also affect humans. Through upstream disease prevention efforts, the health, livelihood, and economic security of downstream human populations can be protected.

Audience

This report was written as guidance for investment and project implementation to reduce risks from climate-sensitive disease. Internal World Bank audiences that stand to benefit the most are Task Team Leaders (TTLs) in countries and regions that are interested in developing coordinated programs incorporating agricultural, health, and environmental activities. Given the cross-cutting themes identified, TTLs with interests in any of these disciplines singularly may also benefit from learning of the co-benefits of inter-sectoral investment and action. Audiences external to the World Bank who may be interested in this work include governments, agencies, and nongovernmental organizations working at any of the intersections of agriculture, health, and environment.

Guide for Readers

This report does not need to be read cover to cover to be useful. Sections have been highlighted below in attempt to draw attention to certain audiences and corresponding "most relevant" sections.

Potentially Most Relevant to Researchers

General information on climate and disease or One Health: pp. 1–5

Climate-sensitive livestock diseases: pp. 5–10

Economic impacts of climate-sensitive diseases: pp. 10–13

Descriptions of tools for reducing climate-sensitive disease risks

- Surveillance systems: pp. 15–18
- Risk maps: pp. 18–23
- Disease outlooks: pp. 23–24
- Early warning systems: pp. 25–29

Potentially Most Relevant to Operational Teams

Approaches to using tools and making investments for reducing climate-sensitive disease risks: pp. 31–32

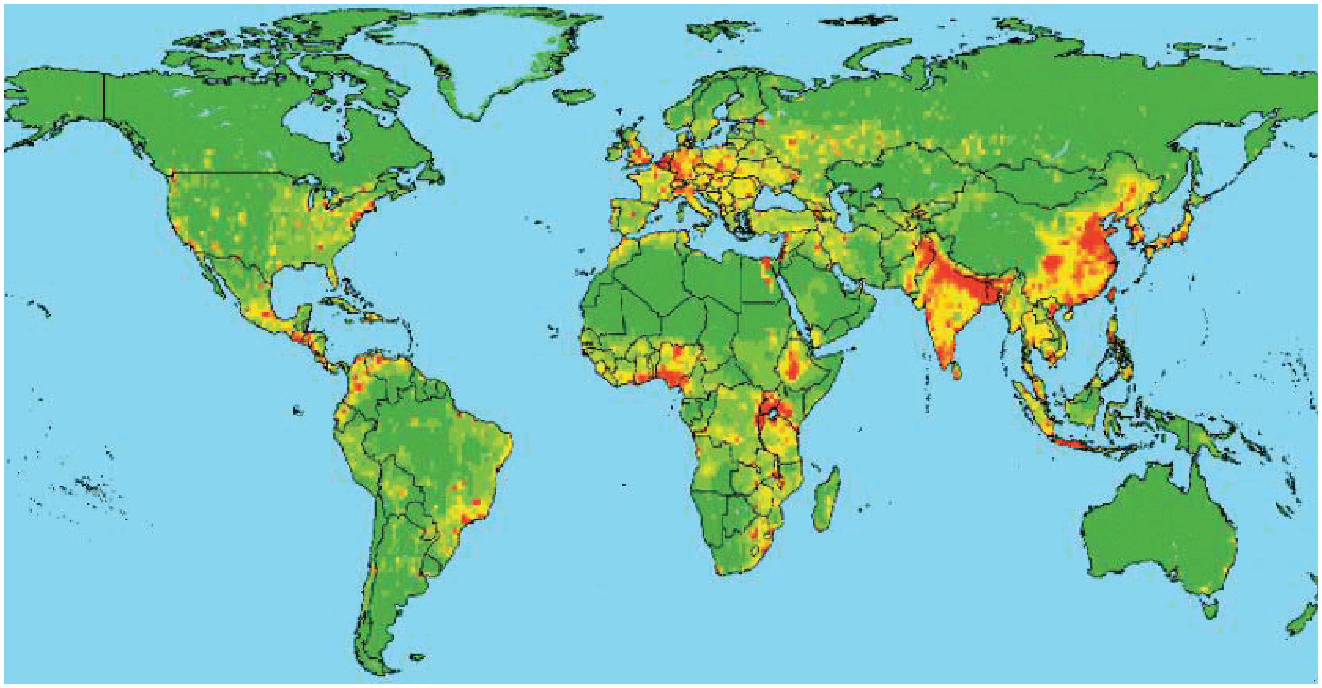
Building knowledge infrastructure: pp. 32–33

Building policy and human resource infrastructure: pp. 33–37

Building ICT infrastructure: pp. 37–39

Building physical infrastructure: pp. 39–40

Zoonotic Pathogens from Wildlife (Jones et al. 2008)



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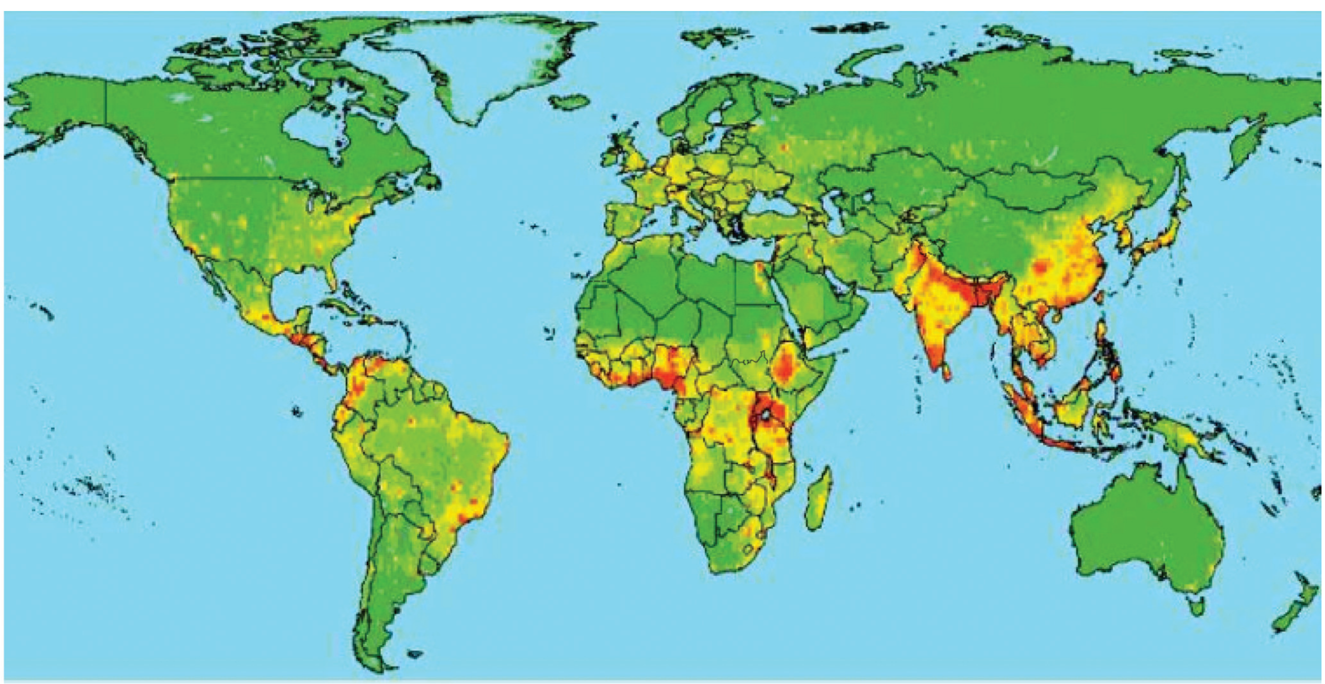
Zoonotic Pathogens from Non-Wildlife (Jones et al. 2008)



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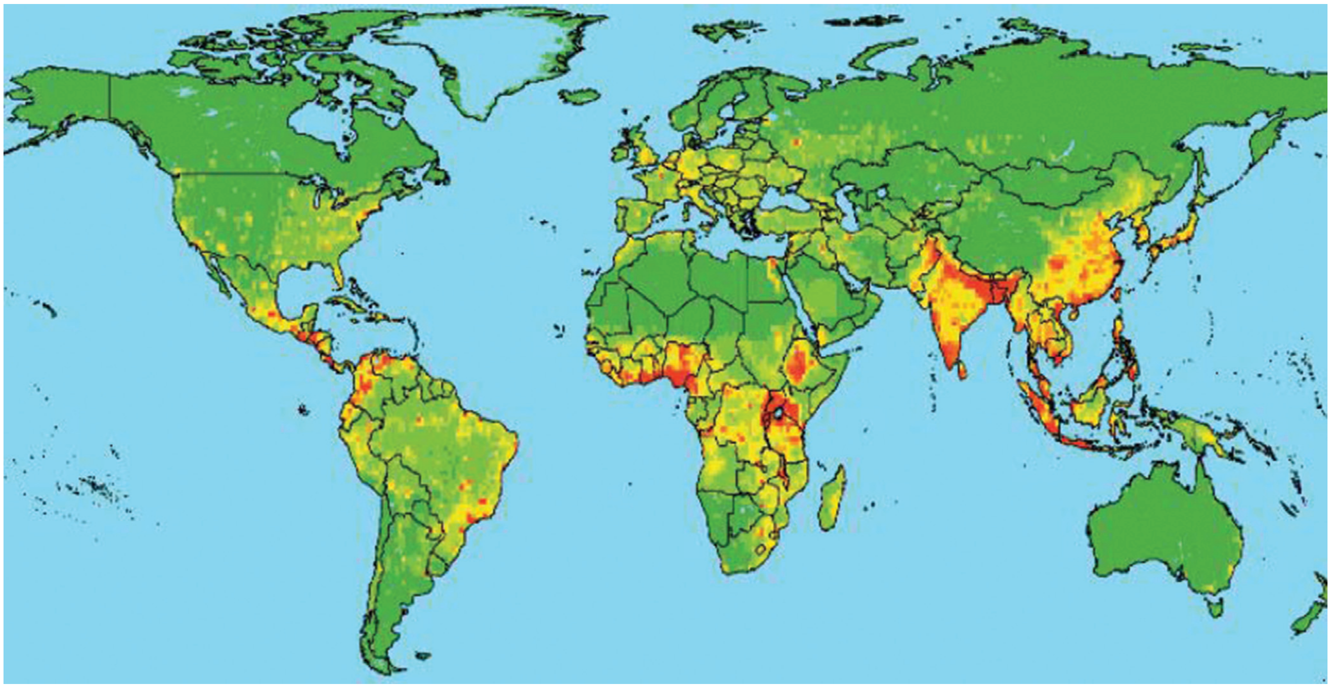
Vector-Borne Pathogens (Jones et al. 2008)



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MAPS: Global distribution of relative risk of emerging infectious disease events. Derived for EID events caused by zoonotic pathogens from wildlife, zoonotic pathogens from non-wildlife, and vector-borne pathogens. The relative risk is mapped on a linear scale from green (lower values) to red (higher values).

Chapter 1 KNOWLEDGE FOR ACTION

This chapter includes state-of-the-art knowledge of key livestock diseases, their relationship to climate change, and the economic and social impacts that these diseases have on human health, well-being, and livelihood.

Key messages:

- Livestock are fundamental to the health and livelihood of many in the developing world, accounting for 40 percent of agricultural gross domestic product, employing 1.3 billion people, and providing one-third of human protein intake.
- Climate-sensitive diseases have significant impact on the livestock sector in poor countries, having already led to hundreds of millions of dollars in losses in recent decades.
- Infectious disease stands to be particularly affected by climate change; many viral, bacterial, and parasitic infections depend on climate variables like temperature, humidity, and precipitation.
- There are many climate-sensitive livestock diseases; this report highlights three of particular economic and health importance: Rift Valley fever, Bluetongue, and East Coast fever.
- All regions are subject to climate change/variability and are at risk of emerging new climate-sensitive diseases; the three disease examples provided in this document provide important examples that are relevant to all regions.

1.1 BACKGROUND

Livestock is a key economic component of the agriculture sector, accounting for 40 percent of global agricultural gross domestic product, employing 1.3 billion people, and providing one-third of human protein intake (Steinfeld et al. 2006). Livestock plays an especially crucial role in developing countries. In addition to protein and income, it provides draught power, transport, fertilizer, holds cultural power, and bestows status, collectively making it an important lever of economic and social development (Randolph et al. 2007).

Infectious livestock diseases pose a serious threat, and disease outbreaks have major socioeconomic impacts through losses incurred by outbreaks and through costly measures taken at individual, national, and international levels for prevention and control (Otte, Nugent, and McLeod 2004). For zoonotic diseases (those that can be transmitted from animals to humans), the costs are even higher because they include the additional impact on human health (Rushton, Heffernan, and Pilling 2002). A recent study carried out by the International Livestock Research Institute (ILRI) noted that the greatest burden of zoonotic disease falls on the poorest livestock keepers, with 2.3 billion human illness and 1.7 million human deaths per year. Unsurprisingly, these burdens are felt in countries with large pastoralist populations, with Ethiopia, Nigeria, Tanzania, and India having some of the highest burdens (Grace et al. 2012).

The *World Development Report 2010* estimated the costs associated with climate-sensitive health impacts (in humans and animals) to be as high as 9 percent of gross domestic product (GDP) in certain countries (World Bank 2010b). Despite this, investments to mitigate climate-induced diseases and health risks are only about 1–2 percent of overall climate sector investment.

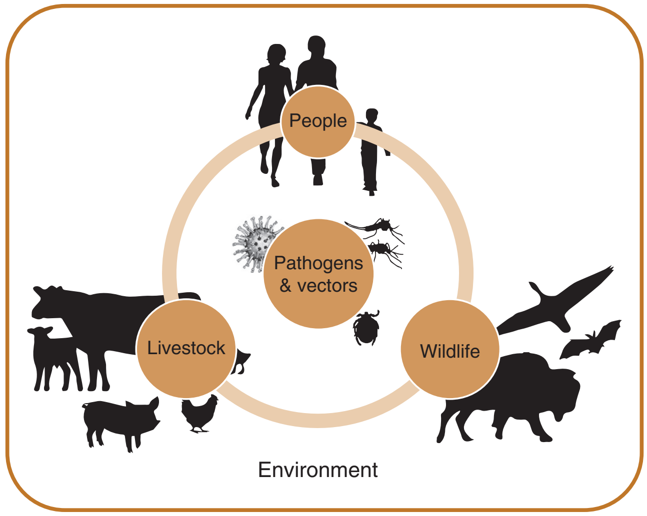
Several examples illustrate these aggregated numbers. Rift Valley fever, a mosquito-borne virus that is responsible for significant morbidity and mortality in humans and animals, had estimated trade-related economic losses as high as $60 million between 2006 and 2007 in East Africa alone (Little 2009). Tick-borne diseases, such as theileriosis (in animals), have been estimated to cost $384.3 million annually in India and $54.4 million in Kenya (Jongejan and Uilenberg 2004). The cost of inaction against livestock trypanosomiasis in

Nigeria is estimated to be 10 billion Nigerian Naira/year (~$60 million) (Fadiga, Jost, and Ihedioha 2011). In the developed world, the risks are also real, as evinced in the 2006 Bluetongue epidemic in the Netherlands, which accounted for €32.4 million in country losses and €164–175 million in losses upon its European spread (Velthuis et al. 2010).

> Global demand for animal-based protein is predicted to grow and to lead to increasing livestock populations, with the cattle population increasing from 1.5 billion to 2.6 billion and sheep and goats increasing from 1.7 billion to 2.7 billion between 2000 and 2050 (FAO 2009). The human population is expected to reach 9 billion by 2050, and the average global temperature is on track to increase by several degrees Celsius by the end of century (IPCC 2007). Together, these projections portend problems for the incidence and transmission of diseases that thrive in overpopulated, warm environments.

FIGURE 1.1: General Context of Emerging Infectious Diseases

[Changes in Demography (Demographic Transition, Urbanization), Livestock (Increasing Densities, Off-land Production), Wildlife (Land Pressure), and the Environment (Climate Change, Land Use Change) are the Main Components Affecting the Conditions of Emerging Infectious Diseases]



1.1.1 Livestock Diseases and Collaborative Health Systems

The genetic pool and origin of most emerging infectious diseases can be identified in wildlife (Jones et al. 2008; Cleaveland, Laurenson, and Taylor 2001). The domestication of animals, however, has led to new evolutionary opportunities (Diamond 2002; Wolfe, Dunavan, and Diamond 2007). During the "first epidemiological transition," humans began congregating in more sedentary agricultural societies and establishing larger communities in cities, providing opportunities for pathogens such as malaria, smallpox, measles, and tuberculosis to emerge and spread (Harper and Armelagos 2010).

The "second epidemiological transition" coincided with the industrial revolution, when improved nutrition and more-effective public health measures resulted in a decline in early mortality from infectious disease. Yet as populations aged, people began to experience a concomitant rise in chronic disease such as heart failure, cancer, and diabetes (Barrett et al. 1998), effectively substituting one cause of death for another.

We are now in the midst of the "third epidemiological transition," which is characterized by the emergence or re-emergence of pathogens in a context of fast demographic changes, globalization of production and trade, and changes in land use and climate (figure 1.1).

Along with the most dramatic increase in human population in history, the twentieth century saw a profoundly accelerated rate of urbanization (from 13 percent living in cities in 1900 to 49 percent in 2005), providing new habitats for vectors, concentrated populations of human hosts, and a substantial increase in demand for livestock products. In parallel, and following the green revolution in crop production, a livestock revolution fundamentally changed the way livestock were raised and traded (Delgado 1999; Steinfeld et al. 2006). The shift can be characterized by a change in practices from local multi-purpose activity to market-oriented production and integrated processes, a decreasing importance of ruminants compared to monogastric species (pigs, poultry), more large-scale industrial production closer to urban consumption centers, an increase in the use of cereal-based feed, and an increase in the volume of trade of live animals and animal products. Such changes in human and livestock numbers and distribution have been so significant that people and their livestock represent today more than 95 percent of the terrestrial vertebrate biomass (estimate based on Smil 2002 and on FAO 2009).

The epidemiological connectivity of the human and livestock populations has also been considerably expanded through the globalization of trade and travel. While epidemiological theory predicts that an increase in the number and connectivity of hosts should result in higher disease persistence and spread, the effects of those changes in human and animal populations have been largely tempered by the rapid parallel developments in human and animal health—that is, with the advent of vaccination, medication, and increased investments in disease prevention and control. Yet as the history of emerging diseases has demonstrated, pathogens adapt to these new patterns of human and animal populations (Antia et al. 2003) and challenge our ability to control them (Daszak, Cunningham, and Hyatt 2000). The direct costs of four emerging disease outbreaks over the last decade are estimated at over $20 billion, and indirect costs to economies are thought to be greater than $200 billion (World Bank 2010b). If indirect losses to other parts of the animal production chain, trade, and tourism are included, these costs are considerably higher.

Alongside the changes in host abundance and connectivity, emerging and re-emerging diseases affecting people and livestock are strongly influenced by environmental changes in land use (Patz et al. 2004) and climate (Epstein 2001). The World Health Organization (WHO) estimates that one-quarter of the global burden of diseases in humans, disproportionately felt in the developing world, is due to environmental change (Prüss-Ustün and Corvalán 2007). Similar estimates have not been made for livestock, although given the shared environmental pressures on them, it can be inferred that a corresponding statement could be made for animal diseases.

1.1.2 Relationship between Climate Change, Climate Variability, and Livestock Disease

A number of studies have explored the potential effect of climate change on infectious diseases in animals (de la Rocque 2008; Baylis and Githeko 2006; Heffernan, Salman, and York 2012). Collectively, these reviews highlight that climate change and climate variability may influence virtually all components of disease systems (figure 1.2): the pathogen (for instance, influencing the development rate or survival outside the host or vector), the host (through the immune response or changes in host distribution), and the vectors (arthropod vector development is tightly linked to climatic parameters such as temperature and humidity). In addition, climate change and climate variability may strongly influence diseases by indirect effects such as movements of hosts resulting from floods or heat waves or climate-induced changes in land use or land cover. Our current capacity to predict the actual impact of climate change on livestock diseases is somewhat limited, but it can be improved in the future, particularly with some of the methods detailed later in this report (Heffernan, Salman, and York 2012).

