One Health for One World:
A Compendium of Case Studies
Veterinarians without Borders/ Vétérinaires sans Frontières – Canada

Veterinarians without Borders/ Vétérinaires sans Frontières – Canada (VWB/VSF) is a Canadian charitable, secular veterinary-based organization, whose mission is to work for, and with, those in need to foster the health of animals, people and the environments that sustain us.

VWB/VSF’s vision is a healthy world for people, animals, and our shared ecosystems. In keeping with this integrated, systemic vision, VWB/VSF is committed to local ownership through participatory and inclusive approaches to development.

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One Health: An Introduction

We live in one world. The anatomy of that world can be characterized through analyses of its many levels of spatial topography; its physiology is comprised of feedbacks among nutrient cycles, human behaviour, and the activities of all species on the planet, as delicate and complex as any physiological cycles described for animals and people. When we see the planet from economic, cultural, biological and spiritual perspectives, we are all seeing the same planet, but from different angles. The picture of the blue planet taken by astronauts from space, now indelibly ingrained in how we as a species think of ourselves, showed us that our health, and the health of our only planet, cannot be sundered.

The recognition that the health of people, other animals and the ecosystems of which we are a part are inextricably woven together and is as old as human culture. More than 2500 years ago, Hippocrates urged physicians to consider where their patients lived, the foods they ate and waters they drank, their lifestyles, and the seasons of the year. In the 1800s, Rudolf Virchow argued that there should be no dividing line between human and animal medicine, and that the causes of human disease were social and political. In the 1900s, Calvin Schwabe traced the roots of Western medicine to the “one medicine” of ancient Egyptian and Dinka priests, and argued that we needed to return to those roots. Similar pathways of understanding can be traced through ancient Chinese, Arab, and Indian cultures.

Much of this integrative thinking was pushed into the background in the mid-twentieth century as many leaders and scholars were lured by the vision that infectious disease had been conquered, and that through basic scientific understanding, advanced technology and unlimited electrical power, humanity had somehow been freed from the bonds of nature.

In the late 20th century, this vision was clearly demonstrated to be an illusion. A better understanding of the physiology of the planet showed us that all was not well. The global effects on the ozone layer of chlorofluorocarbons (CFCs), the appearance in the maternal milk of arctic-dwelling people of persistent pesticides --used to great effect to control malaria in the tropics, and, most recently, the globalization of infectious diseases, the emergence and re-emergence of diseases in animal populations, and from animals into people, have demonstrated once more not only that we are one animal among many, in an inter-connected planet, but that the planet is having health problems.

How to achieve, in policy and practice, one health in an inter-connected world, however, has lagged behind our intuitive recognition and scientific evidence that this should be the right way to proceed. There are many reasons for this, including both a lack of scientific theory to inform the evidence, and a lack of understanding of how we could bring this complexity into the ongoing, necessary decisions and activities of daily political and economic life. Much of the early work for integration in practice grew out of local, community-based initiatives of the Healthy Communities and health promotion movements, and geographically regional efforts such as the International Joint Commission of the Great Lakes and WHO-led activities related to malaria, rabies and other tropical diseases.
Emerging from these localized, largely community-based activities and disease-focused regional projects have been programs in ecosystem approaches to health of Canada’s International Development Research Centre, several international Communities of Practice for Ecosystem Approaches to Health (CoPEHs) and the International Association for Ecology and Health. Parallel to this, in the field of environmental management, there has been a tremendous amount of activity in characterizing the complexity of the biosphere, and initiating adaptive, appropriate responses for management. For instance, the Resilience Alliance is a global network of ecology and social change scholars that has been on the forefront of activities linking our best understanding of how complex social-ecological systems function, how human activities are affecting ecosystem services, and how those impacts, in turn, affect human well-being.

Many of the most promising organizational responses to complex social and ecological problems have come from the world of business management. The International Society for Systems Sciences has for many decades served as a venue where these adaptive, systems-based organizational responses have been presented and debated.

Thus, much of the theoretical and practical groundwork has already been done. We are poised on the verge of moving the integrative agenda to higher levels of policy and global practice. The integrative agenda is moving forward under various names, including (but not restricted to) “One Health”, “One World One Health”, and “Ecohealth”. Each of these terms has been adopted and championed, for slightly different reasons, and with slightly different emphases, by a variety of international organizations.