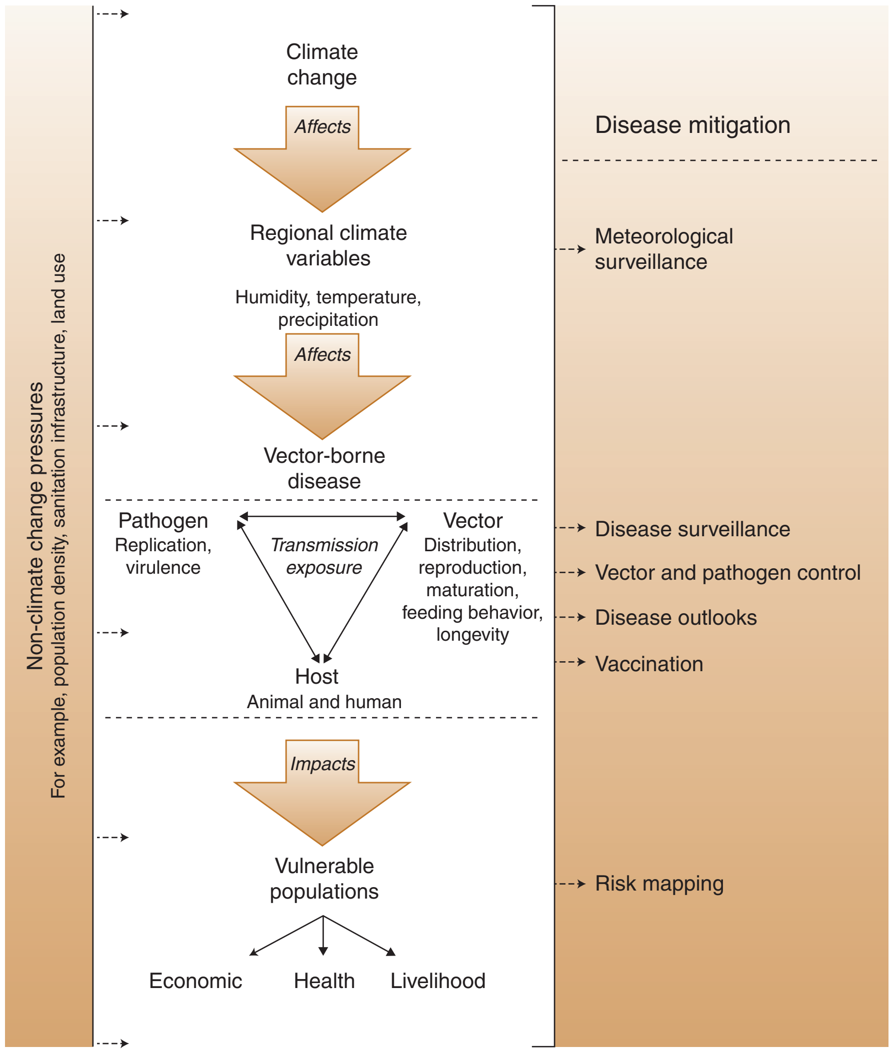
Climate change occurs at a global scale, yet it impacts regional and local environmental systems—and subsequently affects regional disease profiles. The focus of this report is the additionality of this climate-change-related burden, independent of other environmental pressures. Determining the exact degree to which climate change affects diseases is challenging in light of the multitude of factors that determine disease transmission, such as species interactions, vegetation, land degradation, food resources, population, and the baseline health of species. And yet it is possible to make some inferences about how climate change will affect diseases in any given region with an understanding of how certain diseases are sensitive to the environment.

> It is essential that the global community consider climate change's impact on health—both animal and human—given its potential to undermine global economic systems and livelihoods, particularly of the least-resilient populations.

In most disease systems, climate change is occurring concurrently with anthropogenic and natural drivers of change, making it difficult to disentangle respective impacts. Rapid transformation in land use, increase in trade and movements of live animals, increase in trade of goods that may harbor breeding vectors, changes in the distribution and abundance of livestock, or changes in the genetic composition of hosts, for example, may all affect disease systems.

The relationships between climate change, climate variability, and disease are disease-specific. In 2008, the World Organisation for Animal Health (OIE) *Scientific and Technical Review* published a review of the impact of climate change on both the epidemiology and the control of animal diseases (de la Rocque 2008), and the state of knowledge on the effect of climate change was reviewed for several diseases and disease groups, including Rift Valley fever, Bluetongue, avian influenza, tick-borne diseases, mosquito-borne diseases, leishmaniasis, and helminthiasis. The review demonstrated a contrasting range

FIGURE 1.2: Mechanistic Pathways by Which Climate Change May Influence Climate-Sensitive Vector-Borne Diseases



of potential effects in different diseases systems. Strong evidence supported the impact of climate change on some diseases, for example on the northward expansion of Bluetongue (Purse et al. 2008).

The potential impact of climate on diseases transmitted by arthropod vectors is strongly scale-dependent in space and time. Temperature affects arthropod vector development at embryonic, larval, and pupal stages, it influences adult feeding behavior, and it affects adult life spans. Similarly, aquatic or moist environments are often needed for breeding stages so that high precipitation can create more reservoirs and thus amplify the number of breeding sites. All vector species distributions can therefore be defined by their temperature and moisture ecological niche, which are defined by both a lower and an upper bound. The Intergovernmental Panel on Climate Change (IPCC) predictions for future temperature and rainfall are notoriously heterogeneously distributed throughout the globe (IPCC 2007), and highlight not only changes in the averages but also the extremes. The impact of such changes on different vectors is therefore likely to vary substantially from place to place, with higher vector populations in some parts of the world (regions that have recently become part of the niches) and in lower populations in others (regions that are no longer suitable). In addition, a general rise in annual mean temperature may have very different effects on vector populations according to the season: increased winter temperature may have a positive effect through a lower winter mortality, whereas increased summer temperature may have the opposite effect through an increased mortality in adults. Both spatial and temporal heterogeneity of the predicted changes, combined with the inherent uncertainties in climate projections, make predictions difficult, even for a single disease system.

While there are clear difficulties in assessing the overall impact of climate change and variability on livestock diseases, careful assessment and prediction in some regions and disease systems remain possible, as demonstrated by the numerous studies that have used statistical modeling to forecast the future distribution of species or disease (Rogers, Hay, and Packer 1996; McDermott et al. 2002; Purse et al. 2008). Even if other mechanistic causes are implicated, addressing and mitigating the potential effects of climate change and climate variability on livestock disease has much benefit, particularly in the developing world, where humans and livestock live so close together.

1.1.3 Climate, Diseases, and the Emergence of "One Health"

The impact of climate change on diseases is not unique to livestock. Human, plant, and other animal diseases are all affected by changing climatic conditions. Further, each affects the other and can lead to serious harm to economic and human well-being. Plant and animal diseases can lead to malnutrition and famine in humans, and animals and humans can be affected by common pathogenic agents (zoonotic diseases).

One Health is a recognized framework that acknowledges the systemic connectedness among human, animal, and environmental health. These considerations have long been important to health care practitioners, as humans have historically lived intimately in the environment. As cities have emerged, technology progressed, and allopathic medicine become the predominant medical paradigm, this inherent understanding about disease and health has been displaced by disciplinary silos. In recent decades, however, renewed interest in jointly considering these different spheres of health has occurred. Global trends in environmental change, travel, population growth, and the livestock industry have resulted in a booming era of emerging infectious disease. A total of 335 EIDs have been identified in humans since 1940, of which three-quarters are zoonotic, including HIV, Ebola, SARS, and avian influenza (Jones et al. 2008; Taylor et al. 2001). Climate is thought to have a role in some of these emergent events; for example, recent work has suggested that variations in climate may have established environmental conditions ripe for avian influenza—a disease with catastrophic financial impacts that span sectors as diverse as livestock, tourism, and health care (Shaman and Lipsitch 2012).

The additional effect of climate change on health is difficult to calculate for one species, let alone for collaborative health systems that include humans, animals, and the environment. Nevertheless, in pairing what is known about the effect of climate change on the health of one species with what is known about how the health of one species affects another, logic can help us see how climate change is undeniably linked to health in many spheres of life, regardless of our incomplete understanding. It is not necessary to establish clear causal links between climate change and environmental change before adaptation strategies can be developed and implemented (Black and Nunn 2009).

Recent One Health Actions

In recent years the international community has taken increasing notice of both the threat that climate change poses to disease and the importance of collaborative health among humans, animals, and the environment.

In April 2011, the African Union Commissioner of Rural Economy and Agriculture, jointly with the UN Economic Commission for Africa, WHO's Regional Office for Africa, Columbia University International Research Institute, and Ethiopia Climate and Health Working Group, committed to take actions to build a climate-resilient healthy community through integrating climate-health risk management. In October 2011, a conference was held among the International Institute for Strategic Studies and members of the medical community, exploring the linkages between climate change, security, and health (inclusive of disease). Recent reports by the Natural Resource Defense Council, the Union of Concerned Scientists, and Accenture have tallied the health costs due to climate change and found billions of dollars worth of impact. In 2009, the World Organisation for Animal Health released a list of diseases that are at risk of being affected by climate change. In 2008, the American Veterinary Medical Association issued a statement drawing attention to the impact of climate change on animal health. Over the past decade, the World Health Organization has published a number of articles and reports on how climate change will affect health and, in particular, disease—and WHO is also currently partnering with the UN Development

(*Continued*)

Recent One Health Actions (*Continued*)

Programme and the World Meteorological Organization (WMO) to build paired climate and disease surveillance systems.

Global One Health conferences were held in Switzerland and Thailand in 2012 and 2013 to discuss the threats and opportunities of One Health actions. In 2011, the Global Initiative for Food System Leadership at the University of Minnesota convened a conference to assess the global implementation of One Health. In 2010 and 2012, the World Bank published two volumes of One Health work: *People, Pathogens, and Our Planet* (World Bank 2010a). In 2009, a One Health Commission was endorsed by a number of UN organizations (the Food and Agriculture Organization [FAO] and WHO), the OIE, and the Centers for Disease Control and Prevention. And in the past decade, dozens of nonprofits, professional organizations, and universities have initiated One Health programs.

1.2 KEY CLIMATE-SENSITIVE DISEASE THREATS

Key Messages:

- Climate-sensitive livestock diseases can be ranked according to various criteria, such as economic impact, epidemic potential, and zoonotic or public health dimension.
- Rift Valley fever is a vector-borne viral disease transmitted by several species of mosquitoes that have facilitated epidemics in Africa and in the Arabian Peninsula, with dramatic impact on animal and human health due to its zoonotic dimension. The disease has been shown to be sensitive to climate.
- Bluetongue is a vector-borne viral disease transmitted by several species of *Culicoides* midges. The disease is endemic to many tropical climates, though it has invaded Europe in the last decades with a massive economic impact, mainly through disruption of trade. Recent evidence suggests that the northward shift of the disease could have been caused by climate change.
- East Coast fever is a vector-borne parasitic disease transmitted by ticks that is endemic in many southeast African countries, where it has a continuous and significant economic impact. The disease has received comparatively less attention than RVF and BT, though its transmission via vector species suggests it may be sensitive to climate.

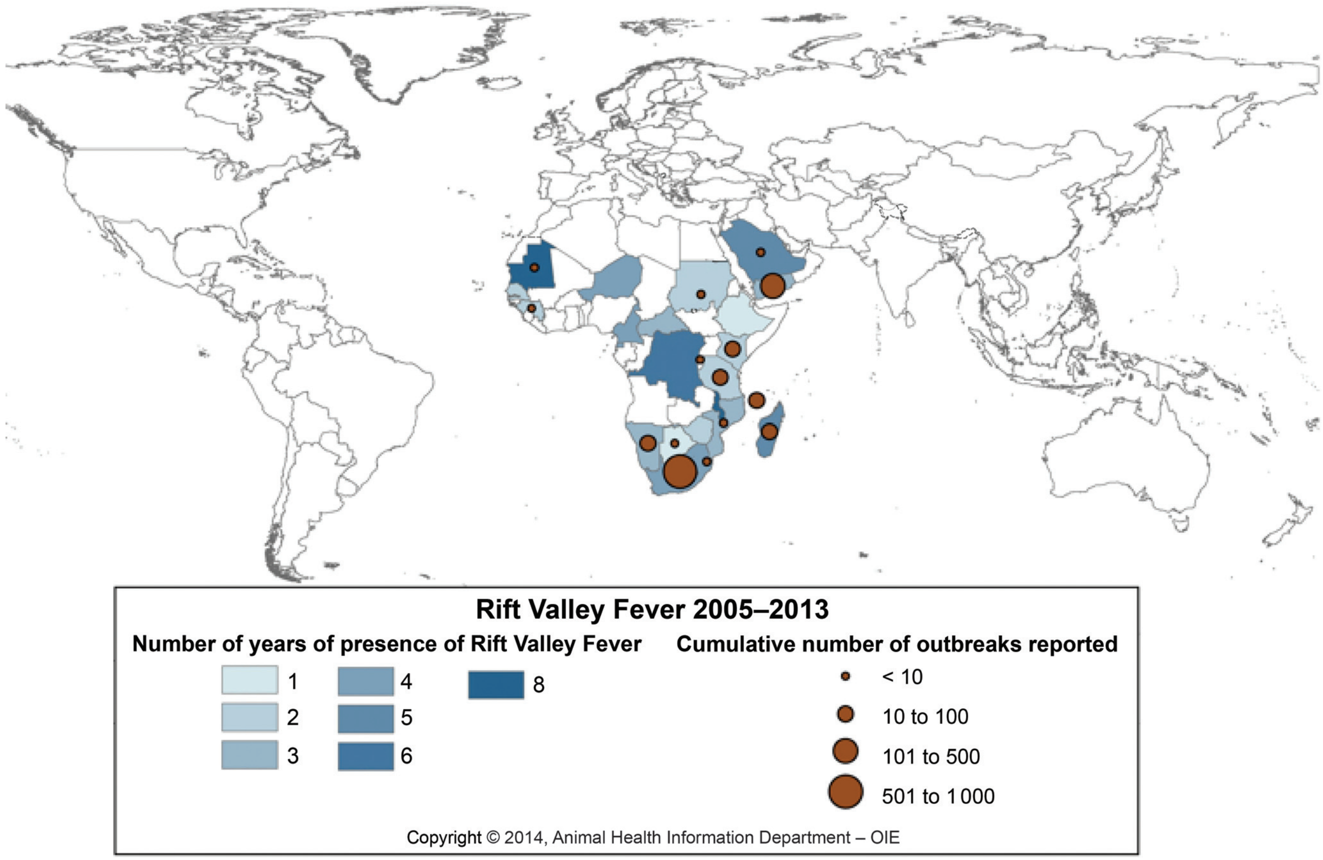
Rift Valley fever, bluetongue, and East Coast fever were chosen for this report given the breadth of successes and challenges each embodies and the opportunity to derive a spectrum of lessons learned. RVF, for example, is present in both humans and animals, has affected large parts of Africa, and has been piloted in several early warning system models. Bluetongue is found only in livestock and is currently a significant problem for European countries, yet it has also been the subject of early warning systems and monitoring and surveillance programs. ECF is relatively less tracked in early warning systems, but it has had significant economic impact in East Africa and is transmitted by ticks, as opposed to either RVF or BT, which are transmitted by mosquitoes and midges, respectively.

Rift Valley fever is a viral zoonosis transmitted by mosquitoes that primarily affects animals, though sometimes it infects humans. The disease has had significant impact on both animal and human health in East Africa and, recently, the Middle East. Outbreaks have occurred in Kenya (1968, 1978–79, 1997–98), Sudan (1973, 1976), Somalia (1997–98), Tanzania (1977, 1987, 1997), Zambia (1973–74, 1978, 1985), Zimbabwe (1955, 1957, 1969–70, 1978), Mozambique (1969), South Africa (1974–76, 1981, 1996), Namibia (1955), and for the first time off the African continent in 1998–2000 in Saudi Arabia and Yemen (figure 1.3). These outbreaks have caused widespread morbidity and mortality and resulted in hundreds of millions of dollars in agricultural, trade, health care, and tourism losses (Rich and Wanyoike 2010). The 1997–98 occurrence was the largest documented outbreak ever in the Horn of Africa, involving five countries, the loss of ~100,000 domestic animals, and ~90,000 human infections (Woods et al. 2002).

The disease is transmitted by a broad range of mosquitoes, though certain Aedes species can act as reservoirs during inter-epidemic years. Increased precipitation in dry areas leads to explosive hatching of RVF-harboring mosquito eggs, which when combined with immune-naive animal populations can lead to outbreaks. Juveniles are most at risk, with mortality rates ranging from 20 percent to 100 percent, depending on animal (OIE 2009).

The disease affects animals and humans. In animals, it primarily affects sheep, cattle, goats, camels, and wild ruminants, resulting in

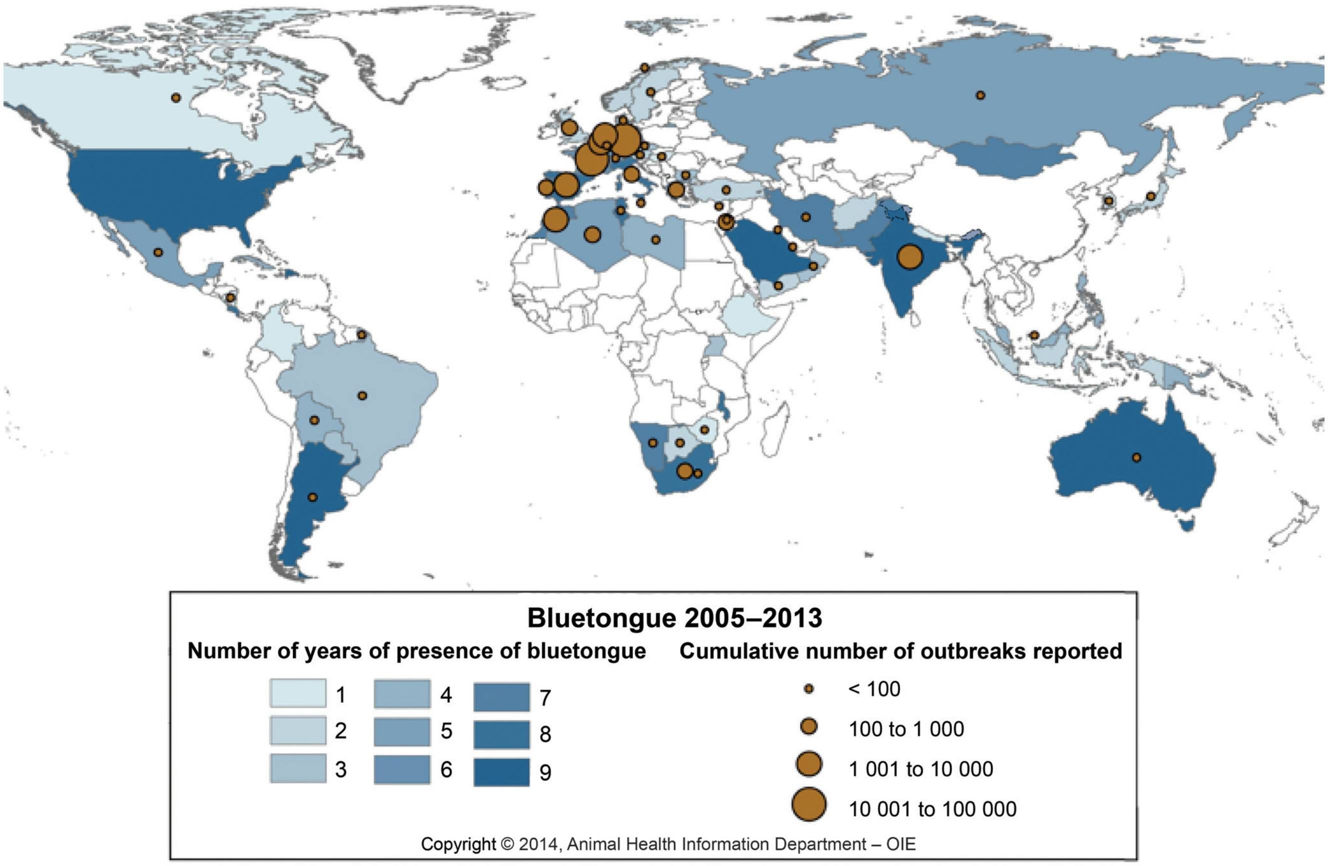
FIGURE 1.3: Distribution Map and Number of Outbreaks for Rift Valley fever During an Eight-Year Period (OIE 2014).



high rates of abortion and neonatal mortality (LaBeaud, Kazura, and King 2010). The majority of human infections result from direct or indirect contact with the blood and organs of infected animals. Transmission often occurs during slaughtering or butchering, assisting in animal births, providing veterinary care, or disposing of carcasses and fetuses. As a result, certain occupational groups such as herders, farmers, butchers, and veterinarians are at higher risk. The virus infects humans either through direct body fluid contact or via aerosols produced during slaughter. In some cases, humans can also be infected by mosquitoes and blood-feeding flies. So far no human-to-human transmission has been observed (WHO 2010). The total case fatality rate varies widely by epidemic, though it is less than 1 percent overall. Most sufferers typically experience a mild form of the disease that is characterized by flu-like symptoms that persist for four to seven days. A small minority can experience eye lesions, meningo-encephalitis, or hemorrhagic fever (Davies 2010).

There are no specific treatments once infection has occurred in animals or humans; prevention and control are therefore the only measures for avoiding disease transmission and outbreak. There are multiple vaccine options for animals (attenuated/inactivated), although none are currently licensed for humans. Sanitary prophylaxis is also recommended, including wearing protection at slaughterhouses and during veterinary procedures, draining standing water and providing vector control in mosquito-prone areas, and running community awareness campaigns that highlight the unsafe consumption of raw animal tissues and protection against mosquitoes (OIE 2009; WHO 2010).

FIGURE 1.4: Distribution Map and Number of Outbreaks for Bluetongue During an Eight-Year Period (OIE 2014).



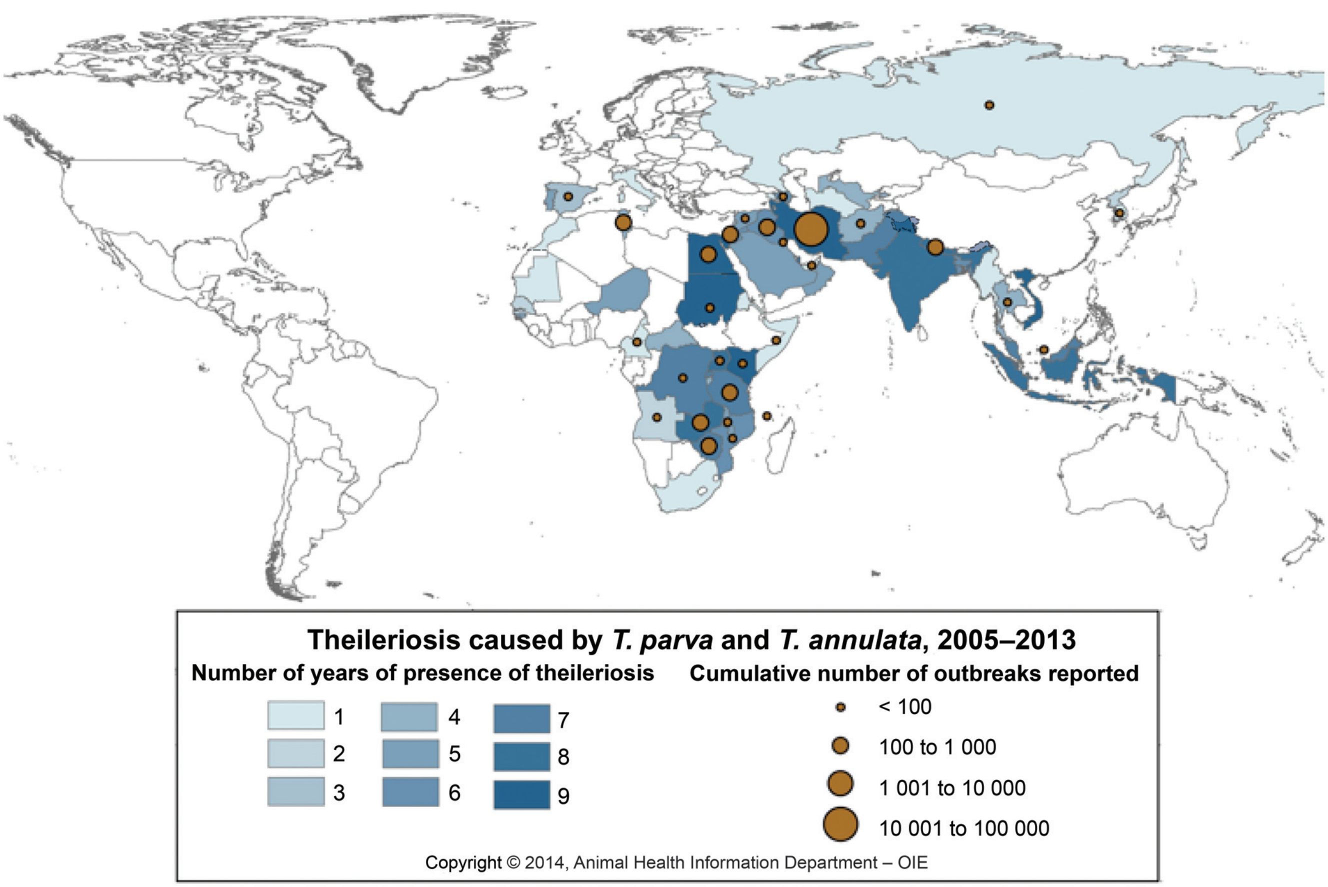
A Closer Look: The Epidemiologic Cycling of Rift Valley Fever

Mosquitoes of the *Aedes* and *Culex* genera are the main vectors of RVF, but they have been shown to have a different ecology and potential role in the persistence and spread of the disease. *Aedes* females typically lay their eggs in the mud of small water bodies. Even when they become desiccated, the eggs can survive several years and will hatch when they are exposed again to a short period of flood. If no further cycles of desiccation and flooding occur, the population remains low because the eggs need a period of desiccation for embryogenesis. As a result, regions characterized by a succession of dry and wet periods provide the most suitable environment for egg survival and development. Vertical transmission of RVF in *Aedes* has been suggested by field data (Linthicum et al. 1985) and provides a mechanistic pathway for the reservoir of the virus during inter-epidemic periods. *Culex* females, in contrast, lay their eggs on the surface of water and need permanent water to develop, as the eggs cannot survive desiccation and are abundant in irrigated areas. No evidence of vertical transmission of RVF in *Culex* has been found. Some particular sequence of floods inundating small ponds and water bodies can thus affect the epidemiologic cycle of RVF in *Aedes*, and result in the subsequent infection of nearby livestock (Wilson 1994; Chevalier et al. 2004). If the natural RVF immunity in susceptible livestock is low, the disease spreads rapidly and can become amplified through horizontal transmission by *Culex* mosquitoes.

Bluetongue is a vector-borne virus that affects ruminants, primarily sheep, occasionally goats and deer, and cattle (Sperlova and Zendulkova 2011). It is transmitted by various *Culicoides* species of biting midge (Purse et al. 2005) and can result in severe clinical symptoms, sometimes leading to death (Wilson and Mellor 2009). The OIE has had it historically listed as a "notifiable disease" since the 1960s due to the high associated economic costs. The virus is found on all continents (figure 1.4), although different serotypes result in markedly different impacts. In recent years it has achieved significant visibility after emerging in Europe in 2006 (Saegerman, Berkvens, and Mellor 2008). In the Netherlands alone, the costs associated with this outbreak amounted to hundreds of millions of euros (Velthuis et al. 2010).

The disease is characterized by fever, oral and nasal hemorrhage, excessive salivation, and nasal discharge. In some cases, the tongue will appear cyanotic and swollen, hence the name. Among domestic animals, disease is most severe in sheep, with mortality rates up to 70 percent in most susceptible breeds, and in some wild species such as whitetail deer and pronghorn antelope, with mortality rates up to 90 percent. Cattle usually do not express clinical signs except with the BT virus strain 8 recently found in Europe. BT does not establish persistent infections in animals, though the disease is maintained through infected cattle and wild ruminant reservoirs. The disease is then transmitted by the midge vector, which is itself positively sensitive to certain climatic factors, such as high rainfall, warm temperatures, and high humidity.

FIGURE 1.5: Distribution Map and Number of Outbreaks for Theileriosis During an Eight-Year Period—That Is, Caused by *Theileria parva* (ECF) and *T. annulata* (OIE 2014).



There is no efficient treatment for BT other than to engage in prophylactic measures. In disease-free areas, animal movement control and quarantine must be enforced. In infected areas, vector control is recommended. Vaccines are also currently available, although they sometimes require serotype specificity in order to be fully effective. The disease is not zoonotic and cannot infect humans (OIE 2009).

East Coast fever is a cattle disease endemic to regions from southern Sudan to South Africa and west, to eastern Democratic Republic of Congo (figure 1.5). It is caused by the parasite *Theileria parva,* one of six species of Theileria that infects cattle. Human theileriosis is also caused by genus Theileria, though it is of a different species: *microti* (OIE 2009). A related disease, tropical (or Mediterranean) theileriosis is caused by *T. annulata* and is endemic in North Africa, southern Europe, parts of eastern Europe, the Indian subcontinent, China, and the Middle East. Annual costs associated with the livestock disease are in the hundreds of millions of dollars.

Parasites are transmitted by several species of Ixodid ticks that have historically been hosted by African buffalo; only the relatively recent introduction of cattle to the region has resulted in the new parasitic target. Infected ticks can remain in grazing lands for up to two years, depending on climate. Warmer temperatures speed up parasite maturation and subsequent diminished tick-attachment to infection time. The ticks can be found from sea level to over 2,500 m in any area where the annual rainfall exceeds 500 mm. Without tick presence, the parasite is unable to complete its life cycle and disappears (OIE 2009).

ECF affects cattle differentially, with exotic species mortality approaching 100 percent in some areas. Indigenous Zebu cattle tend be less severely affected, although they nearly always show some morbidity (OIE 2009).

Treatment can be both preventative and therapeutic (see table 1.1.) Acaricide pour-ons are frequently used to kill the ticks, although they are expensive, can be environmentally detrimental, and can lead to resistance in the targeted species. A number of vaccines are also available in various forms to prevent parasitism. Chemotherapeutic agents, such as buparvaquone, are used to treat cattle once infected, but they do not always completely eradicate the infections. Best-practice methods tend to use a combination of tick control, vaccination, and chemotherapy (OIE 2009).

TABLE 1.1: Key Disease Characteristics for Rift Valley Fever, Bluetongue, and East Coast fever

	RVF	BT	ECF
Current Distribution	Africa	Latitudinal	Southeast Africa
Primary Regional Impact	African, Arabian peninsula	Europe	Southeast Africa
Zoonotic	Yes	No	No
Vector	Mosquito—various species, for example, Aedes and Culex	Biting midges, especially various *Culicoides* species	Ixodid ticks
Species Affected	Primarily sheep, cattle, goats, and wild ruminants; humans	Primarily sheep, occasionally goats and deer, and cattle	African buffalo, cattle
Treatment	Prophylaxis only	Prophylaxis only	Prophylaxis, acaricide

1.3. ECONOMIC AND LIVELIHOOD IMPACTS OF CLIMATE-SENSITIVE LIVESTOCK DISEASES

Key Messages:

- The individual and collective economic impact of RVF, BT, and ECF has not been estimated globally, but examples are available for some countries that illustrate the magnitude of the impact.
- For RVF, in Somalia the epidemic prevented 8.2 million small ruminants, 110,000 camels, and 57,000 cattle from being exported, corresponding to economic losses for the livestock industry estimated at $109 million in 1998–99 and at $326 million in 2000–02.
- For BT, in Netherlands alone the 2006 and 2007 epidemics had a net cost of 32.4 million and 164–175 million euros, respectively.
- The annual cost of ECF was estimated at $88.6 million in Kenya, $2.6 million in Malawi, $133.9 million in Tanzania, and $8.8 million in Zambia.
- Robust assessment of economic and livelihood impact in many countries is impaired by difficulties in assessing indirect impacts and by the lack of epidemiological data.

1.3.1 Economic/Livelihood Impacts of Three Diseases

RVF is enzootic in most sub-Saharan African countries (Davies 2010) and has been recorded (Clements et al. 2007a), either through diagnosis during epidemic or through sero-surveillance surveys (Gonzalez et al. 1992; Mariner, Morrill, and Ksiazek 1995), even in countries where there have never been any significant outbreaks (such as Niger, Burkina Faso, and Gabon). The virus has also spread to Egypt (Meegan, Hoogstraal, and Moussa 1979; Arthur et al. 1993), Madagascar (Andriamandiby et al. 2010), and the Arabian Peninsula (Ahmad 2000; Davies 2006), predominantly through the (legal or illegal) commercial transport of live animals. In these naive areas, RVF develops as epidemics, usually resulting in significant human as well as animal fatalities. In areas where RVF is known to regularly circulate, extensive epidemics are commonly reported when there is a concordance of reduced population immunity of livestock (Thiongane et al. 1994) and an increase in vector activity triggered by climatic or other environmental events (Chevalier et al. 2004). In particular, floods may trigger the "en masse" hatching of *Aedes* vector eggs that can harbor the virus during inter-epidemic periods (Linthicum et al. 1985).

The impact of RVF has only been formally quantified in a limited number of studies carried out in Kenya (Rich and Wanyoike 2010), Tanzania (Sindato, Karimuribo, and Mboera 2012), and Somalia (Cagnolati, Tempia, and Abdi 2006). The direct economic impact of the disease is due to the loss of livestock; the indirect impact on the value of surviving stock and levels of trade can also be considerable. In Tanzania, for example, the losses caused by the 2006/07 epidemic were estimated as 16,973 cattle, 20,913 goats and 12,124 sheep, corresponding to a value of $6.44 million (Sindato, Karimuribo, and Mboera 2012). In Somalia, Cagnolati et al. (2006) estimated that the epidemic prevented 8.2 million small ruminants, 110,000 camels, and 57,000 cattle from being exported, corresponding to economic losses for the livestock industry estimated at $109 million for the first ban (February 1998–May 1999) and at $326 million for the second ban (September 2000–December 2002). In Kenya, Rich and Wanyoike (2010) estimated the overall cost of an RVF outbreak to the economy, including all potential indirect impacts, to be $32 million. Simulation studies have also been looking at the potential outbreaks in countries where the disease is currently absent. They concluded, for example, that an RVF epidemic spreading through Southeast Texas could lead to total costs ranging between $121 million and $2.3 billion (Hughes-Fraire et al. 2011).

Bluetongue has been historically broadly distributed and endemic between 35°S and 40°N parallels, where it has a relatively limited clinical impact except on exotic breeds that have been recently introduced. For this reason, BT was not listed as a disease with a high impact on the poor by the ILRI study (Perry, Randolph, and Thornton 2002). However, the disease has had a much more serious impact when occurring beyond its historical range, and it caused epidemics with significant mortality in the Mediterranean countries between 1998 and 2004 (Mellor et al. 2008) and in northwestern Europe in 2006–08 (Saegerman, Berkvens, and Mellor 2008). The overall economic impact of these epidemics has not been estimated at the European scale. However, studies have attempted to integrate all direct and indirect costs in some countries. In the Netherlands, for example, Velthuis et al. (2010) estimated that the BT epidemics had a net cost of 32.4 million and 164–175 million euros in 2006 and 2007, respectively. Comparable figures were obtained in the analysis by Häsler et al. (2012) in Switzerland. Similarly, the 2007 BTV-8 epidemic in France was estimated to have cost $1.4 billion (Tabachnick, Smartt, and Connelly 2008), and it is important to note that a large share of these costs arose from restrictions on movement and trade. Given that the Netherlands has a standing stock of approximately 4.5 million cattle and small ruminants, that the EU has 271 million cattle and small ruminants according to FAOSTAT (FAO 2009), and that the extent of the Bluetongue invasion included many different European countries, one can safely assume that the financial impact of the epidemics must have been in the range of hundreds of millions of euros. Even in those countries where the disease did not fully take hold, such as the United Kingdom, costs of vaccination were considerable.

A comprehensive economic impact assessment of East Coast fever was made by Minjauw and McLeod (2003) in their study of the impact of tick-borne diseases in Asia and Africa. They calculated an annual cost of $88.6 million in Kenya, $2.6 million in Malawi, $133.9 million in Tanzania, and $8.8 million in Zambia. In a different study, Mukhebi, Perry, and Kruska (1992) estimated the cost of ECF to be $168 million in eastern, central, and southern Africa. In Tanzania, the total economic loss caused by ECF was estimated at $247.7 million by Kivari (2006)—somewhat higher than that estimated by Minjauw and McLeod (2003).

The economic and livelihood impacts of RVF and ECF in Africa are therefore extremely high and diverse. The impact of these diseases on poor livestock owners, in addition to the direct loss of animals, includes reduced production and household meat consumption, high cost of animal health care, reduction of inputs to crop systems, falls in stock value, inhibited access to communal grazing areas, and a decrease in social capital such as perceived wealth and status. All these factors influence the cash flow and income of poor livestock owners, their nutritional status, and ultimately their entire livelihood (Minjauw and McLeod 2003).

Primary regions of concern for these diseases are Africa, the Middle East, and North Africa for RVF; Africa, the Middle East, North Africa, Europe, Central Asia, South Asia, East Asia and the Pacific, and Latin America and the Caribbean for Bluetongue; and Africa for ECF.

1.3.2 Quality/Robustness of Data

The figures provided in the preceding section demonstrate that while RVF, BT, and ECF have a substantial economic impact, the estimates vary considerably in terms of the extent and level at which they have been estimated, and the quality of the data on the economic impact of these diseases can be improved. The obstacles to effective assessment are different for each disease.

For BT, the developed countries affected by outbreaks generally have good veterinary services and infrastructure, as well as a disease registry that allows the estimation of direct impact in terms of mortality and/or abortion caused by the disease (Perrin et al. 2010). The assessment can become somewhat more difficult when the direct impact of the disease includes reductions in productivity of milk or meat, which may vary according to management practice and breed. In addition, as highlighted by Wilson and Mellor (2009), the direct costs of BT represent only a fraction of the cost incurred by the disease, and a large share of the cost is due to trade restrictions. As a consequence, the costs are strongly dependent on the control strategy that is being implemented and that may change over time in response to the epidemiological situation.