Ecohealth (Ecosystem Approaches to Health), has been developed over the past few decades by networks of researchers and Communities of Practice, many supported by Canada’s International Development Research Centre. “Ecohealth” is also the name of the official journal of the International Association for Ecology and Health. Ecohealth is comprised of a variety of systemic, participatory approaches to understanding and promoting health and well-being in the context of complex social-ecological interactions.

One World, One Health™ (OWOH) has been championed by the Wildlife Conservation Society an organization based in New York. At an international meeting convened by WCS in 2004, a group of experts stated twelve principles of OWOH which they called “The Manhattan Principles.” The principles affirm the interconnectedness of the health of people, domestic animals and wildlife, and the resilience of ecosystems, and propose forward-looking, adaptive approaches to managing these interactions. OWOH was subsequently discussed and moved forward at a series of in-
International meetings in Beijing and New Delhi on avian and pandemic influenza. These efforts culminated in a joint Strategic Framework document: Contributing to One World, One Health: A Strategic Framework for Reducing Risks of Infectious Diseases at the Animal-Human-Ecosystems Interface” in Sharm el Sheikh, Egypt (2008). The strategic framework was developed and written by the Food and Agriculture Organization of the United Nations, United Nations Children’s Fund, World Health Organization, World Organisation for Animal Health, the World Bank, and the United Nations System Influenza Coordination. Environmental and wildlife organizations were lamentably absent from this document. This was partly redressed by the active presence of the Wildlife Conservation Society (WCS), at an expert consultation undertaken by the Public Health Agency of Canada and held in Winnipeg in March, 2009 entitled “One World, One Health: from ideas to action”. The over-arching goal of the strategic document and its implementation is to address the root causes of infectious disease emergence, rather than simple reacting to diseases as they occur.

Of the three terms, one health has been mostly closely associated with human and animal health organizations both nationally and globally. Thus ecohealth emphasizes integrated practice for human development, OWOH emphasizes the importance of paying attention to ecological and wildlife contexts to promote global health, and one health emphasizes the importance of promoting human health outcomes, particularly with regard to zoonotic diseases. In practice, there has been a convergence of these general notions toward an integrated consideration of public health, animal health and ecological health. While there are differences in emphasis among the organizations espousing one name or another, the underlying premise – that the health of people, wild and domestic animals, and ecosystems share a common fate – is not being contested. For practical purposes, this document uses one health as a generic term to refer to all variations of these integrative global concepts and activities.

As is evident in the case studies gathered here, there is still a tendency for health-related organizations to revert to a relatively simple animal-human dyad, rather than considering the roots of human well-being (and ill health) in the dynamics of complex ecological systems. Nevertheless, these cases represent steps in the right direction.

The global initiative to address the one health of the one world that we share as multiple species is being carried forward through advances in theory and practice around the world. This compendium is intended to bring together stories of some of the initiatives that have been informed by one health thinking, and which have begun the journey toward a more integrative understanding of health and well-being. We hope that this compendium can serve as inspiration that this seemingly Herculean task of promoting one health for one world is, in fact, not just desirable, but also effective in producing outcomes, efficient in resource use, and practically possible in an imperfect world.

A note on the organization of this compendium.

Each case study is organized into four sections:

1. The Disease, which gives basic information about the clinical disease and the infectious agent associated with it;
2. The Animal-Human-Ecosystem Dynamics, which describes why this disease is an appropriate candidate for one health approaches;
3. Response and Conclusions, which sets out ways in which some organizations have responded to the disease using one health principles; and
4. Policy Implications, which suggests some implications for government, business or research policies.

Many people have contributed to the writing of these case studies, some of them having been involved directly in the work described. They are listed in the back of the Compendium. Nevertheless, the editor takes full responsibility for the way in which their work is described in one health terms. All statements in this Compendium are verifiable from scholarly or government documents. Selected references are given in a special section at the back. In a few cases, where statements may have political implications, the original sources are footnoted.
North America and Europe

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Q Fever
Pandemic Influenza H1N1 2009 Virus (pH1N1)

The Disease

The pandemic influenza H1N1 2009 virus (pH1N1) is a new strain of influenza. Prior to 2009, H1N1 primarily affected only pigs; however the pH1N1 virus emerged in humans in April 2009. In June 2009, the World Health Organization (WHO) raised its pandemic alert level to Phase 6, indicating that an influenza pandemic was underway. To date, more than 212 countries have reported laboratory confirmed cases of pH1N1, including at least 15,921 deaths.

Influenza viruses are commonly detected in pigs, which can become infected by humans, birds or other pigs. In fact, pigs represent a mixing vessel in which influenza viruses from different species can swap genes. For at least 80 years, influenza viruses known as “classical swine H1N1” viruses have circulated in North American pigs. This swine influenza is a contagious respiratory disease of pigs commonly occurring in North America, South America, Asia and Europe. Although rare, the illness which is caused by Influenza A viruses can be transferred from pigs to humans normally through close contact with sick animals. In the late 1990s, a series of reassortment events occurred between influenza viruses found in pigs, humans and birds. Mixing of these “triple reassortant North American swine influenza viruses” with Eurasian swine viruses likely resulted in the 2009 H1N1 influenza virus.

The signs of illness are similar in both humans and pigs, and include symptoms such as fever, cough, and runny nose. In humans, the pH1N1 influenza virus is contagious and is spread from person-to-person when an infected person coughs or sneezes. Viruses can also rest on surfaces such as doorknobs, phones and cups, and can be picked up on hands and transmitted when someone touches their eyes, mouth, and/or nose. The risk of being infected with pH1N1 from the consumption of pork or pork products is considered negligible.

Those at high risk for developing complications and at greater risk for severe illness related to pH1N1 includes adults aged 65 years and older, children less than 5 years of age, persons with underlying medical conditions, and pregnant women. In Canada, persons hospitalized and admitted to intensive care units (ICU) due to pH1H1, had a median age of 29 years and 46 years respectively. Of persons who were hospitalized, 20% were pregnant. Of those who died, the median age was 53 years and 82% had underlying medical conditions. Overall, receiving the H1N1 flu vaccine is the best protection against pH1N1.

Animal-Human-Ecosystem Dynamics

Given the global spread of pandemic H1N1 2009, collaborative partnerships were forged nationally, among provinces and territories across Canada, and with international partners. When pH1N1 emerged in Mexico in April 2009, the Public Health Agency of Canada assisted Mexico by testing H1N1 flu virus specimens in its joint human-animal national laboratory and Canadian laboratory scientists and epidemiologists were dispatched to Mexico to help Mexican officials investigate the outbreak. Canada’s missions abroad also provided information to trade partners and importers highlighting the safety of Canadian pork products. Daily coordination and infor-
Information sharing conference calls were being held with Canadian provincial and territorial public health authorities and international partners to address the pandemic.

Health ministers from the G7 countries (Canada, France, Germany, Italy, Japan, United Kingdom, United States), Mexico and the World Health Organization met in Brussels in September 2009 for a special ministerial meeting of the Global Health Security Initiative (GHSI). The meeting focused on effective public health measures to respond to the pH1N1 virus. A statement setting out the common approaches adopted by the G7 countries and Mexico, as well as next steps related to collaborative work on pH1N1 were adopted for a global approach to pandemic management. The fundamental importance of exchanging information and coordinating measures at the international level was recognized, calling for global solidarity in supporting countries around the world to tackle the pandemic.

The Public Health Agency of Canada and Health Canada worked in close collaboration with other national regulatory and public health authorities to respond to the pandemic virus. There has been a global commitment amongst regulatory authorities to share clinical and safety data on H1N1 vaccines in real-time and to rapidly share information on any potential adverse events following immunization.

Other international collaborations included regular reports from countries notifying the presence of the pH1N1 2009 influenza virus in animals to the World Organisation for Animal Health (OIE). According to the OIE, this has shown that disease surveillance in animals and reporting mechanisms function well and, that the majority of OIE Member Countries (including Canada) act in full transparency with the international community.