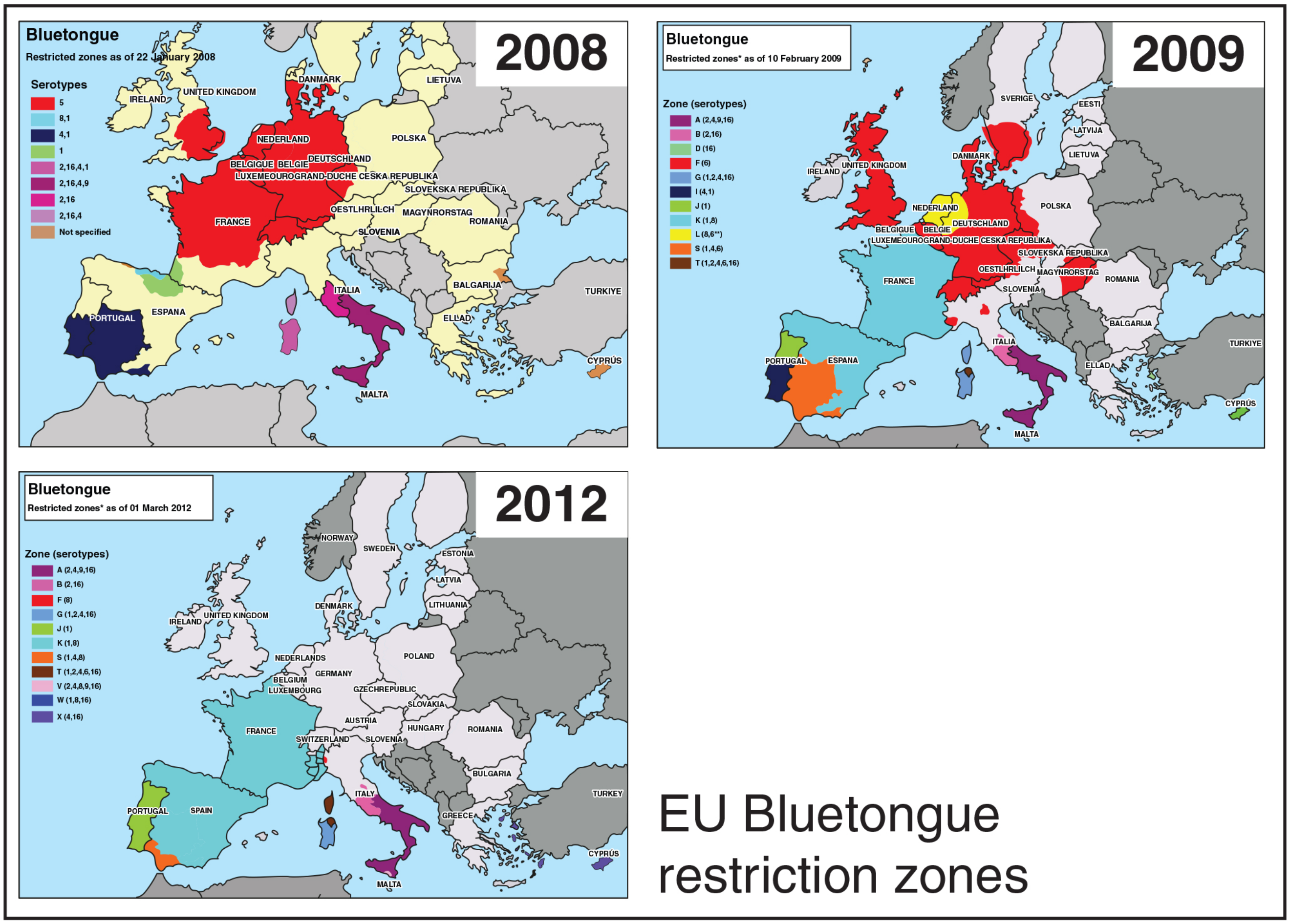
Movement restrictions, for example, that were implemented in Europe at the start of the BT epidemics had a very high economic impact. As the epidemic progressed, the restriction zones were modified. Figure 1.6 shows the distribution of BT restriction zones in January 2008, February 2009, and March 2012, with each color indicating regions from which movements were restricted. This illustrates how the spatial structure of these restrictions evolved over time, effectively complicating economic assessments. Other prevention and control strategies such as serological surveillance in sentinel animals, entomological surveillance, and vaccination are also part of the costs that need be integrated into any economic impact assessment (Häsler et al. 2012). With economic assessment having to include both direct and indirect impacts influenced by the epidemic and national disease control strategies themselves, the overall assessment across multiple countries for a disease like BT is challenging.

With RVF, systematic cross-sectional or longitudinal surveillance data are scarce. The impact of the disease in countries where animals are found to be sero-positive but do not have outbreaks, or in periods between epidemics, can be assumed to be relatively low. In epidemic conditions, detailed data have been obtained through case reports and targeted surveys. The available economic impact assessments relate primarily to the number of outbreaks and to the morbidity and mortality in animals and people. In these circumstances, assessing the indirect impact of the epidemics can be carried out through market surveys quantifying the economic loss along the value chain as well as the consequences of trade disruption (Rich and Wanyoike 2010).

With respect to ECF, the lack of available estimates of the prevalence and incidence of different tick-borne diseases makes it difficult to determine individual impact (recalling that ECF is merely one type of theileriosis). Nevertheless, the regions (see figure 1.5) are potentially at risk from the introduction (or re-introduction) of tick-borne pathogens. This situation is illustrated by *T. parva,* the cause of classical East Coast fever, which was eradicated from South Africa, Swaziland, and southern Mozambique some 40 years ago (Norval et al. 1991), although its tick vector, *Rhipicephalus appendiculatus,* is still abundant. By using available data on incidence, and by combining these data with livestock and vector distribution and the costs of tick control, Minjauw and McLeod (2003) were able to estimate the annual financial impact of ECF at a continental level. Estimates of costs by different authors are not always comparable, however, because they distribute tick control costs between each of the diseases being controlled (for example, anaplasmosis, babesiosis).

In sum, the different diseases (and composite ecology) present a range of challenges in estimating total economic costs and illustrate the difficulty in applying any one methodology to a portfolio of diseases that are related only in that they are vector-borne and are sensitive to climate. Accurate estimations of costs require uniquely considered methodology on a disease-by-disease basis.

FIGURE 1.6: Distribution of BT Restriction Zones in the EU in January 2008, February 2009, and March 2012, with Each Color Indicating Regions within which Movements Were Permitted (http://ec.europa.eu/food/animal/diseases/controlmeasures/bluetongue_en.htm)



1.4 VULNERABLE POPULATIONS

Key Messages:

- People in developing regions are particularly vulnerable to the negative economic, social, and health impacts of climate change.
- Human vulnerability (inclusive of health, economics, and livelihoods) is affected by the vulnerability of animals' health to climate change, but this has been the focus of few studies.
- Reducing climate-sensitive livestock disease risks can be aided through the identification of vulnerable populations.

Developing regions are vulnerable to economic, social, and health damage resulting from climate change, although for different reasons (Woodward 2011). Geographic, demographic, socioeconomic, and biological factors, for example, all contribute to general levels of vulnerability; in the case of livestock diseases, this profile is largely colored by those whose livelihoods are most directly connected to livestock. Pastoral and agro-pastoral communities will be particularly affected, given their nutritional and trade-based income dependencies (Rich and Wanyoike 2010), although industrial communities that depend on higher value-intensive dairy and beef industries are also at risk.

The IPCC defines vulnerability as "the degree to which individuals and systems are susceptible to or unable to cope with the adverse effects of climate change" (IPCC 2007). Understanding a population's capacity to adapt to new climate conditions is critical to realistically assessing the impacts of climate change (Kovats, Ebi, and Menne 2003).

This report explores human vulnerability (inclusive of health, economics, and livelihoods) to the impacts of climate change on animal diseases. Little work has yet been done on this facet of climate change impact, although some insights can be derived from the work done on human health, which states that health vulnerability to climate change can be defined as a function of sensitivity—the extent to which health, or systems upon which it depends, are influenced by changes in weather and climate (the exposure–response relationship), of the levels of exposure to weather or climate-related hazards (including the magnitude, rate, and character of climate variation), and of adaptation—the measures and actions that can reduce the burden of specific adverse health outcome (Kovats, Ebi, and Menne 2003).

Applying this framework to assess the health vulnerability of animals provides the first component of a tool that can be used to assess human vulnerability to climate-sensitive animal disease. The unique characteristics of each climate-sensitive livestock disease and specific region within which it acts ensures that there will be a spectrum of vulnerable populations that require country-level and local investigation. Climate change will simply magnify the risk to these populations and compound existing issues of poverty and disease (Woodward 2011). Identification of vulnerability should be performed on regional, national, subnational, local, and individual levels. Multiple vulnerabilities will increase the relative risk to certain populations and can be considered as either additive or multiplicative, depending on the specifics. Identifying and comparing relative vulnerabilities provides some insight as to which adaptations can be most useful and where they are most effectively implemented. And this will help establish a project scope. In particular, minimizing climate-sensitive livestock disease risk requires identification of vulnerable populations before the threats can be targeted and reduced or eliminated (Ebi et al. 2011).

Chapter 2 ACTIONABLE TOOLS TO REDUCE CLIMATE-SENSITIVE DISEASE RISKS

This chapter describes the tools and components of early warning systems for the risk management of climate-sensitive disease: surveillance systems, risk mapping, and disease outlooks. Underlying knowledge, applications, and best-practice examples are provided.

2.1 SURVEILLANCE SYSTEMS

Key Messages:

- Surveillance systems are key to knowing where and when a disease occurs; they also provide baseline data for risk models.
- Both active and passive surveillance are important tools that can be used to generate most accurate disease profiles.
- Geospatial and information technology is increasingly important for developing accurate surveillance methodologies.

2.1.1 Surveillance Systems: General Principles

Knowing where and when a disease is circulating is key to informed disease prevention and control strategy. Good surveillance systems have high detection sensitivities (the capacity to detect disease events), specificity (avoiding false positive detection), simplicity, adaptability (ability to scale up in the case of an unexpected event or epidemic and to scale down when disease impact is low), and cost-efficiency (Dufour, Hendrikx, and Toma 2006). These attributes are true regardless of whether a disease is human- or animal-specific.

Surveillance is a continuous and systematic process that can be characterized by the collection of relevant data for a population, time period, and location; the integration of data at a higher level and their analysis; and dissemination of results and recommended actions to stakeholders. In many countries, animal disease surveillance is typically organized through an active network of veterinary officers at different administrative and field-based levels. In recent years, a number of surveillance systems have developed to include a centralized authority with inputs from stockholders themselves.

Good diagnostic capacity underlies accurate data collection. Clinical diagnosis and sample collection are carried out in the field, although laboratory diagnosis can be used to confirm clinical suspicions. Laboratories equipped to run these diagnostics are often centralized at subnational, national, or international levels (OIE reference laboratories, for instance). Increasingly, laboratory diagnosis can be decentralized through the use of rapid field test kits. The benefit of these is that they provide a first screening of field samples so that only positive samples are sent for final confirmation at centralized (national or reference) labs. Effective data management and information systems are essential to ensure a smooth and rapid flow of information back and forth between the central veterinary services and field veterinarians. Together, field kits and centralized facilities can provide a rapid and comprehensive perspective of the disease situation.

For the purposes of this report, surveillance can be thought of in two ways: passive and active. Passive surveillance is the routine collection of disease reports from field practitioners who are themselves informed of potential cases by livestock owners reporting clinical manifestations. Active surveillance is the active search for new cases in the field and is usually carried out during high-risk periods or in high-risk regions (that is, at the beginning of an epidemic).

Active Surveillance in Action

The Thailand Department of Livestock Development launched a country-wide survey involving several hundred thousand trained volunteers to search door-to-door for evidence of highly pathogenic avian influenza (HPAI) H5N1 (Tiensin et al. 2005). The surveys enabled the creation of an unprecedentedly detailed data set of HPAI cases and poultry census data at the village level and effectively helped the country to efficiently target control and surveillance.

In some developing countries, epidemiological networks enabling disease surveillance have been gradually developed (despite sometimes unfavorable contexts of declining resources and infrastructure) and are becoming technically and institutionally well established (Bendali 2006; Ouagal et al. 2008). Yet they are often limited by poor access to field information and insufficient laboratory diagnostic capacities. Further, limited external financing that is disease-crisis-specific can prevent long-term sustainable solutions (Ouagal et al. 2008).

Participatory disease surveillance is a particular form of active surveillance that occurs at the village or household level and that can complement centralized surveillance programs. Livestock owners are most often able to recognize major disease problems in their area. Questionnaires and active community engagement can aid in the epidemiological risk assessment of any given area and can be carried out by an investigation team going from village to village to administer the questionnaires. The technique has been instrumental in global Rinderpest eradication programs (Jost et al. 2007) and has been used in both rural and urban settings in Africa (Malak et al. 2012) and Asia (Azhar et al. 2010).

Over the past several years, geospatial and information technology has supported the development of innovative approaches for disease surveillance and mapping. Mostly developed for human health applications, initiatives such as the Google trends project can provide early warning of epidemics based on the frequency of Google searches on the relevant disease-related terms (Ginsberg et al. 2008). Widespread use of mobile technology in the developing world also has much to offer to disease-related information exchange between stakeholders and formal authorities and is being piloted in some studies in Africa (Aanensen et al. 2009). (See also LIDC 2010). Other web-based initiatives developed for human health, such as Healthmap (http://healthmap.org), which is based on automated data mining of digital news reports, also offer useful templates for animal health surveillance. A number of initiatives have been undertaken in recent years to improve disease surveillance (IOM 2007), with support from top philanthropic organizations such as the Rockefeller foundation, the Bill & Melinda Gates Foundation, and Google.org, tackling many of the challenges common to human and animal health.

2.1.2 Surveillance Systems: Knowledge and Applications

Rift Valley Fever

Due to limited veterinary resources in countries affected by RVF, surveillance during inter-epidemic periods is neither continuous nor systematic. Rather, a number of project-based or local studies have tried to establish the presence of RVF, predominantly through sero-prevalence studies to confirm the disease in livestock or humans. This methodology has been employed in countries where the disease was not previously known to occur, such as Burkina Faso (Gonzalez et al. 1992), Cameroon (LeBreton et al. 2006), Chad (Ringot et al. 2004), Gabon (Pourrut et al. 2010), Niger (Mariner, Morrill, and Ksiazek 1995), and Nigeria (Olaleye, Tomori, and Schmitz 1996). In countries where RVF is known, such as Egypt (Abd el-Rahim, Abd el-Hakim, and Hussein 1999), Kenya (Munyua et al. 2010; Murithi et al. 2011), Madagascar (Andriamandimby et al. 2010), Mauritania (El Mamy et al. 2011), Senegal (Chevalier, Thiongane, and Lancelot 2009), Somalia (Soumare et al. 2007), Sudan (Hassan et al. 2011), South Africa (Archer et al. 2011), Tanzania (Mohamed et al. 2010), Yemen (Abdo-Salem et al. 2006), and Zambia (Samui et al. 1997), serosurveillance has also been a helpful tool (Thiongane et al. 1994). At the start of an epidemic, often the only disease data available has been acquired through case reports and targeted, or risk-based, surveys (Soumare et al. 2007; Munyua et al. 2010). The general lack of inter-epidemic surveillance means that awareness of RVF risks is lowered, and the early detection of epidemics therefore less likely, resulting in diminished timeliness and effectiveness of appropriate mitigation measures (Jost et al. 2010).

Both main elements triggering RVF epidemics—reduced immunity and rainfall-induced vector increases (see section 2.2.3)—can be targeted by longitudinal serological and entomological surveillance. GIS-based approaches that use environmental and climatic data (Anyamba et al. 2009), data on historical outbreaks, statistical sampling theory, or even expert knowledge (Clements, Pfeiffer, and Martin 2006) can be used to target these surveillance efforts and optimize the resources needed. Importantly, local knowledge can be polled: Jost et al. (2010) showed that pastoralist livestock owners "were aware of the unusually heavy nature of the rains and flooding before the outbreak of RVF in their areas, noticed mosquito swarms that were unusual because of their intensity and the physical characteristics of the species involved (Aedes spp.), and noted unusually high morbidity and mortality in their flocks consistent with RVF." Much benefit can be gained for RVF surveillance from livestock owners' knowledge and participatory approaches, particularly if paired with effective data analysis and dissemination.

Surveillance and mitigation measures are difficult to disentangle. Recent decision-support systems reflect this, such as those developed by ILRI and FAO, which strongly support a phased approach, unfurling a series of interventions that includes communication, coordination, surveillance, early warning systems, and disease and vector control, that are specific to each region and geography of outbreak (ILRI/FAO 2010).

Bluetongue

Current surveillance for Bluetongue in the developing world is rare; the current state of the art is illustrated by the surveillance concentrated in regions in the developed world that have been afflicted with the disease or are considered at risk for the future. Yet it is included here given that some of the lessons learned from developed world experiences may have something to offer to developing regions.

At the European level, Bluetongue surveillance is mandatory under European Commission Regulation No 1266/2007 and must include clinical, serological, and entomological components. The obligations differ according to whether a given serotype is considered to be present (see figure 1.6). Within restriction zones, surveillance is carried out through networks of sentinel unvaccinated, susceptible animals and through networks of vector surveillance. The overall objective of these programs is "to detect the introduction of new Bluetongue serotypes and to demonstrate the absence of certain Bluetongue serotypes." Other objectives may include the seasonally vector-free period and identifying vector species (EC Regulation No 1108/2008). Outside the restriction zones, surveillance targets "detecting any possible incursions of the Bluetongue virus and demonstrating the absence of that virus in a Bluetongue-free Member State or epidemiologically relevant geographical area" (EC Regulation No 1108/2008) and is carried out effectively through passive clinical surveillance and active laboratory-based surveillance based on at least one annual serological/virological survey. Further details of the BT surveillance obligations are set out in the EC Regulation No 1108/2008. EU member countries are requested to submit to the EU monthly, biannual, or yearly reports, depending on their restriction zone status. In practice, each member state has the freedom to establish its own surveillance system, provided that it complies with the EC minimum regulation and that countries have developed several integrated information systems to collect and disseminate Bluetongue disease and vector surveillance data.

Since BT was first detected in Italy in August 2000, authorities have invested substantial resources to develop a structured surveillance and early warning system for the disease (Giovannini et al. 2004a, 2004b). The surveillance system is based on two main components. The first, periodic testing of unvaccinated sentinel cattle uniformly scattered throughout the country, aims to assess the incidence of infection in non-immunized strata of ruminant animals and to inform movement control planning. The second, a network of permanent traps sampled weekly year-round, intends to define the geographical distribution of vectors and their seasonal population dynamics. All surveillance data are integrated into a GIS-based information system with a web interface that allows the collection, management, and dissemination of data collected by field veterinarians (Conte et al. 2005). The surveillance is based upon daily "a) recordings of all suspected and confirmed BT clinical cases; b) recordings of the results of periodic testing of sentinel animals; c) reports on monitoring of the spread of vectors and their seasonal dynamics; d) recordings of all diagnostic results; e) recordings of the progress of vaccination campaigns" (Conte et al. 2005). This system is beneficial to both centralized decision makers and field veterinarians, providing national-level perspective and information that can assist practitioners in daily tasks (that is, identifying municipalities in the infected zone or in buffer radii). Here, too, the collection of surveillance data is tightly linked with control and mitigation operations (mainly movement control and vaccination), with the information systems ensuring a swift flow of information between the different levels of responsibilities. Livestock owners can also benefit from the system through access to a publicly available view of web-based information systems, for instance to verify the BT status of geographical areas where they want to move animals.

Many other developed countries have developed BT surveillance by using modeling and/or simulation target surveillance (Bonfanti et al. 2008; Racloz et al. 2008; Gubbins et al. 2010; Szmaragd, Gunn, and Gubbins 2010), by identifying new methods to survey vector populations (Meiswinkel et al. 2008), or by developing innovative surveillance systems. For example, Hadorn et al. (2009) presented a cost-effective surveillance system for BT in Switzerland based on the combination of improved passive clinical surveillance in cattle and sheep, relying on increasing awareness of BT symptoms by farmers (Stuber et al. 2009), concurrent with a targeted bulk milk-testing strategy of dairy cattle herds in high-risk areas.

East Coast Fever

The surveillance of ECF is not systematic in the countries where the disease is present, and similar to RVF, surveillance tends to be replaced by case reports. Several specific projects have nevertheless attempted to establish the distribution of ECF prevalence in a number of countries: in domestic cattle in Zambia (Simuunza et al. 2011), in free-ranging buffaloes in Namibia (Pascucci et al. 2011), and in longitudinal studies in Uganda (Rubaire-Akiiki et al. 2006; Ocaido, Muwazi, and Opuda 2009). ECF vectors have also been subject to cross-sectional studies providing data that may support epidemiological surveillance at the country scale, for example in Rwanda (Bazarusanga et al. 2007), and at the scale of Africa as a region (Cumming 1999, 2000). An interesting pilot study for ECF is the disease surveillance program that was implemented in East Africa, which explored the use of mobile phone collection of epidemiological data relevant to ECF, anthrax, rabies, Peste des Petits ruminants and foot-and-mouth disease (LIDC 2010).