**Key Policy Implications**

Information from current and past pandemics can provide useful insights for future planning. In particular, open lines of communication and cooperation among those working with animal health in many countries, trade, tourism and human health enable earlier detection and management.

Some of information about the spread of pH1N1 was made available to both professionals and the lay public through a variety of electronic, tracking and mapping systems, some of them available as “smart phone” applications. If handled well, this can facilitate public awareness and support appropriate interventions. Several guidance documents have been put forward by the Public Health Agency of Canada, including clinical, laboratory, animal health and surveillance guidelines to address pH1N1.

While the organizations involved have made many steps in the right direction, what has been largely missing at the policy level is a consideration of the social-ecological context within which this pandemic emerged. Such considerations will be necessary to minimize risks of further similar events.
West Nile Virus

The Disease

West Nile Virus (WNV), a member of the Japanese encephalitis group of viruses, was first identified in Uganda in 1937 and was generally known to cause mild disease symptoms in humans. By the 1990s, the disease was recognized in large areas of Africa and Eurasia, and, after 1999, entered and spread rapidly across North America and throughout the Western hemisphere. Sometime in the 1990s, and with increasing frequency, WNV infections were reported with greater severity, and sometimes fatal neurological signs.

The infection is now known to cause symptoms that vary in presentation from mild influenza-like fevers and aches to severe neurological symptoms, paralysis and death. Some species of birds carry the virus without serious consequences to themselves, and are recognized as the primary vertebrate reservoir for the virus. *Culex* spp. mosquitoes are the primary vectors that carry the virus from animal to animal, and some species may pass the virus through their eggs from one generation to the next. Both infection and symptoms of a wide range of severity have been reported in a variety of birds, mammals, reptiles and amphibians. The virus has now been isolated from more than 61 species of mosquitoes, 1300 species of birds, and 130 species of non-avian vertebrates.

Animal-Human-Ecosystem Dynamics

The entry of WNV into North America in 1999 has been attributed to the importation of infected birds from the Middle East, accidental importation of infected mosquitoes or larvae in cargo, or the movement of infected people. The rapid spread and maintenance of the infection across North America has been influenced by the nature of the virus itself and its ability to infect many species, changing weather patterns, landscape ecology, urban planning (including the placement of lawns and trees, and design of storm sewers), interactions among species, migration of people and other animals, lack of immunity in humans, prior health status and behaviour in relation to landscapes and other species.

Response and Conclusions

The introduction into Canada of this disease, involving mosquitoes and birds, and with a range of clinical presentations, posed serious scientific and organizational challenges for response. First confirmed in August, 2001 in a wild bird in Ontario, by 2002 cases in both horses and

people were being reported in Ontario and Quebec, and by 2003 cases were reported in mosquito pools, birds, horses and humans in Manitoba, Saskatchewan and Alberta. Although at least one senior government scientist confessed that they were surprised by the speed and size of the spreading epidemic, and were “nearly blindsided”\(^1\), the operative word being “nearly”, Health Canada actually moved very quickly. They convened a West Nile Virus National Steering Committee (NSC) which issued a National Response Plan in July of 2000 with input from representatives of government ministries responsible for environment, pest control, public health, wildlife and agriculture, and coming from different levels of government and academia. Within a year (by 2002) the NSC issued national guidelines which urged the “dedicated cooperation and participation” of all levels of government as well as community organizations and the general public. By 2003, Ontario, the “ground zero” for the epidemic, had put forth a “Preparedness and Prevention Plan” which involved government ministries of health, agriculture, environment and natural resources, universities and the Canadian Cooperative Wildlife Health Centre.

With input from the public, including the reporting of dead birds to appropriate authorities, the Public Health Agency of Canada (PHAC), provincial and territorial Ministries of Health, the Canadian Cooperative Wildlife Health Centre, Health Canada’s First Nations and Inuit Health Branch, Canadian Blood Services, and Héma-Québec have built an integrated national surveillance network. Based on the information gathered PHAC produces a variety of reports and maps, summarizing West Nile Virus activity at the national level and works with provincial and territorial health partners in public health messaging.

*Key Policy Implications*

Clear lines of communication and free sharing of data from multiple jurisdictions and organizations are important for rapid, effective, and sustainable responses to complex emerging disease problems. After the emergence of WNV in the northeastern USA in 1999, Health Canada responded quickly to develop and coordinate surveillance, testing, response and control activities as well as communications products in order to prepare for the possible emergence of WNV in Canada in 2000. This approach should be considered a template for issues that involve multiple sectors, disciplines and levels of government. Organizational issues need to be sorted out before a crisis, and be put into place as a permanent feature of relations among government departments, and between governmental and non-governmental institutions.
Enteric Bacterial Pathogen and Antimicrobial Resistance Surveillance

Background

Antimicrobial resistance (AMR) is a growing health concern that threatens animal and human health worldwide. Resistant bacteria are those that are able to replicate in the presence of antimicrobials at levels that normally suppress growth or kill the bacterium. Resistance can be either intrinsic due to naturally occurring characteristics of the bacteria or acquired. Bacteria can acquire resistance through mutation of pre-existing genes or through transfer of resistance determinants from other bacteria (horizontal gene transfer). Selection for resistance against one type of antimicrobial may also co-select for resistance against other, unrelated antimicrobial agents.

The Animal-Human-Ecosystem Dynamics

Antimicrobial use (AMU) in animal and human populations is considered to be the major driver of AMR emergence and persistence. For example, this is demonstrated by the identified link between avoparcin use and resistance to the antimicrobial vancomycin in Europe. A host of local factors including veterinary and human patterns of antimicrobial use, attitudes towards antibiotic usage, and the degree of interactions between people and animals, play an important role in the development of AMR. However, the international movement of people, animal and animal products means that AMU and the accompanying regulations in one country can affect the efficacy of a particular antimicrobial in another.

Figure 1, The intersection of enteric agents, animals and humans, and the environmental factors that influence the occurrence of zoonotic bacterial infections and the emergence of antimicrobial resistance

C-EnterNet: Zoonotic enteric pathogens
CIPARS: Zoonotic enteric pathogens and commensals, and antimicrobial use

Antimicrobial Use
- Physicians
- Veterinarians
- Farmers

Animal Husbandry and Management

Population density

Economic/Trade

Bacterial

AMR

ANIMAL
- Companion
- Food animals
- Wildlife

HUMAN
- Healthy
- Young/Elderly
- Immuno-suppressed
- Occupational exposure

ENVIRONMENT
Infections caused by enteric pathogens are common in Canada. Although most infections result in sub-clinical or mild illness, they can cause severe disease, particularly in children and immuno-suppressed individuals. Many of the enteric pathogens that infect Canadians are zoonotic in origin (Figure 1). Disease caused by resistant enteric bacteria may be more difficult, more expensive and take longer to treat. Selection for resistant bacteria has important implications for the long term efficacy of available antimicrobial drugs and acquisition of resistance may also affect the pathogenicity and epidemiology of zoonotic bacterial agents. The impact of AMR on the health of Canadians cannot be fully evaluated without considering the transmission and dissemination of the bacteria themselves.

Response and Conclusions

The Public Health Agency of Canada supports two complimentary surveillance programs that take a holistic approach to enteric bacterial disease and AMR (Figure 1): 1) the Canadian Integrated Program for Antimicrobial Resistance Surveillance (CIPARS) monitors epidemiological trends in resistance among zoonotic bacteria and in AMU, and 2) C-EnterNet monitors trends in zoonotic pathogens at sentinel sites (Figure 1). Both programs collect data from animal and human sources but where CIPARS collects broad nation-wide data, C-EnterNet operates through intensively sampled local sentinel sites. Both programs work with multiple stakeholders (producers, agricultural industry groups, food retailers, other federal agencies, provincial governments, animal and human health laboratories, and researchers at various universities), to generate and collect data that better informs understanding of the transmission of zoonotic bacteria, risk factors for infection, and the drivers of AMR and AMU. There is a great deal of information sharing between CIPARS and C-EnterNet, other federal agencies and international bodies, and results from both programs are publicly accessible. Both programs provide a research platform that aims to identify and understand how livestock husbandry and production methods, environment, wildlife, companion animals, exotic pets, and socio-economic factors and high-risk human populations are affected by and contribute to zoonotic bacterial infections and AMR (Figure 1).