2.2 CLIMATE-SENSITIVE DISEASE RISK MAPS

Key Messages:

- Risk maps rely heavily on accurate collection of disease data.
- Risk maps enable better prioritization of surveillance, prevention, and mitigation efforts.
- Risk maps have been used extensively for BT and RVF and to a lesser extent for ECF.
- In many studies, risk maps have consisted of mapping the distribution of vectors; recent works have enabled modeling of diseases themselves.

2.2.1 Risk Maps: General Principles

The distinction between risk maps and early warning systems is nuanced. Early warning systems can best be thought of as the comprehensive set of information and actions that alert decision makers to impending harm. Risk maps are merely one component of this in that they are the application of data to a visual media that facilitate the communication of threats. Risk mapping is a useful tool in disease mitigation in that it can be used to distinguish areas that experience epidemic and seasonal transmission from those with more stable or continuous transmission patterns, for which EWS will be less useful (Kuhn et al. 2005). Maps make it possible to visualize areas of greatest threat so that disease mitigation efforts can be most effectively developed and implemented.

Creating risk maps requires a variety of technical inputs that vary by region and disease. In the case of climate-sensitive diseases, it requires both environmental and disease data. Once the environmental parameters that affect a disease are defined, data points can be collected from a variety of environmental and health resources (table 2.1). Multiple environmental indicators for disease can be overlaid to produce the most comprehensive results. Disease data, such as incidence and type of animal that it affects and historical records of outbreaks, can then be added to the map so that correlations can be identified. Comparisons in both spatial and temporal dimensions can be made, enabling predictions for regions and periods of time. Other inputs, like vulnerability status, can also be added to the map, bolstering the robustness of the tool so that best adaptations can be made.

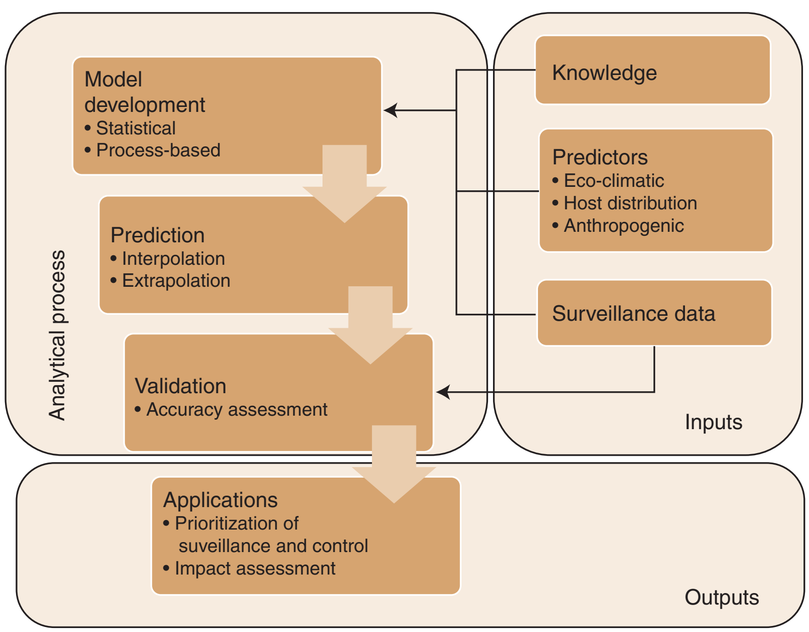
TABLE 2.1: Early Warning System Data and Risk Mapping Technical Resources

Africa Real Time Environmental Monitoring System (ARTEMIS)
Committee on Earth Observation Satellites (CEOS)
Emergency Prevention System for Transboundary Animal Diseases (EMPRES) Programme
European Space Agency Data Sets
FAO GeoNetwork
Global Risk Identification Programme (GRIP)
Group on Earth Observation (GEO)
International Research Institute for Climate and Society
NASA Goddard Spaceflight Center
OIE World Animal Health Information Database (WAHID)
RVF Activity Database in Kenya, Zimbabwe
SERVIR Regional Visualization and Monitoring System
U.S. DoD Global Emerging Infections Surveillance Program
U.S. NOAA Climate Prediction Center (including ANHRR)
World Animal Health Information Database (WAHID)

The production of disease risk maps requires a number of initial decisions—namely, what sort of risk is to be mapped and what methods are available to produce them (see figure 2.1). The definition of risk is a moveable feast, and while the simplest one may be the straightforward presence of the disease, or perhaps the number of cases in a particular place, a proper understanding of the risk posed by a disease requires estimating the risk of introduction, the chance that the disease once introduced becomes established, and then the likelihood that it will spread from established pockets into nearby areas, with estimates for the last two stages of both distributions and case numbers.

In reality, however, these ideal requirements are very rarely met, and the great majority of risk maps are based on the prediction of some index of disease presence. In the case of vector-borne diseases, the index of presence produced may not be for the disease itself but for its vector, as this may be easier to estimate than pathogen presence is, and the risk assessment thus produced becomes potential rather than actual presence. Risk (defined as an index of presence of either vector or disease) can be assessed in the field either by direct measurement through surveillance and monitoring programs or by modeling prediction and projection. The former tends to be expensive and time-consuming, especially in remote areas and for rare diseases, and is frequently replaced with reporting (which may or may not be reliable) or the collection and analyses of disease records from medical facilities and hospitals. While these data are certainly an improvement over no data at all, they can be misleading because the data sources may be biased or incomplete and only representative of certain areas or categories of host population. Surveillance is discussed further in the previous section.

FIGURE 2.1: Inputs, Analytical Process, and Outputs Typically Involved in Disease Risk Mapping



Disease risk maps are produced by modeling in two ways, each with markedly different structures and assumptions: biological mechanistic (or process-based) models and statistical models. Biological models are based on a detailed knowledge of the actual processes underlying the presence of a disease or its vector. These models are clearly hypothesis- rather than data-driven, and if the hypotheses are wrong, then so will the model predictions be wrong. Data-driven or statistical models are essentially pattern matching procedures based on the known presence of a disease (or vector) over space and/or time (Rogers and Randolph 2006). Temporal models usually imply time series analyses that look at trends in historical data and then project them into the future or that apply the trends found in one place to another (similar) place. They focus on looking at the way disease occurrence has fluctuated in the past and assume the same is going to happen elsewhere or in the future. Spatial distribution models first find statistical relationships between a disease and predictor data sets and then apply these relationships to the predictors of data to produce disease risk maps. There are many well-established methods for this type of modeling (Elith et al. 2006), and they are widely available in specialized software packages.

Statistical models are advantageous over biological models in that they are quite adaptable and can be used to model almost anything within a known distribution. On the other hand, they are difficult to use and require considerable supporting data, which are not always available for the desired parameters.

The inputs needed for disease risk maps obviously depend on the type of model. For biological models it may be necessary to know details of the population at risk—for example, the number of susceptible and immune animals or people, the rate of development of the disease once caught, the percentage mortality, the contact rate between infected and susceptible animals/individuals, the effects of environment on disease, host and vector distribution and abundance, the movement and immigration of susceptible and infected individuals, transmission routes and rates between hosts (and, if relevant, vectors), and the role of alternative disease reservoirs.

For data-driven models, there are two primary disease-related requirements. The first is reliable input disease (or vector) data to calibrate the models or to act as the skeleton framework within which new values can be interpolated or extrapolated. "Garbage in, garbage out" is particularly relevant here, as the modeling will merely match any defect in the data with more. It is therefore absolutely essential to ensure that the input training data are as accurate and representative as possible. In particular, it is important that a robust sampling and surveillance strategy is defined, and this can be very resource-intensive. The second important element is reliable host and, for vector-borne diseases, vector data. A vector-borne disease cannot exist unless both are present, and their abundance and distribution will determine the severity of any outbreak and its potential for persistence and spread.

Additional predictor variable datasets will be needed to apply and map the relationships identified during the modeling process. There is a wide range of potential predictor variables—essentially, any that might have a relationship to the presence or severity of a disease or its vector(s), including climatic parameters such as temperature, precipitation, and humidity; environmental parameters like vegetation cover and type, soil moisture and water, host distribution; topographic variables like altitude or slope; and anthropogenic factors such as agriculture and use, population, and trade pressures.

Fortunately, the availability of spatial data sets has blossomed in recent years and there are hundreds of datasets of global imagery in the public domain for major climatic and environmental variables. With all such datasets there is an issue of scale and resolution in time and space, with "better" resolution requiring more processing but resulting in finer detail of prediction. There are also challenges in using appropriate means, averages, or summaries of each covariate within the modeling procedures. Data reduction techniques like Fourier processing, however, can be used to extract biologically meaningful summaries from large and long-running datasets.

In the context of climate-sensitive diseases and potential effect of climate change, it is of course necessary to acquire projected climate data sets, of which again there are a large number, representing a range of "scenarios" assuming different rates in carbon dioxide increase (and thus temperature and rainfall change), and a number of global climate models (GCMs), which predict a wide range of different outcomes. It has now become standard practice to use the average of a number of GCMs (so-called ensembles) to try to produce a consensus set of projected outcomes.

The outputs required for a risk map may include disease incidence, prevalence, presence or absence, case numbers, and vector abundance or presence, as well as the probability of introduction, establishment, or spread or the spread rate of both vector and disease. While there may be a preference for a particular output in principle, the choices in practice are usually mostly dictated by what processes are best understood (for biological models) and what disease or vector data are actually available or can feasibly be collected with the resources available (for data-driven models). The availability of such data depends on the disease and the location, though most frequently produced outputs are some index of presence or absence, usually expressed as a probability. Biological data-driven models can be refined by using "masks" to improve the outputs; for example, climate, environment, or land use are often used to restrict the areas where a disease or vector can be present.

In recent years it has become increasingly clear that a simple prediction—a "one off" model—is not enough, primarily because the models all have errors implicit in the relationships used to build them and because a single model may, simply by chance, be one with a substantial error. As a result, it is important to use methods that can provide some description of uncertainty or error in the predictions. This largely relies on producing a large number of models with automated software, each using a random subset of the disease or vector data used to calibrate or "train" the models. The replicates are then averaged to produce a single output with an associated error.

2.2.2 Utility of Risk Maps

The development of a risk map serves many different purposes in the context of the mitigation of livestock diseases. First, risk maps help better target surveillance and control in high-risk areas, for which there are several other examples of uses than those highlighted in the previous section concerning RVF and BT. One is the risk of HPAI H5N1 that was mapped in Thailand based on intensive disease surveillance surveys and that detailed a poultry census (Gilbert et al. 2008). The data allowed identification of optimal allocation of surveillance effort (McCarthy et al. 2010) in the countries that have succeeded in eradicating the disease, despite poor agricultural and environmental conditions.

Second, disease risk maps can also be used to evaluate how changes in one parameter of the model can affect the extent of regions at risk. This principle underlines most studies that have looked at the potential effect of climate change on the distribution of vector-borne disease, including BT (Guis et al. 2012) and ECF (Olwoch et al. 2008). Disease risk maps can be combined with socioeconomic parameters to assess and map the potential economic benefit of trypanosomiasis control in West Africa (Shaw et al. 2006, submitted) for example, and this can be further developed to quantify the resulting cost benefit ratios for different control techniques, as demonstrated for the Horn of Africa. The insights gleaned here can then be used to design and target interventions most effectively.

Third, risk maps can be useful in the development of movement control maps. HPAI H5N1 in Thailand is also illustrative here, wherein free-grazing ducks were identified as being the greatest risk associated with the presence of the disease (Gilbert et al. 2006). In the following months, Thailand implemented movement control policies that prevented the transport of ducks over long distances, which had an immediate impact by reducing the number of outbreaks in the following year. Bovine tuberculosis is another example where statistical data-driven approaches developed to map the risk of the disease in Great Britain quantified the impact of cattle movement on disease risk (Gilbert et al. 2005) and guided the introduction of movement controls.

Fourth, disease risk maps are an extremely efficient way of communicating information about diseases to decision makers and to a lay audience. Proper communication, recruitment of experts (both modelers and communicators), and in-country trainings will be indispensable steps in the implementation and use of this tool (see also chapter 3).

VOICES FROM THE FIELD

Using Risk Maps in Malaria Control in Africa

Dr. Judy Omumbo, Policy Impact Unit, Malaria Public Health Cluster (KEMRI/University of Oxford collaborative program)

"We recently carried out a study to assess how risk maps are used in decision-making for malaria control in Africa.

Climate is a key driver of malaria transmission in Africa, and there are several risk maps that have been produced at the continental and national scale. So, we went through national malaria control policy documents, national strategies and applications for global funds to better understand what risk maps are effectively used. It was very interesting to find that risk maps had been identified for the large majority of countries with endemic malaria in Africa. Those maps ranged from simple eco-climatic descriptions to more complex maps of modeled malaria-parasite prevalence.

However, only five countries used national malaria maps to design, control, or make decisions on how to allocate resources. In other words, a limiting factor is not necessarily the availability of risk maps, but rather is the development of the science to policy and practice dimensions. There is a need to explore ways to improve how these types of data are used for more effective control.

One way to achieve this is to build platforms at the country level to better link risk mapping with policy, strategic planning and financing. In addition, ensuring country ownership of epidemiological risk maps and research outputs can better enhance their value and application in the long-run."

2.2.3 Risk Maps: Knowledge and Applications

Rift Valley Fever

Risk maps generated by Ken Linthicum and Assaf Anyamba have successfully predicted RVF outbreaks in the Horn of Africa. Using sea surface temperatures (SSTs), rainfall, and the Normalized Difference Vegetation Index (NDVI), they have been able to show high risk correlations with El Niño–Southern Oscillation (ENSO) and to map these areas for use in early warning systems (Witt et al. 2011; Anyamba et al. 2009). The maps are then transmitted to international organizations and governments to warn them of the high disease risk resulting from the ripe environmental conditions.

This work has been instrumental in illustrating how remote sensing can be used to predict vector-borne disease epidemics. Although this work focuses on RVF in East Africa, the potential uses for other diseases and regions are clear (Anyamba et al. 2012). For example, in Senegal, high-resolution satellite imagery has been used to map fine-scale distribution of water ponds (Tourre et al. 2008; Vignolles et al. 2010) and has been combined with rainfall data to map the RVF risk (Tourre et al. 2009). Other studies have mapped suitable vector habitat for RVF directly using serological data (Clements et al. 2007b). At the continental scale, Clements and colleagues have compiled the available data on RVF in Africa (Clements 2007a) and used a knowledge-based approach to produce a comprehensive continental risk map (Clements, Pfeiffer, and Martin 2006).

Bluetongue

The majority of risk maps published for BT have intended to map the distribution of disease vectors as indicators of spread potential. This has been carried out at continental and national levels in Europe and North Africa (Baylis et al. 2001; Wittmann, Mellor, and Baylis 2001; Tatem et al. 2003), Spain (Calvete et al. 2008; Acevedo et al. 2010), Italy (Conte et al. 2003, 2007), Calabria (Calistri et al. 2003), Sicily (Purse et al. 2004), France (Guis et al. 2007), Morocco (Baylis and Rawlings 1998; Baylis et al. 1998), and South Africa (Baylis, Meiswinkel, and Venter 1999). The distribution maps were produced using data-driven approaches. They used several remotely sensed indicators to identify the eco-climatic signatures characterizing locations where vectors were known to be present and applied the resultant statistical model to the predictor variables in order to map the areas with similar conditions. These models have proved particularly useful in mapping areas at risk of BT transmission and in identifying key variables influencing the distribution of vectors. However, the predictions of data-driven models depend heavily on the data that have been used to "train" them. Consequently, different models based on different training sets may produce different outcomes for the same region, as in the cases of Italy and Sardinia (Calistri et al. 2003; Pili et al. 2006). Additionally, since these models only attempt to predict the distribution of known and identified vectors, they cannot predict some events like the spread of BT through new vector groups, as was the case during the 2006 BTV-8 epidemic in the Netherlands, Belgium, France, and Germany. Here, BT was introduced well beyond the distributional limits of the traditional vector of Bluetongue in the Mediterranean basin, and it was in fact later demonstrated to be mediated by entirely different groups of *Culicoides* vectors with different habitat and climate preferences (Purse et al. 2007, 2008).

Over the last few decades, BT has definitively expanded its range northward in Europe—the likely result of climate change causing the latitudinal shift of its primary Mediterranean basin vector, *C. imicola* (Purse et al. 2005). Yet with the BTV-8 epidemic that spread through other communities of vectors in northwestern Europe, it became clear that this mechanism could only partly explain the shift of BT and that other mechanisms, such as changes in vector identity, vectorial capacity, extrinsic incubation period, or biting rate possibly linked to climate change could have also had some causative effect (Guis et al. 2012).

The distribution of vectors mapped through data-driven models has not been the only approach used to map the risk of BT. Hartemink et al. (2009) developed a process-based mathematical model that integrates data on the distribution of vectors, animal hosts, and transmission parameters to map the distribution of R_0 in the Netherlands. (R_0 is the average number of secondary infections arising from one single infected in a totally susceptible population; an epidemic dies out if R_0 is < 1 and may spread if R_0 > 1.) Other authors have used and analyzed case data to investigate the factors associated with BT presence directly (Allepuz et al. 2010; Silbermayr et al. 2011), or to quantify the rate of disease spread (Gerbier et al. 2008; Pioz et al. 2011). Recently, Guis et al. (2012) published a study based on an integrated mechanistic model of BT transmission risk that quantified the potential role of climate change in the northward expansion of Bluetongue in Europe over the past several decades. The model was then applied to an ensemble of 11 regional climate models to project the distribution of BT risk in the future.

It has also been noted that BT can spread over long distances though wind-aided dispersal of its vectors, and several studies have found spatio-temporal correlations between the wind and BT spread (Ducheyne et al. 2007; Kedmi et al. 2010; García-Lastra et al. 2012; Sedda et al. 2012), establishing the basis of research efforts to produce maps quantifying the wind-resultant BT risk (Gloster et al. 2007b; Hendrickx et al. 2008; Ducheyne et al. 2011).

When BTV-8 was spreading in northwestern Europe, countries such as France and Germany used GIS-based risk maps to prioritize surveillance, targeting the fringe of vector distribution, looking for expansion (Racloz et al. 2008; Koslowsky et al. 2004). Risk maps based on wind-modeling were also used in a number of cases to assess BTV risk in the United Kingdom (Gloster et al. 2007a) and to define (and subsequently modify) movement restriction zones and areas where vaccination was recommended, as well as to predict its northward spread (Ducheyne et al. 2011). Such techniques enabled veterinary officers in Belgium to decide whether there was a risk of introduction of BTV from France and thus whether there was a need for preventative measures.

East Coast Fever

Compared with RVF and BT, there has been relatively little work to map the risk of ECF. Two studies have mapped the distribution of ECF vectors in Africa (Randolph 1999; Cumming 2000), and risk maps integrating vector, host, and/or climatic data have been produced in a limited number of studies in the central highlands of Kenya (Diaz et al. 2003), in Zimbabwe (Pfeiffer et al. 1997), and at the scale of Africa (Lessard et al. 1988). Recently, a study by Olwoch et al. (2008) used tick, climate, and cattle data to predict the possible effect of climate change (as predicted by the nested regional climate model DARLAM) on ECF in sub-Saharan Africa.

2.3 CLIMATE-SENSITIVE DISEASE OUTLOOKS

Key Messages:

- Disease outlooks aim to provide long-term projections of disease trends so that disease control and mitigation efforts can be integrated into long-term planning.
- Few disease outlooks are yet available for any diseases.