Social sustainability is a critical tenet of an integrated approach to AMR. Emergence of resistant bacteria may have large economic implications by reducing the efficacy of certain antimicrobials, and thereby increasing the cost of infection (for example, longer hospital stays), and through the consequential changes in AMU for disease treatment and prevention in people and animals. Recent analysis of CIPARS data identified a link between ceftiofur (an antimicrobial of high importance to human medicine) usage in poultry and ceftiofur-resistant *Salmonella Heidelberg* isolates obtained from people and chicken meat in Québec. Because *S. Heidelberg* is a common serotype that can cause disease in people, this finding had important potential implications for human health. Communication of this information led to a voluntary ban on the use of ceftiofur in 2005 and the ongoing collection of surveillance data provided the opportunity to follow trends in human and animal infection and in AMR. Once adequate evidence has been collected, this information can then be used to inform policy on the appropriate use of antimicrobials. Surveillance data can also be used to provide guidance to physicians and veterinarians in their selection of appropriate antimicrobials and how these drugs are dispensed.
Key Policy Implications

C-EnterNet and CIPARS have successfully operated for 5 and 8 years, respectively. Their success had led to an expansion of their surveillance network to include additional agricultural commodities in CIPARS and a new C-EnterNet sentinel site. A large part of this success and the sustainability of these programs can be attributed to ongoing collaborations with multiple stakeholders and the flexibility of all the partners to adapt to changing needs and conditions. These programs serve as a model for how government agencies can address, in an integrated fashion, urgent problems and issues that cut across multiple departments and jurisdictions.
Hantavirus

The Disease

Hantaviruses were first identified as the cause of haemorrhagic fever with renal syndrome (HFRS) in Europe and Asia, and, in the 1990s, as the cause of hantavirus cardiopulmonary syndrome (HCPS) in the Americas. In East Asia (China and the Korean Peninsula), hundreds of thousands of people are reported to be infected each year. The “Sin Nombre” strain of hantavirus was first identified as causing a severe disease outbreak of HCPS in 1993 in the Southwest region of the United States; however its range has now been described as including all of the Americas. Humans can contract hantavirus infections if they are exposed to infected saliva, feces or urine from rodents, which are the primary reservoirs worldwide. In North America, deer mice (Peromyscus maniculatus) are the main reservoirs, although rice rats, cotton rats and white-footed mice also transmit the virus. The rodents excrete the virus in their urine, saliva, and droppings. A person may be exposed to hantavirus by breathing contaminated dust from places where these rodents live. The geographical range of hantavirus coincides with the habitat of the deer mouse and other wild rodent hosts, and it is more frequently found in rural or semi-rural areas.

Early symptoms of HCPS include fatigue, fever and muscle aches. These may also be accompanied by headaches, dizziness, chills, and abdominal problems, such as nausea, vomiting, diarrhea, and abdominal pain. More advanced symptoms appear between 4 to 10 days and include coughing, shortness of breath, pulmonary edema and, possibly, cardiac failure. There is no specific treatment for HCPS, however early recognition and hospitalization in an intensive care unit aid with recovery. Although the frequency of HCPS is relatively rare in North America, the disease is fatal in approximately 45% of the cases.

Animal-Human-Ecosystem Dynamics

Given the transmission route of the hantavirus, the occurrence of the disease is closely related to the presence and density of wild rodent populations in a given region, which in turn are influenced by availability of food. An analysis of the environmental and climatic conditions associated with the 1993 HCPS outbreak in the Four Corners region (New Mexico, USA) found that the outbreak was preceded by an unusually wet winter caused by a strong El Niño event. The heavy rains likely boosted the food supply (vegetation and insects) available to the rodents, leading to a 20-fold increase in their population, thereby increasing rodent-to-rodent contact and the propagation of the virus. Soon afterwards, the rodent population surpassed its carrying capacity, the region experienced colder than average temperatures and precipitation plummeted. These conditions might have stressed the already too-large rodent population and pushed the animals to seek food sources and refuge inside homes, outbuildings, and barns, thus increasing rodent-to-human contact. This pattern, above average rainfall followed by cooler and drier conditions, also preceded an outbreak of HCPS in western Paraguay in 1995 to 1996.

There are also social factors that affect the likelihood of suffering HCPS. Some studies have linked exposure to the virus with activities such as farm work, threshing, herding or sleeping on
the ground. However, the main cause remains domestic or peri-domestic exposure to rodents. A large percentage of hantavirus infections have occurred in persons of lower socioeconomic status because poorer housing conditions and agricultural activities favor closer contact between humans and rodents. However, suburbanization, wilderness camping, and other outdoor pursuits have spread infection to persons of middle and upper incomes.

Response and Conclusions

Given the lack of vaccines, current research focuses mainly on disease detection and prevention. Studies increasingly favor longitudinal, multi-level and multivariate analysis of factors that could signal a potential risk. Figure 1 maps some of the linkages among components affecting deer mouse population and human disease and provides a quick overview of the uses of different kinds of surveillance. Information from levels 1 and 2 (and the modifiers in the left column), may provide long lead times, but uncertain risk predictions. This is useful for land use planning and estimating budgets for health agencies. Focusing on levels 5 and 6 provides greater accuracy but the information is less useful for long term planning.

Health agencies have typically worked together across jurisdictions for interventions. For instance, during the Four Corners outbreak, the New Mexico Department of Health, the Arizona Department of Health Services, the Colorado Department of Health, the Utah Department of Health, the Indian Health Service, the United States Centers for Disease Control and the Navajo Nation Division of Health collaborated to identify, diagnose and contain the virus. Navajo medical traditions were also considered, as their oral tradition contains accounts of the 1918 and 1933-34 outbreaks, which occurred after wet summers made the harvest plentiful. The connection between environmental and social conditions and the occurrence of disease is clear. However, while ecologists and animal health specialists have worked on issues related to the natural ecology of the disease, their involvement in defining and responding to the problem has often been indirect, through health departments.
Key Policy Implications

From a one health perspective, much of what is important for hantavirus management is directly relevant for managing other rodent-borne diseases such as leptospirosis, plague, and typhus.

There is a need to promote and support integrated research and monitoring of synergistic effects and disease dynamics resulting from the interaction between climate, land use change, housing and rodent populations and to integrate an understanding of rodent-associated infections into planning for land use and housing.

Public education of front-line health workers, based on monitoring of level 1-3 variables, should include recognition of the disease and its causes, and of high risk groups on managing interactions with rodents (use of masks, for instance, when cleaning old buildings).
Waterborne Diseases: An Outbreak of *Escherichia coli* in Walkerton, Ontario, Canada

*The Disease*

The bacterium *E. coli* lives in the intestines of humans and other animals as a normal inhabitant. Of the numerous strains of *E. coli*, the O157:H7 strain may cause diarrheal illness in humans. Approximately 15% of children, and a much smaller percent of adults, with diarrhea caused by *E. coli* O157:H7 suffer from a life threatening condition called Hemolytic Uremic Syndrome. Roughly 5% of persons with Hemolytic Uremic Syndrome die.

Walkerton is a rural town with a population of approximately 5,000 people in the province of Ontario, Canada. In May 2000, *E. coli* O157:H7 contaminated the municipal water system resulting in approximately 2,300 people becoming ill and at least seven deaths.

The social-ecological system within which the largest waterborne outbreak in Canada occurred included events and circumstances pertaining to animals, the environment, humans, regulatory policies, and economics. An integrated one health approach attempts to understand the interrelatedness of these components in order to obtain an overall view of the system and thus be able to better maintain the balance of health. The following provides a brief description of the role of each of the components in the Walkerton outbreak.

*Animal-Human-Ecosystem Dynamics*

Cattle are the main reservoir for *E. coli* O157:H7, although other animals may host the bacteria. The bacteria are most frequently transmitted to humans through food contaminated with cattle manure (e.g. ground beef), however, transmission can occur by direct contact with animals and via water.

The bacteria were found to be present in the cattle on a farm that bordered the location of one of the wells that provided water to the municipal water distribution system. Heavy rains resulted in the bacteria being carried underground with subsequent direct entry into the well.