2.3.1 Disease Outlooks: General Principles

Disease outlooks apply in two general situations: the introduction and establishment of a disease in a region where it was previously absent and the increase in incidence and/or prevalence, or the occurrence of more epidemics, within regions where diseases are already present. Developing long-term disease outlooks or projections is challenging because different factors may influence introduction and spread. For example, in a region where a disease is absent, climate may become suitable as a result of climate change, but the disease may never spread if it is never introduced through trade, tourism, wind patterns, or some other transplantation event. Conversely, repeated introduction may never lead to establishment and spread if the environmental conditions are not exactly right, given the subtle sensitivities of both diseases and vectors. Furthermore, projections often ignore the evolutionary capacity of disease and vectors to adapt to new conditions, given the complexity in incorporating this into a model. Adding to the difficulty of definitively making long-term climate-related projections is the temporal uncertainty and spatial heterogeneity associated with climate change projections on global and regional scales.

Health impact models are also constrained in that there are a number of inputs besides just environmental variables that determine their outcomes. A multiplicity of socioeconomic factors and policy decisions determines diseases and can often be too complicated to include in long-term health models, regardless of whether these are for animals or humans (IPCC 2007). For example, failure to implement appropriate and timely mitigation measures in the United Kingdom resulted in an excess of bovine TB, a previously controllable disease. Regarding the environmental determinants alone, improvements or expansion of control activities may prevent spread, or indeed eliminate a disease from areas where it is historically present, as in the cases of malaria in Europe and North America and of rinderpest in Africa.

In considering the economic impacts of diseases in the future, it is important to note that the link between GDP and burden of diseases is confounded by social, environmental, and climate factors (Arnell et al. 2004; van Lieshout et al. 2004). In this context, global macroeconomic trends can drastically affect resources directed to disease mitigation or the research needed to develop new control methods, and such factors can dwarf the likely impact of climate and environmental change of disease levels (Gething et al. 2010). Discerning the economic impacts of these future disease threats is therefore virtually impossible because economic scenarios cannot be directly linked to disease burdens and most attempts to do so are often constructed as "what if" scenarios rather than firm projections.

2.3.2 Disease Outlook: Knowledge and Applications

Few disease outlooks or projections have been published in the literature regarding any climate-sensitive diseases that might affect rural pastoralist farmers.

Outlooks have been produced for some diseases in the European Union, and RVF is frequently cited in risk assessment as being a possible contender for introduction to Europe (López-Vélez and Molina Moreno 2005; Martin et al. 2008) or the United States (Konrad, Miller, and Reeves 2011; Hartley et al. 2011), although the precise mechanisms supporting those increased risks are diverse. These outlooks are further supported by studies that gauge expert opinion (Gale et al. 2010), also identifying RVF as one of the diseases believed to have an increased risk of introduction into Europe (EFSA 2013). Climate matching approaches and projections according to climate change scenarios have been produced to map the projected distribution of the vectors for BT in Spain (Acevedo et al. 2010) and for ECF in Africa (Olwoch et al. 2008), and they found respectively a low impact and a noticeable impact in vector distribution. Perhaps the most elaborate model used to make predictions on disease has been produced at the European level by Guis et al. (2012), who used an epidemiological model of BT transmission, adapted for two hosts and two vectors to quantify the possible impact of climate change on BT R_0 in northwestern (a 4.3 percent increase per decade) and southwestern Europe (a 1.3 percent increased per decade). Most of this increase is mediated by the effect of temperature on the extrinsic incubation period (the period between infection of the vector and its ability to infect the next host). Although there are currently no models for these outlooks in Asia, Africa, or South America, lessons learned from the European studies can be applied to diseases in these regional contexts.

Establishing outlooks is important when building long-term disease mitigation plans as it provides a framework for governments to invest in research in order to reduce uncertainties and to develop disease mitigation efforts. Although it is true that climate change will affect diseases in regions differently, current data indicate that, on average, emerging climate patterns—like increased temperatures and precipitation—will lead to increased geographic distribution of certain diseases. It may also be that "what if" scenarios can be effective tools for planning, particularly if they incorporate socioeconomic or policy-related factors.

2.4 EARLY WARNING SYSTEMS

Key Messages:

- Early warning systems aim to provide short- or mid-term disease forecasting so that appropriate interventions and mitigation efforts can reduce the impact of an epidemic.
- Climate-based EWS have been developed for RVF in East Africa and have proved useful in predicting recent outbreaks.

2.4.1 Early Warning Systems: General Principles

Because the geographic and seasonal distributions of many infectious diseases are linked to climate, the notion of using climate variables to predict disease and establish EWS has long been an area of academic, practical, and political interest. Many of the major climate-sensitive human diseases are associated with some sort of EWS research or development activity. Climate-sensitive animal diseases are also increasingly being explored. Capabilities in building efficient disease EWS blossomed in the 1990s, coinciding with the widespread availability of relevant spatially explicit environmental data, improvements in data storage and epidemiological modeling technology, and increased awareness of anthropogenic climate change (Kuhn et al. 2005).

Using climate data to predict disease occurrence or outbreak dates from the first half of the twentieth century. Researchers in India developed an early warning system for malaria based on rainfall, the prevalence of enlarged spleens, economic conditions (such as the price of grains), and a coefficient for epidemic potential. The system predicted epidemics from 1921–49 in Punjab, and retrospective analyses have revealed the probable accuracy of the projections (Swaroop 1949). Additional work was done to explore the associations between pneumonia, smallpox, tuberculosis, and leprosy and various climatic variables such as temperature, humidity, rainfall, and wind. Datasets were kept on decadal scales for thousands of sites, demonstrating the potential feasibility and utility of such methods for widespread surveillance, even when using few variables, primitive models of measurement, and incomplete knowledge of the effects of climate on all aspects of disease (Kuhn et al. 2005).

Today the health sector (animal or human) is better positioned to provide the required inputs and utilize the potential benefits of EWS. Disease diagnostic tools to monitor incidence and transmission are globally available; environmental monitoring systems, such as satellites and meteorological stations, are accessible online; and advances in statistics and epidemiology allow for more accurate measurement of climate-disease associations. At present, many early warning systems exist for a range of climate-sensitive impacts. Famine, for example, though not explicitly disease-related, has clear association with climate through its effects on crop production,

VOICES FROM THE FIELD

The Liver Fluke Climate Forecast in the United Kingdom

Prof. Matthew Baylis, Head of the Department of Epidemiology and Population Health Institute of Infection and Global Health, University of Liverpool.

"An interesting example of early warning system applied to livestock diseases in the United Kingdom is the liver fluke forecast. What drives the forecast is a monthly 'fluke index' based on the relative levels of rainfall and potential transpiration. If rainfall is higher than potential transpiration, then there is a net accumulation of moisture on grass, leading to a higher index. This is done for those months (May to October), which are warm enough for flukes to survive.

According to Dave William, from NADIS (http://www.nadis.org.uk/), the forecast is emailed every month, in slightly different formats depending on the recipients to i) all the UK veterinary practices who registered into the system, ii) farmers associations of the ruminant sector (English Beef and Sheep Meat Industry EBLEX, Hybu Cig Cymru Meat Promotion Wales HCC, Quality Meat Scotland QMS), iii) to the Animal Medicine Training Regulatory Authority to be distributed through their to Continuous Professional Development training and iv) to farm businesses. The forecast is also featured on the NADIS web site.

An interesting feature of the forecast is that it stimulates discussion between the farmer and his vet about individual farm conditions. It highlights sustainable control of parasites in sheep in a seasonal context and the vets central role in parasite control.

So, the system is not directly targeted at farmers themselves, but at veterinarian practitioners as a way to improve their service and interactions with their customers, which in return improves the overall control of those parasitic diseases."

The current forecast can be viewed at http://www.nadis.org.uk/parasite-forecast.aspx.

and it was one of the early health impacts to be rigorously invested in, with operational programs on global, regional, national, subnational, and local levels (Kuhn et al. 2005). Many diseases and pests with major impacts on humans, such as malaria, dengue, cholera, influenza, and locusts, for example, are all widely supported by EWS programs.

Early warning systems are also under development for a number of climate-sensitive animal health impacts. In 2004–09, the first phase of an EWS was implemented by the International Fund for Agricultural Development (IFAD) and the World Bank to protect herders in Ethiopia. With a goal of strengthening the resilience of the rural poor and increasing their ability to cope with external shocks (such as the impact of drought on livestock), the project has in these initial stages focused on strengthening the institutional capacities of indigenous social organizations so that communication and any necessary technologic components of EWS can be successfully rolled out (IFAD 2009).

CASE STUDY

IFAD/World Bank Ethiopian Pastoralist Community Development Project

The project aims to improve the prospects of achieving sustainable livelihoods among herders living in arid and semi-arid lowlands. It seeks to harmonize the development of Ethiopia's lowlands and its more fertile highlands, and reduce vulnerability to drought and the risk of local conflict.

The first phase of the project (2004–09) was a response to drought and to the need to create sustainable livelihoods for herders. In partnership with the World Bank, the project established early warning systems and disaster preparedness plans, through a participatory approach to programming, implementation and monitoring. The objective was to strengthen the resilience of the rural poor and increase their ability to cope with external shocks, while making them less vulnerable to drought and other natural disasters, thus indirectly promoting climate change adaptation. Initial activities included strengthening the institutional capacity of indigenous social organizations.

The disaster-preparedness and contingency fund (DPCF) will be created in the second phase, with separate "windows" for early response and disaster-preparedness investment financing. Through the disaster-preparedness strategy and investment program (DPSIP) subcomponent, the project will identify local needs for long-term regional disaster-preparedness and mitigation. Under the DPCF, each region will receive DPSIP grants to finance disaster-preparedness investments.

Source: IFAD 2009.

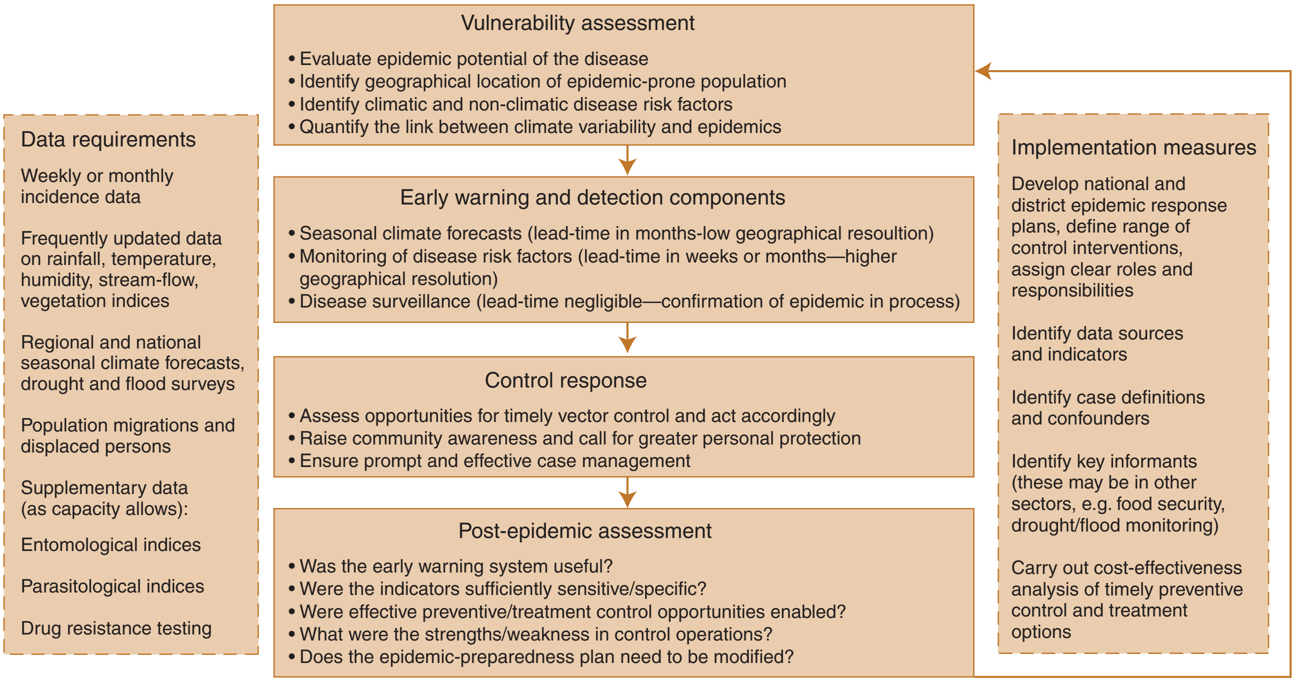
WHO has published specific recommendations regarding the development of climate-sensitive disease EWS (see figure 2.2). Although formulated for climate-sensitive disease risks in humans, the similarity to diseases in animals allows considerable transferability of ideas and applications, hastening the speed with which animal EWS can be generated and implemented.

A number of WHO Special Program for Research and Training in Tropical Diseases pilot studies have been in progress in seven central Asian countries, which have followed this scheme. Throughout, it has become apparent that proper vulnerability assessment by collaborative national and international agencies is key to the successful design of regional and effective transboundary mitigation programs, and that this stage may take substantially longer than initially envisaged, in part because it involves significant in-country capacity building and training prior to implementation. Some of these initial vulnerabilities and capacities with regard to animal health can potentially be determined through a tool like the OIE Performance of Veterinary Services, as described in more detail in chapter 3.

In evaluating the potential utility of early warning systems, WHO recommends that disease EWS be developed only if the disease is epidemic-prone. That is, "an occurrence in a community or region of cases of an illness … in excess of normal expectancy." Outbreaks also qualify under this designation when they are epidemics "limited to localized increase in the incidence of a disease, for example, in a village, town or closed institution" (Last 2001). Because epidemics and outbreaks differ only in the scale of their effects, a climate-sensitive disease EWS will be effective for both (Kuhn et al. 2005). Using this criteria, EWS can be targeted to regions and resources maximized.

The primary aim of EWS is to predict the occurrence of an epidemic with a sufficient lead time that allows actions to be taken to mitigate its extent and impact. Including risk maps as part of an EWS allows prioritization of the surveillance and control activities, improving their efficiency. For any EWS, it is thus essential to characterize the lead time, the spatial and temporal scale of the predictions, and the uncertainties of outputs, and to ensure that adequate contingency

FIGURE 2.2: Framework for Developing Early Warning Systems for Climate-Sensitive Diseases (Adapted from: Kuhn et al. 2005)



plans associated with each step of the warning are clearly identified. Those principles are elaborated on in chapter 3.

2.4.2 Early Warning Systems: Knowledge and Applications

At present, there is little integration of EWS into disease control decision making (Kuhn et al. 2005). Yet there are some positive examples to draw from. An RVF EWS provided decision support to international organizations during epidemics in 2007 and 2010 in East Africa (Anyamba et al. 2009). Some animal health information systems also exist at the global scale, such as the FAO Empres-I information system (http://empres-i.fao.org/eipws3g/) and the World Animal Health Information System of the OIE (http://web.oie.int/wahis/public.php?page=home), although these systems rely largely on reported confirmed cases, and thus provide little lead time or early warning.

In addition to the official notification of disease or infection outbreaks, FAO, OIE, and WHO systematically collect, verify, analyze, and respond to information from a variety of sources, including unofficial media reports and informal networks. In 2006, these heuristics were combined to launch the Global Early Warning System for Major Animal Diseases, including Zoonoses, or GLEWS, forming a new and wide-reaching collaborative.

Rift Valley Fever

Of the three diseases detailed in this report, RVF provides the best example of an EWS tool. As previously noted, RVF epidemics in East Africa have been linked with inter-annual climate variability and above normal rains and floods triggered by ENSO. Coupling climate and disease data is thus possible by collection of the right sources. For example, detection of SST and thus the ENSO event itself is the necessary first step establishing this kind of seasonally determined early warning system. These data alone, however, do not provide spatially detailed information about where the excessive rain will occur within regions, and so looking to historic patterns and identifying anomalies in rainfall and vegetation (via the NDVI) from satellite imagery (available, for example, from NASA/NOAA) can be used to refine spatial predictions (Anyamba et al. 2009). Coordinating these data with disease sensitivities to these environmental variables can provide public health officials with warnings on multiple levels: general warnings sent when an ENSO is detected and proximal early warnings once severity and weather patterns emerge. During the 2006–07 and 2010 outbreaks, a six-week lead time was provided, which and had the ultimate effect of diminishing overall RVF impact.

VOICES FROM THE FIELD

Experiences with RVF Early Warning in Kenya in 2010

Dr. Peter Ithondeka, Director of Veterinary Services, Kenya

"Decision-making in RVF outbreak cycles is always difficult because it involves balancing the lack of perfect information with the need to make a decision to prevent losses. If a decision is taken too early with scant information, the likelihood of taking a wrong decision is increased and unnecessary costs will result from inappropriate activities. If a decision is taken too late, the opportunity to intervene effectively may be lost, leading to unmitigated impacts. The decision-maker has to balance the risks of over-reacting against those of under-reacting.

In 2010, we received an early warning that due to an ENSO situation, we could experience abnormal rainfall resulting in floods in high risk areas for RVF. Within the areas identified as high risk with early warning maps, we had worrying evidence from the field: there was an upsurge in food rot, many areas were flooded, and within those, there were many sites where we knew that RVF outbreaks had occurred in the past and that we hence considered as high risk.

So, we combined the forecasted risk map with our local knowledge to conclude that there was a very high risk of RVF outbreaks, and that those outbreaks would be concentrated in those areas. So, we took the decision to concentrate our distribution of vaccines in those areas, such as to prevent as much as possible the extent of the outbreak.

It is always difficult to retrospectively assess what would have happened if we had taken another decision, but we believed that this was quite successful."

Bluetongue

Although several systems have been described in the literature for BT EWS (Giovannini et al. 2004b; Racloz et al. 2006), they are not by definition truly EWS because they only embody the disease surveillance component, offering little lead time ahead of an epidemic. Analysis and monitoring of wind patterns have, however, been used successfully in the United Kingdom to ensure early detection by targeting surveillance in areas of high risk from introduction of the disease from continental Europe, and to define the potential for spread within the country as a whole. In this regard, the lessons learned here may be more useful for long-term disease outlooks through the analysis of wind patterns.

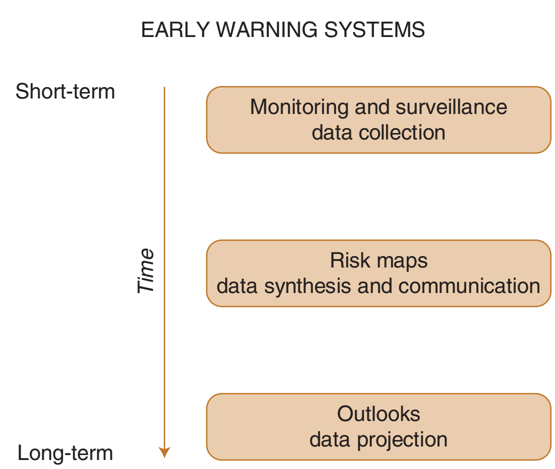
East Coast Fever

A strong correlation between the sero-prevalence of *T. parva* and the presence of ENSO has been noted in southern Zambia (Fandamu et al. 2005, 2006). Although ECF is more an endemic than epidemic disease, the results—if confirmed in other countries and regions—could confirm the ENSO correlations and enable better disease predictions. As of yet, however, there is little literature or experience with early warning systems for ECF.

2.5 COMPLEMENTARY NATURE OF SURVEILLANCE SYSTEMS, RISK MAPS, AND DISEASE OUTLOOKS WITHIN EARLY WARNING SYSTEMS

Monitoring and surveillance detect early signs of a growing epidemic in the field and provide the network for facilitating the early dissemination of recommendations. These disease data are complemented by climatic data (observed in and transmitted by weather stations or remote sensing modalities) and ancillary data (that is, spatial distribution of livestock and breeds). These three types of surveillance data can then be used to build reliable risk maps and disease outlooks, which can in turn be aggregated to establish a base of information for dissemination through early warning systems (see figure 2.3.) In effect, EWS are the overarching tool that enables threat alerts early enough for preventative action; surveillance systems provide the inputs for the visualization and perception of risk; risk maps aid in the discernment and

FIGURE 2.3: Different Components of Early Warning Systems and Their Relationship



VOICES FROM THE FIELD

Why Risk Mapping and Early Warning Systems Are Not Used More Widely

Dr. Diarmid Campbell-Lendrum, Team Leader for Climate Change and Human Health, World Health Organization

"There are many scientific and policy rationale for using climate-driven risk maps and early warning systems in climate-sensitive diseases. Climate is intrinsically variable in space and time, and the overall future impact of climate change further emphasizes the need for a better understanding of its influence on diseases. In addition, there is a strong demand from the countries themselves for such systems. However, there are today few climate-based early warning systems used to influence disease control decisions.

There are many reasons for this. In some instances, climate is one of the many determinants of diseases, and the complexity of integrating all factors becomes a real obstacle. In other instances, systems are in place, but address no real stakeholders who could convert the system outputs into actions. Other problems can be a lack of added value of the system over the knowledge of the users in the field.

I think that in the future, one should pay attention to embed risk mapping and EWS into operational decision support systems, to share lessons and systems with other hazards for which EWS have been developed successfully, and to evaluate the benefit of those systems against criteria that are relevant to decision-makers."

communication of these associated threats; and disease outlooks provide an opportunity for temporal understanding and long-term planning.

Unfortunately, many gaps still exist in the development and implementation of each of these tools. Considering them together as integrated components under the early warning system framework will optimize their utility and potential for impact, regardless of the disease that they address. Preparing these approaches now will protect the health, livelihood, and financial futures of those most at risk for generations to come.

Chapter 3 INVESTMENTS AND APPROACHES FOR ESTABLISHING EARLY ACTION CLIMATE-SENSITIVE DISEASE RISK REDUCTION TOOLS

This chapter proposes investments that will address the underlying requirements for establishing climate-sensitive disease risk reduction tools. It contains a synthesis of reviewed literature and outcomes achieved during an expert-level consultation on climate-sensitive disease risk reduction. Steps to assess baseline capacities are also included.

Key Messages:

- Preparing climate-sensitive disease risk reduction tools requires minimum investment in a number of areas: knowledge, policy, human resources, information and communication technology, and physical building.
- Investment in individual project components in each of these infrastructure areas will help build the capacities of countries so that they can effectively implement and use risk management tools.
- Many of the actions and project components leading to the strengthening of these capacities are interrelated and co-dependent, necessitating investment packages that address a portfolio of needs.
- The actions required to bolster these areas are not necessarily specific to any one disease.
- Investment in project components can have co-benefits for a variety of non-disease-related development needs.

3.1 REQUIREMENTS FOR EARLY ACTION TOOLS

The development and implementation of the tools highlighted in chapter 2—surveillance systems, risk maps, disease outlooks, and early warning systems—require basic levels of underlying infrastructure. This infrastructure can be deconstructed into five main categories: baseline knowledge, policy, human resources, information

Proposed Priority Investment Needs

The project components in this box have been highlighted as priorities for investment based on their basic utility in the development of climate-sensitive disease risk reduction tools. The knowledge infrastructure is the obligatory first stage of investment, and EWS messages is the last. The other project components can be concurrently enacted throughout an integrated process of investment.

Phase 1:

- Knowledge: Needs assessments and baseline surveys of basic capacities of institutions, individuals, and technical and physical infrastructures

Phase 2:

- ICT: Climate-sensitive disease web-portals inclusive of integrated EWS information, risk maps, disease outlooks
- ICT: Mapping, GIS, and modeling software
- ICT: New and/or integration with current hydro-met information systems
- Human Resources: Workforce trainings (policy makers, veterinarians, physicians, environmental scientists, communication experts, others) through short courses, workshops, and sponsored advanced degree programs on general climate-sensitive disease information as well as specialized technical aspects of the work (such as disease diagnostics, GIS, computer programming)
- Policy: Coordinated animal health–human health collaboration mechanisms through, for example, committees and cross-sectoral working groups at national/regional levels

Phase 3:

- ICT: EWS messages disseminated through new media: websites, mobile phones, social media

TABLE 3.1: Climate-Sensitive Disease Investments

INFRASTRUCTURE REQUIREMENT	INVESTMENT FAMILY	PROJECT COMPONENTS REQUIRING INVESTMENT
Baseline Knowledge	Information Product and Knowledge Generation	• Needs assessments and baseline surveys of basic capacities of institutions, individuals, and technical/physical infrastructures • Climate-sensitive disease risk catalogues and impact assessments at national and regional levels • Feasibility studies for risk management tools, such as EWS messaging
Policy and Human Resources	Institutional Strengthening and Professional Capacity Building	• Workforce trainings (policy makers, veterinarians, physicians, environmental scientists, communication experts, others) through short courses, workshops, and sponsored advanced degree programs on general climate-sensitive disease research as well as specialized technical aspects of the work (such as disease diagnostics, disease risk mapping (GIS and spatiotemporal modeling), computer programming) • Environment, disease, and ICT workforce recruitment • Coordinated animal-human health collaboration committees and cross-sectoral working groups at national/regional levels • Early warning protocols for specific climate-sensitive diseases
	Community Capacity Building	• Climate-sensitive disease and ICT user trainings at local and subnational levels • Community support groups and knowledge exchanges
Information and Communication	Information Dissemination	• Climate-sensitive disease publications disseminated to professional and lay audiences • Climate-sensitive disease and EWS messages to be disseminated through traditional media resources: print, television, radio, community theatre • EWS messages disseminated through new media: websites, mobile phones, social media
	ICT Capacity Building	• Digital climate-sensitive disease libraries at regional/national level • Climate-sensitive disease web-portals inclusive of integrated EWS information, risk maps, disease outlooks • Mapping, GIS, and modeling software • New and/or integrated with current hydro-met information systems • Innovative data collection approaches
Physical	Building and Construction	• New or retrofitting of current facilities to create coordinated animal-human health–environmental data collection and collaboration centers at national/regional levels; to include meeting facilities, high speed Internet, resource libraries, and computers equipped with mapping, modeling, climate, and disease monitoring software • Rapid diagnostic laboratories equipped to process climate-sensitive diseases • ICT networks

and communication, and physical buildings (see table 3.1). Each necessitates investment, although the type and amount of investment and the level at which it is targeted will vary by region and country. This chapter establishes what these underlying requirements are and describes possible approaches by which investment needs can be determined and met so that the risk reduction tools can be widely, rapidly, and effectively adopted. Many of the requirements depend on other ones, and so it is important to develop a range of investment to cultivate a healthy operational environment for climate-sensitive disease preparedness. The requirements and approaches in this chapter are not specific to any of the diseases detailed throughout the report; where specific disease considerations are necessary, they are noted in the text. Although broadly applicable, it is worth noting that disease prevention efforts should be focused on the diseases that are most economically and medically costly to the populations that suffer them, and they should be considered on a country- and region-specific basis.

3.2 REQUIREMENT 1: BASELINE KNOWLEDGE

Information products are important for enabling understanding on multiple levels and across disciplines. Not only will they help users stay up to date with the most recent knowledge, they can encourage further engagement in regional contexts and can link practitioners with others around the world.

Project Component: Performance of Baseline Surveys, Assessments, and Feasibility Studies and Creation of Catalogues

Achieving baseline knowledge is a fundamental requirement for the development of any of the risk reduction tools detailed in this report. Strong region and nation-specific information products will help target investment in the areas where it is needed the most. In this regard, a number of initial studies are necessary to set the stage for project investment and implementation. Key actions that will facilitate this include the following: conducting needs assessments and baseline surveys of the basic capacities of institutions, individuals, and technical and physical infrastructures (for example, on veterinary services performance, see box below); creating climate-sensitive disease catalogues and impact assessments at national and regional levels; and performing feasibility studies for the proposed risk management tools within current infrastructures.

Surveys

Coordinated deployment of surveys and assessments may yield the best and most unified results. In some cases, current resources can be drawn upon to achieve outcomes; in others, unique interviews and research will need to be conducted. Specific assessment modality will vary by the subject of the survey and will use a number of methods. Assessing institutional capability, for example, could include an inventory of the number of relevant departments within an institution, the number of policies in place that address climate-sensitive disease, and the history of institutions able to successfully deal with health threats. Individual assessments might include, on the professional side, tallying the number of trained persons who could serve a role in the implementation of risk management tools, interviewing them about their availability to engage in this work, and gauging their perceptions of general success of this initiative. For the community component, interviews could be conducted to understand general awareness for these climate-sensitive disease threats and local and traditional approaches to managing environmental and disease threats. Regarding technical and physical infrastructures, hydro-meteorological and disease surveillance data can be quantified, ICT capabilities measured, and abundance and integrity of scientific facilities assessed.

> *Highlighted Approach*
>
> The OIE PVS Pathway (PVS stands for Performance of Veterinary Services) is an internationally recognized system of measurement and evaluation of national veterinary services based on OIE standards, helping countries identify their deficiencies, prescribe solutions, and undertake strategic actions. Assessments with these tools have been completed in around 120 countries, comparing performance to international standards of veterinary service quality and guiding assistance with investment decision making. The results of these assessments provide comprehensive and objective information for donors and partners willing to help countries strengthen their animal health systems efficiently (OIE 2014).

Disease Catalogues

The creation of climate-sensitive disease catalogues is important because it will alert health specialists to the potential threats a region is facing and/or those that are likely to increase with climate change. The availability of such catalogues will increase overall awareness of climate-sensitive diseases and enable better preparedness and faster response time in the event of an outbreak. Determination of the specific disease threats will also enable the enaction of targeted measures to prevent disease spread, such as maintaining vaccines for certain diseases on hand or engaging in mitigation efforts like spraying for insects, which apply to specific diseases.

Feasibility Studies

Conducting feasibility studies presumes there is an underlying level of infrastructure sufficient to support some degree of risk management tool implementation. This method might include the pilot launch of one of the tools to determine how rapidly and efficaciously it could be enacted, providing an applied check on the results determined in the baseline knowledge assessments.

> In each of the following sections, questions are provided that can be used to guide program managers in efforts to establish this infrastructure project inception phase.

3.3 REQUIREMENTS 2 AND 3: POLICY AND HUMAN RESOURCES

The two requirements in the institutional strengthening and capacity building category are difficult to disentangle, as policy relies upon human resources to be enacted, while, conversely, human resources often require policy for organization and structure. Investment in these two areas will ensure a nourishing socio-political environment within which the risk reduction tools can develop and thrive. The specific approaches incorporate a combination of capacity building and policy actions that taken collectively will create strong institutional and human capacity to support and use the risk management tools.

Project Component: Workforce Capacity Building and Recruitment

Risk reduction tools are useless without a capable workforce to employ them. Once the range of stakeholders is identified, specialized and directed training programs can be developed to train workers at all levels, including pastoralist farmers, veterinarians, physicians, health care extension workers, environmental specialists, ICT specialists, epidemiologists, and government officials involved in decision making. The nature of this training will coincide with the technical requirements in the subsequent section, so that the technology and user capabilities will co-develop.

The first step in this process, as noted in the previous section, would be to conduct baseline surveys that determine the core competencies of different types of workers. Tiered and directed training can then be optimally targeted to those most in need.

The approaches to this are many. Client country-driven training programs can be established where capacity is greatest, fostering ownership and autonomy over climate-sensitive disease initiatives. Intergovernmental agencies (WHO, OIE, the UN Development Programme, the WMO) and development banks can offer training, providing the advantage of institutional centralization and regional congruency in training received. Training modalities currently exist on climate change and disease at both WHO and WMO, which have recently partnered to address climate change and health threats. Third-party experts can also be called upon to provide the expertise and training; for example, the International Research Institute for Climate and Society at Columbia University provides training modules to build a range of climate change and disease technical competencies, such as access to environmental and climate data, epidemiologic and environmental data integration, disease transmission and climatic analysis, and disease outbreak forecasting.

The content of these trainings will depend largely on the capabilities and needs of the training audience. Yet there are certain must-have training needs that will ensure the effective use of the climate-sensitive disease tools. Topics for these include basic understanding of how climate change and disease are related, using risk maps and early warning systems, rapidly responding to disease outbreaks, integrating health and environmental services, and communicating health and climate concepts.

INCEPTION PHASE QUESTIONS: WORKFORCE CAPACITY BUILDING

What are the current capacities of the workforce in each sector?
Which sectors need training?
Which sectors have priority training needs?
Which sector training needs correspond with other project components (for example, technical infrastructure)?
What kind of training do professionals in each sector need?
Where can individuals achieve the training/who will provide it?
What resources are available for the training?
Are there on-going training modalities that can integrate climate-sensitive disease trainings?

Project Component: Workforce Recruitment

Another way to improve the overall quality of the workforce is to develop incentives for training and recruiting technical specialists. Attractive salary packages and healthy programmatic budgets for developing innovative climate change and disease approaches can both harness top talent within a country as well as lure leading professionals to countries and regions and encourage collaboration among local and international workforces. The development of in-country talent will raise the profile for the issue nationally, while the attraction of external experts can raise the profile of climate-sensitive diseases on an international level and create opportunities for expert and political engagement. Joint programming through other universities and institutions, staff exchanges, professional fellowships, and other professional development programs that establish international knowledge exchange can also be effective.

INCEPTION PHASE QUESTIONS: WORKFORCE RECRUITMENT

What types of professionals are lacking?
From where can these professionals be attracted?
What kinds of resources will it take to attract the right professionals?
Once recruited, where will the professionals work?

Project Component: Coordinated Animal-Human Health Collaboration Committees and Cross-Sectoral Working Groups at National/Regional Levels

Establishing overall governance and accountability mechanisms is imperative to ensuring the successful implementation and continuation of a climate-sensitive disease initiative. Without high-level government support for policies on climate risk management, it will be difficult to achieve the resources necessary to keep interest and action alive. Obviously, the fact that a disease is climate-sensitive does not automatically justify the implementation of national surveillance and control programs. Conducting a prioritization exercise at the national or regional level would provide solid socioeconomic grounds to advocate investment in major diseases, whether they are climate-sensitive or not. Some regional committees are also well positioned to address transboundary diseases. All the major diseases of climate-sensitive importance fall under this category. Targeting them collectively in a way that transcends national boundaries, rather than through a piecemeal, country-by-country approach, offers the best chance to overcome these diseases.

To address this critical aspect of coordination and collaboration, a first step should be to understand the various existing formal and informal relevant collaborative mechanisms at national and regional levels that could serve as entry points to further build upon and consolidate performing ones.

If the establishment of a formal committee would be deemed most appropriate, the next steps could include convening and establishing a multi-sectoral national or regional steering committee for control of climate-sensitive disease. This should include, at a minimum, representatives from decision-making bodies (the Ministries of Health, Agriculture, Environment/Meteorological Agencies); national and international research institutions and technical agencies and universities; end-users of climate-sensitive disease plans, such as farmers; and the people who work with these groups, such as veterinarians and community communication specialists. To avoid overlap and inefficiency, this may make use of existing committees, such as the task team for implementation of the Libreville Declaration on Health and Environment in Africa (Libreville 2008), any committees devised during and after avian influenza outbreaks, and any standing committees that are currently addressing One Health challenges. The committee should also include a link to national bodies covering related functions, such as national climate change committees and strategic planning committees responsible for human and animal health. If pre-existing institutions are capable of taking on a climate-health element, they should be used first.

This committee would serve multiple functions including, but not limited to, being an entry point for international climate-sensitive disease efforts (along with local authorities); coordinating interventions aimed at responding to any kind of climate-sensitive disease related event; developing and implementing pre-operational documents such as EWS protocols, needs assessments, and/or contingency plans; and overseeing training and education efforts. Regular communications and interactions with regional bodies and international technical organizations in charge of coordinating and assisting countries on this subject (such as WHO, FAO, OIE) can be ensured through provision of technical advice, equipment, and software.

Approaches to developing these kinds of committees will require investment in dedicated human resources—in other words, individuals who are positioned and capable of bringing together key members of leadership communities to ensure deliverance of these integrated networks and committees. Further, there must be articulated reasons to participate that incentivize leadership and buy-in. Additional resources will then be required to maintain the committees through general staffing and logistical needs.

Information on recommended actions (prevention, control, surveillance, spreading the word, increased awareness, and so on) should always accompany information communicated to stakeholders, and the resource needed to follow recommended actions should be in place. Information should be available on the benefit of mitigation actions in terms of relevant criteria (prevention of productivity or trade-related losses, number of cases prevented, and so on).

INCEPTION PHASE QUESTIONS: COLLABORATIVE HEALTH COLLABORATION COMMITTEES

What are the existing mechanisms of cross-sectoral collaboration at subnational, national, and regional levels, if any, that can be further developed to address climate-sensitive disease issues?
If a committee should be developed, are there any committees in place that could serve as a model?
Which agencies are active in the relevant fields and should be included on the committee?
What professional level should the committee represent?
Should the committee be regional or national?
What tasks should the committee be responsible for and what will the outputs look like?
How often and where should the committee meet?
What will be the relationship of this committee to other committees and international organizations?
What power will this committee have?

Project Component: Early Warning Protocols for Climate-Sensitive Diseases

The development of early warning protocols provides the best hope for unified and consistent responses by policy makers and practitioners on a range of levels. Given the complexity of information coming into decision makers and the need for rapid action, it is imperative to carefully design protocols that outline what actions need to be taken and by whom. Best practices for the development of protocols of this sort can be learned from disaster response colleagues who similarly have long-standing and constantly evolving protocols to meet their demands. Architects of these protocols should be a combination of higher-level decision makers who can ensure the protocols will make it into the appropriate hands, as well as on-the-ground practitioners who are familiar with the capacities of those who will be responsible for implementing them. The "nuts and bolts" of early warning protocols—data flow, interdisciplinary partnerships, calibration, pilot-testing—are imperative to identify early on so that the most comprehensive systems can be developed.

INCEPTION PHASE QUESTIONS: EARLY WARNING PROTOCOLS

What diseases will these protocols cover?
Who will be responsible for generating and updating the protocols?
Who will be responsible for enacting and implementing the protocols?
Who will be the beneficiaries of the protocols?
When should the protocols be used?
Should the protocols be nationally/regionally implemented and should they be universal?
What kinds of response protocols currently exist?

Project Component: Community Climate-Sensitive Disease and ICT User Trainings at Local and Subnational Levels

Similar to professional training and education, the benefits of a well-informed, non-specialist community are many. Outreach and understanding campaigns that engage the public can help them prepare for and respond to disease outbreaks, build trust, and enable community members to connect with appropriate authorities to hasten response time and effectively reduce disease risk. In-school courses, community workshops, educational radio and television programming, and community theater can all be used as avenues for communication.

Conducting a participatory needs assessment can be a helpful first step, as it will identify community interests and priorities and acute needs and the capabilities of the end users' communities. To fully earn the trust of a community on something as abstract as "reducing climate-sensitive disease risks," program implementers will have to prove they are there for the community in less abstract, more meaningful ways—for example, by describing outreach efforts in terms locally understood, such as water/land problems, animal health and production services, and human health and well-being. With the needs assessment results in hand, program implementers can begin designing outreach and education efforts that meet the demands of individual communities.

As with the professional training, community efforts will need to focus on key themes, namely basic understanding of climate-sensitive diseases and why they are important to them and their livelihoods, measures that can be taken to mitigate disease risk (such as eliminating standing water to reduce vector breeding grounds and vaccinating animals), what EWS are and how they can use them, and avenues for engagement with centralized authorities. Resources for community outreach efforts such as these currently exist within similar institutions as those detailed in the professional training section. NGOs such as Vétérinaires Sans Frontières and international organizations such as UNICEF also have capabilities in dealing with community outreach and communication. Contracting NGOs or third-party consultancies will be an important part of this process and will require skilled project managers with an awareness of which actors are best positioned to deliver results.

INCEPTION PHASE QUESTIONS: COMMUNITY TRAININGS

What is the current community understanding of climate-sensitive diseases?
What is the current capacity of the community for understanding abstract concepts like climate-sensitive disease?
What is the literacy of the current population?
What languages do members of the community speak?
How can messages be best targeted to reach most community members?
Which members of the community are most important to target?
How does gender or age affect the communication strategy?
How much trust do community members have for government authorities?
Who can lead these trainings?
What community resources exist in place for trainings?
What new resources will be required?
Where does the community typically get their information?
What kind of ICT access and competencies do members of the community have?

Project Component: Community Support Groups and Knowledge Exchanges

Given the complex concepts associated with climate-sensitive diseases and the introduction of new technology and modalities for reducing their risk, appropriate forums for addressing the issues that arise around them will need to be established. Building community support groups or tapping already existing support groups will aid in this effort, improve usability of the risk reduction tools, and hasten the speed at which knowledge and early warning messages can be communicated. Additionally, these support groups will enable two-way communication—allowing for messages and information to come from centralized authorities while providing an opportunity for community members to convey experiences and understandings so that improvements can be made and success monitored.

Outlining the purpose and aims of each group is key and will maximize the usefulness both to group members and to the project interlocutors who work with them. Different groups will be able to offer different kinds of information that can be used in risk reduction. Farmer support groups, for example, will harness the resources of a demographic that is highly knowledgeable about their animals, the nuances of their local environment, and the interplay of disease and environmental change. Much in the same way, medical professionals and extenders can contribute understandings of demographic and disease outbreak that could be crucial in the development of early warning systems in humans. The community support groups can therefore both benefit from and contribute knowledge to centralized agencies.

INCEPTION PHASE QUESTIONS: COMMUNITY SUPPORT GROUPS
Are there current community support groups or knowledge exchanges in place?
How do farmers typically communicate with one another?
How do farmers typically communicate with governing authorities?
What is the literacy rate of pastoralists?
What kind of ICT access do pastoralists have?

3.4 REQUIREMENT 4: INFORMATION AND COMMUNICATION

Information and communication infrastructure is critical for both harnessing environmental and disease data resources and making them available so that they may be used in the development and use of disease risk management tools. There are two components to this: the action of conveying communication and the technical hardware and software capacities that underlie it. In most countries this will exist to some degree. The specialized functions required by the tools outlined in this report will require additional investment. It is important to note that "more data" is not always the solution. Translating, analyzing, interpreting, and using the data requires significant investment as well—investment without which the better collection of data will be ineffectual.

Project Component: Climate-Sensitive Disease Information Dissemination and EWS Messaging

This component will dovetail closely with the professional community capacity building components listed above. Rather than trainings and workshops, this component will focus on the generation and dissemination of the information literature itself: research and "how-to" publications to professional audiences, and pamphlets and lay resources to the community. To ensure the broadest reach, dissemination of up-to-date literature and EWS messages will rely both on human resources and well-functioning ICT systems. Information can be channeled through traditional means such as town halls, school training, television, radio, and theater, as well as through the new technologic infrastructures that are detailed in the next section (cell phones, websites, and social media).

INCEPTION PHASE QUESTIONS: INFORMATION DISSEMINATION
To whom does this information need to be disseminated?
What are the best avenues for dissemination?
How can new technologies best be used to disseminate information?
How do the target audiences typically consume information?
What technologies need to be in place in order for the best dissemination practices to occur?
How do centralized authorities currently disseminate information?
Can any of this information be disseminated through crowd-sourcing equivalents to dissemination?

Project Component: Climate-Sensitive Disease Libraries

Data collected in the field and properly transferred should be organized in a database management system, where data from different origin and type can be centralized, organized according to international standards in meta-data, checked for integrity, made accessible for analysis, and stored in backups on a regular basis. The data will need to be properly geo-referenced and uniform so they can be applied seamlessly across databases for analyses with data from other sectors, such as data on herd population distribution, other disease risk maps, socioeconomic and welfare indicators, administrative units at varying decision-making levels, and climate information. The IT should allow remote access to data through the network to facilitate analysis and modeling by local scientists. The IT should also allow, through a sufficient bandwidth, easy access to international sources of data and scientific journals. Then the information must be prepared so that it is most useful to the recipient audiences, such as policy and decision makers; this may mean it is summarized according to decision-making administrative units.

It is worth noting that there are, however, drawbacks to open-source data. Ownership, need for historical records, capability, server maintenance costs, and ethical oversight can slow or halt the development of such systems. National Health Information systems in many countries offer lessons to deal with these challenges that must be taken into consideration before launching this component of a project.

INCEPTION PHASE QUESTIONS: CLIMATE-SENSITIVE DISEASE LIBRARIES

Who should be responsible for collecting and collating the data?
What system or repository will be used to store the data?
What institution will be responsible for storing the data?
How will these libraries be made accessible to users?
How can these libraries best be kept up to date?
How will these libraries integrate with other libraries and modalities in a region and globally?
What data sources can be drawn from currently existing resources to create these libraries?

Project Component: Climate-Sensitive Disease Web-Portals

It is important to develop a web-based interface with capacity to support weekly, expert-issued disease risk bulletins inclusive of relevant information for climate-sensitive diseases relevant to a given country X (weather forecasts, satellite images, monitoring products, risk models, and so on). Interconnectivity and scalability of this interface is of paramount importance, as it will ideally need to be deployed in multiple countries within a given region. The Famine Early Warning System Network developed for the U.S. Agency for International Development is an example. Software engineers and local users will need to be trained so that they can effectively use and maintain such a system. If the capacity and the data exist, which they may well in many regions, it will be important to acquire, assess the quality, and use these data.

In many instances, there is sufficient existing data on environment and diseases to inform the development of each of our proposed tools. Global research studies and agencies have been collecting disease and climate data for years and in many cases have made the data freely available to the public; the unfortunate caveat is that the data are not universally accessible due to existing policies (or lack thereof) and structures that restrict their availability in the public domain.

Developing these kinds of data-sharing modalities requires first the engagement of global climate and disease communities. Those that have the data are the gatekeepers to the information; achieving their buy-in is essential to creating networks where data can freely flow.

Examples of Data Partners

International Organizations:

Food and Agriculture Organization (FAO)
Global Early Warning Systems (GLEWS – OIE/FAO/WHO)
International Fund for Agricultural Development (IFAD)
International Livestock Research Institute (ILRI)
World Organisation for Animal Health (OIE)
World Health Organization (WHO)

Governmental and Nongovernmental Agencies, Academia, Thematic Groups, and Institutions:

USAID PREDICT
Adapting Livestock to Climate Change, Collaborative Research Support Program at Colorado State University
Climate Change, Agriculture, and Food Security at CGIAR
GALVMed
Global Initiative for Food Systems Leadership at University of Minnesota
Regional Center for Mapping of Resources for Development (RCMRD)
Trust in Animals and Food Safety (TAFS) Forum
Climate, livestock, and disease researchers

The modalities through which these data can be transmitted will depend on the type of data that is flowing. Short messages and warnings, for example, can be transmitted through basic communication technologies like mobile phones. Complex disease profiles and climate data, however, will require more sophisticated software systems like those described earlier.

INCEPTION PHASE QUESTIONS: CLIMATE-SENSITIVE DISEASE WEB-PORTALS

Who will be responsible for moderating and maintaining these portals?
Who will have access to them?
How can access be assured for a wide user audience?
What technology will be required to access the portals?
Can the portals be accessed with mobile technology?
What are the software/hardware needs of the server?
What are the software/hardware needs of the users?
How will information that passes through this portal be regulated and ensured accurate?

Project Component: Mapping, GIS, and Modeling Software

Risk mapping will take many forms and serve a multiplicity of purposes. As detailed in chapter 2, maps will be developed that depict potential risk areas, health care providers, health facilities, community capacities, disease incidence, environmental variables, and others. Before this can occur, countries must acquire appropriate software to map and integrate these inputs. This can be accomplished through a combination of regional, national, and local efforts so that the most comprehensive visual depictions can be delivered.

In recent years, the development of open-source software has provided a wealth of computer programs that can be used free of charge to store, manage, and process spatial data (such as MySQL: database; Quantum GIS: Geographical Information System; R: statistical analysis and modeling). These software are however somewhat difficult to use for non-experts, and several software and hardware solutions are available off-the-shelf for collecting and mapping vector-borne diseases field data, such as VecMap (ESA/Avia-GIS 2012) or EpiCollect (Aanensen et al. 2009), including the possibility to use these input data to model and predict the distribution of vectors based on a sample dataset (ESA/Avia-GIS 2012). In order to maximize usability of these modalities and safeguard intellectual property rights, data sharing protocols and agreements between the producers and users and spatial data must be in place and enforceable. One approach to this would be embedding a digital object identifier with data repository systems so that it can be cited as a scientific publication and encourage the producers of data to share their data sets and keep the corresponding credit (for example, http://datacite.org).

INCEPTION PHASE QUESTIONS: MAPPING, GIS, MODELING SOFTWARE

What are the software/hardware requirements for hosts/developers of this information?
What are the software/hardware requirements for users of this information?
What institutions will be responsible for hosting/moderating these needs?
How will these resources be kept up to date?
What kinds of personnel needs are required to maintain these systems?

Project Component: Hydro-Met Data Services

Hydro-met services are those that provide meteorological information to users. In many cases, these will be pre-established at a country level. Attaining targeted and needed information, however, will require integration of these services with disease data so that the most relevant values can be achieved. For example, many diseases are susceptible to overnight temperatures and relative humidity; assuring variables are delivered is essential to successful delivery of the risk management tools. Sufficient background research must be conducted to ensure the right kinds of data for the right kinds of users are collected and integrated.

Currently, there are World Bank investments, such as the Agriculture Risk Management Information System, that are integrating this information. One approach to the applied utility of hydro-met services to climate-sensitive diseases is to piggyback on the already established services generated under this project. Doing so would save time and resources while facilitating integration of related efforts.

INCEPTION PHASE QUESTIONS: HYDRO-MET DATA SERVICES

What hydro-met services currently exist in the region/country?
Who has access to these services?
Is there currently any integration of these services with health/veterinary/agriculture services?
What is the current physical infrastructure to support hydro-met services?
What is the current software/hardware infrastructure to support hydro-met data services?

Project Component: Innovative Data Collection Approaches

Recent advances in technology and geo-positioning—many recent mobile phones now have a GPS chip—has resulted in easier data collection. This applies to epidemiological data where the availability of rapid lab kits, or even biosensors in the future, may allow molecular diagnostics to be carried out in the field and epidemiological data to become easier to obtain.

INCEPTION PHASE QUESTIONS: INNOVATIVE DATA COLLECTION

What are the current innovation capabilities in a given country/region?
What are the technical capabilities to support innovative approaches?
Who are the potential users and actors of these collection practices?

3.5 REQUIREMENT 5: PHYSICAL INFRASTRUCTURE

Developing new physical infrastructure or re-appropriating current infrastructure is an important step in building a capacity and community of practice. Permanent or semi-permanent and mobile spaces establish a forum for a range of social, operational, and research-based activities that can contribute to disease risk reduction.

Project Component: Coordinated Human and Animal Health Collaboration Centers

Enhancing collaboration among disciplines is of fundamental importance to reducing climate-sensitive disease risks. Eco-climatic conditions that favor climate-sensitive livestock disease often also favor diseases directly affecting people. For example, climatic conditions favoring RVF also tend to support bursts in malaria vector populations, and RVF epidemics have often coincided with malaria outbreaks. There is much mutual benefit in sharing information on risk mapping, early warning systems, and disease outlooks of CSD-IS with other sectors. Conversely, the cost of entomological surveillance or maintaining meteorological ground observation networks can be shared among sectors.

One approach to fostering this work and dialogue is through the establishment or strengthening of current One Health partnerships or collaboration centers that bridge the gap between animal, human, and environmental health. Establishing centers at regional or national levels asserts the recognition that collaborative health systems are important and effectively offers recurrent political support for the issue if well-executed and delivering good results. Functionally, they offer a forum for collaboration and education within which many stakeholders can engage. Purpose-built physical space dedicated to collaborative health systems work will enable the intellectual exchange necessary to launch the necessary cross-disciplinary collaborations. This effort, however, will necessarily need to coincide with capacity building of human and policy resources so that there will be sufficient support and staffing.

INCEPTION PHASE QUESTIONS: COLLABORATIVE HEALTH CENTERS

What are the best locations for these centers?
Can existing facilities be retrofitted or is there a need for new centers?
How big should they be?
What kinds of spaces should they include?
What kinds of technical capacities should they include?
What kinds of building materials are needed for them?
Where can these building materials be sourced?
What are the human resource needs required to build these centers?
What are the human resource needs required to staff the centers?
What kind of environmental impact will these centers have?

Project Component: Rapid Diagnostic Laboratories

The construction of new or the enhancement of existing rapid diagnostic laboratories will increase the capacity for vector/pathogen surveillance and characterization. Currently, many countries lack the ability to identify vectors associated with particular diseases and also the pathogens that they transmit. In-country laboratories will facilitate cataloguing of vector and disease ecosystems, so that monitoring and surveillance can be done accurately. Additionally, they enable important measurements that can hasten the speed of rapid response mechanisms, thus reducing overall exposures.

The OIE PVS Pathway evaluations reports offer a roadmap to strengthen both this surveillance capacity and the laboratory capacities to better diagnose diseases. Modernized laboratory facilities, the provision of equipment and consumables, and concurrent training on sample taking, packing, and sending outbreak investigation and laboratory techniques will greatly improve the overall capacity of the biological components of climate-sensitive disease reduction.

INCEPTION PHASE QUESTIONS: RAPID DIAGNOSTIC CENTERS

What are the best locations for these centers?
Can existing facilities be retrofitted or is there a need for new centers?
How big should they be?
What kinds of spaces should they include?
Do they need to be of a particular biosafety level?
What kinds of technical capacities should they include?
What kinds of building materials are needed for them?
Where can these building materials be sourced?
What are the human resource needs required to build these centers?
What are the human resource needs required to staff the centers?
What kind of environmental impact will these centers have?

Project Component: ICT Networks

Network availability—both mobile and broadband—will affect the ultimate users of any early warning system. Verifying the presence of networks, the number and types of users, and average costs for network access can determine the ultimate usage and success of a system. Where networks are not available, investment can be an important first step in establishing the absolute basis upon which an entire EWS can be built, as it will enable the exchange of raw meteorological and disease data as well as the related messages that can warn of outbreaks and epidemics. If network connections are non-existent or weak, farmers or extension agents will have to travel to centralized locations to receive data and messages, delaying overall responsiveness and increasing disease risk.

INCEPTION PHASE QUESTIONS: ICT NETWORKS

What is the present telecommunication and mobile coverage in the country or region?
Are the telecommunication networks reliable?
What is the level of broadband penetration?
What is the speed of data transfer through the network?
Does the region have reliable access to electricity?
Are there alternative sources for energy generation?
How much of the population has mobile or broadband coverage and devices to access it?
Do farmers have access to networks?
What are the average usage costs?

3.6 CO-BENEFITS OF IMPROVING INFRASTRUCTURE FOR CLIMATE-SENSITIVE DISEASE RISK REDUCTION TOOLS

Improving basic infrastructures for climate-sensitive disease risk reduction tools can lead to co-benefits for a number of other related sectoral development goals. This is due in large part to the basic requirements that these risk reduction approaches target and the breadth of sectors that they incorporate. Examples of potential co-benefits include:

- Improved agricultural management systems.
- Strengthened hydro-meteorological services.
- Improved livestock productivity and outputs due to healthier stocks.
- Reduced zoonotic diseases impact on human health.
- Job creation and increased per capita GDP.
- Decreased long-term veterinary and human health costs.
- Increased transboundary disease management.
- Sustainable agricultural practices.
- Improved disaster preparedness.
- Improved veterinary services delivery to farmers.
- Improved surveillance and control of vector-borne diseases that affect humans.

Climate change and disease, deforestation and biodiversity loss, ocean degradation and depleted fisheries: each is an example of how humans are affecting the global environment in profound ways, which then in turn affects the collective human ability to live and thrive. Ours is an era of complex global challenges that transect geography and sector. Siloed solutions are no long sufficient. Diverse voice and expertise brought together through partnership and shared understanding is the only path forward. Recognizing this and preparing to act, we can then move at scale and speed toward healthier and more sustainable futures for all.

Spotlighting Other World Bank Resources

Best practices for any of these tools and requirements need not be exclusively derived from this paper. There is considerable ongoing World Bank work that incorporates many of these tools in separate capacities. Searching World Bank databases for any of the key terms will yield resources that can contribute to any component of a climate-sensitive disease risk reduction program.

GLOSSARY

Active surveillance: Method by which special effort is expended to discover disease cases, for example through surveying and searches. Includes purposeful gathering of information. *Cf.* passive surveillance.

Biological model: Hypothesis-driven, mathematical model based on a detailed knowledge of the actual processes underlying the presence of a disease or its vector.

Bluetongue (BT): Vector-borne viral disease that affects primarily sheep, occasionally goats and deer, and cattle; transmitted by various *Culicoides* species of biting midge and can result in severe clinical symptoms, sometimes leading to death.

Climate: In a narrow sense is usually defined as the "average weather," but more rigorously as the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years. These quantities are most often surface variables such as temperature, precipitation, and wind (IPCC 2007).

Climate change: Any change in climate over time, whether due to natural variability or as a result of human activity (IPCC 2007).

Climate-sensitive disease: A disease whose incidence or transmission is affected, positively or negatively, by climate.

Climate variability: Variations in the mean state and other statistics (such as standard deviations, statistics of extremes, and so on) of the climate on all temporal and spatial scales beyond that of individual weather events. Variability may be due to natural internal processes within the climate system (internal variability) or to variations in natural or anthropogenic external forcing (external variability). See also climate change (IPCC 2007).

Disease catalogue: Database containing information about type, biologic profile, and incidence of endemic and epidemic diseases.

Disease outlook: Reports and collections of data that provide long-term projection of disease trends for control and mitigation efforts.

Early warning system (EWS): Comprehensive set of information and actions that alert decision makers of impending harm; inclusive of surveillance; aims to provide short- or mid-term disease forecasting so that appropriate interventions and mitigation efforts can reduce the impact of an epidemic.

East Coast fever (ECF): Vector-borne cattle disease endemic to regions of southern Sudan to South Africa and west to eastern Democratic Republic of Congo; transmitted by several species of Ixodid ticks; caused by the parasite *Theileria parva,* one of six species of Theileria that infect cattle.

Endemic: Situation in which a disease is present or established in a country or area over consecutive time periods.

Epidemic: Situation in which new cases of a particular disease in a given population during a given period are significantly higher than baseline.

Hydro-meteorological data: Data that focus on water and associated energy in the atmosphere.

Normalized Difference Vegetation Index (NDVI): Numerical indicator that uses visible (VIS) and near infrared bands (NIR) of the electromagnetic spectrum to assess whether observed target contains green vegetation; as defined by (NIR – VIS)/(NIR + VIS).

Outbreak: Occurrence of one or more animals infected by a pathogenic agent in a group sharing a common environment (for example, a farm or village).

Passive surveillance: Method by which disease cases are uncovered through routine report. No special effort is extended to discover cases. *Cf.* active surveillance.

Rift Valley fever (RVF): Vector-borne viral zoonosis transmitted by mosquitoes that primarily affects animals, though sometimes also humans; transmitted by a broad range of mosquitoes, although certain *Aedes* species can act as reservoirs during inter-epidemic years. In animals, it primarily affects sheep, cattle, goats, camels, and wild ruminants, resulting in high rates of abortion and neonatal mortality.

Risk map: Application of data to a visual media that facilitates the communication of disease threats.

Statistical model: Mathematical model that uses pattern matching procedures based on known presence of a disease (or vector) over space and/or time.

Theileriosis: Parasitic disease caused by any species of genus *Theileria;* can infect humans and animals.

Transmission: Passing of an infectious disease from one infected individual or group to another.

Vector-borne disease: Infectious disease transmitted from one host to another by an insect or any other living carrier.

Zoonosis: Infectious disease transmissible from animals to humans.

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