The municipal water distribution system was operated by the Walkerton Public Utilities Commission (PUC). It was shown that the PUC operators did a number of improper operating practices, including failing to use adequate doses of chlorine, failing to monitor chlorine residuals daily, and making false entries about residuals in daily operating records. The operators knew that these practices were unacceptable and contrary to the Ontario Ministry of the Environment guidelines and directives.

Additionally, it was shown that the Ontario government did not adequately enforce their water quality standards. Cutbacks in government funding for regulatory practices pertaining to water were believed to have contributed to the problem.

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Response and Conclusions

The response to the outbreak was unprecedented in Canada. It involved municipal, provincial and federal levels of government, including numerous departments within each level of government, as well as involvement from the private sector. It was estimated that the Walkerton water tragedy cost a minimum of $64 million (CDN) in direct, tangible costs, and up to 155 million when human suffering and lives lost were considered.4

Subsequent to the outbreak response, the provincial government ordered a public inquiry that documented the events surrounding the outbreak and made recommendations for improvements to the main components of Ontario’s water delivery system, including;

- Source Protection – a multi-barrier approach including watershed-based protection of drinking water.
- Standards and Technology – effective standards and technology for treating water and monitoring water quality.
- Municipal Water Providers – must be accredited and have an approved operational plan.
- Provincial Oversight – two government branches created for watershed planning and water systems oversight, respectively that should be sufficiently resourced.

Key Policy Implications

The approach taken by the inquiry recommendations addressed many of the major human-animal-ecosystem dynamics of the water system, from protection of the source of water in the watershed through to the oversight of water systems by the government. To the extent that the recommendations of the judicial inquiry are heeded, this can serve as a lesson – and a model - for why and how good communication, oversight, ecological thinking, and redundancy of activities can prevent similar outbreaks in the future.

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The Emergence of Neotropical Cryptococcosis in British Columbia

The Disease

*Cryptococcus* is a form of environmental fungus which, historically, only caused sporadic cases of illness in people and terrestrial animals. The primary site of infection is the lung; *C. gatti* can lead to pneumonia or formation of cryptococcomas (tumour-like growths of fungi). The infection can spread to other organs, notably the central nervous system where it causes meningitis or brain cryptococcomas. Animals have tended to have higher rate of central nervous system (CNS) infections than people and a higher rate of death. Respiratory infections are the more common manifestation in people. The usual species of *Cryptococcus* found in BC, which is distributed worldwide, causes mostly CNS infections in immunocompromised persons, particularly HIV-infected persons. Worldwide, British Columbia has the largest documented population of people infected with *C. gatti*. Nevertheless, the number of cases and deaths in people remains relatively low (approx. 300 cases in BC). The number of cases in animals exceeds that of people; but the ability to count animal cases has been impeded by the fact that official surveillance has not been undertaken for this disease.

Animal-Human-Ecosystem Dynamics

In 2001, the epidemiology of cryptococcosis in British Columbia changed. A porpoise was diagnosed with *C. gatti* during an autopsy conducted by the Centre for Coastal Health (CCH). The diagnosis was unusual in a wild marine mammal. In consultation with the head of the provincial diagnostic lab, it was found that private laboratories were reporting an increased number of cases of this disease in dogs and cats. The CCH investigator shared these observations with the local medical health officer who also reported that they were detecting an unusual number of cases in people. Taken in isolation, the case in the porpoise, the increased cases in pets and in humans were not sufficient to cause alarm. However, a comparison of the distribution of cases indicated a disease cluster in the same region of Vancouver Island, and signaled an outbreak. A collaborative investigation of the CCH veterinarians, BC Centre for Disease Control, UBC School of Occupational and Environmental health and Vancouver Island Health Region quickly revealed this to be a tropical strain of *Cryptococcus* that had never before been reported in Canada. Previously, *C. gatti* had been reported from primarily tropical and subtropical regions. The investigation continued to find new cases, expanding the diversity of species involved (dogs, cats, llamas, porpoises, exotic birds, horse, ferrets, squirrels and people) and was able to document the slow spread of this infection. *C. gatti* was found in the environment in 2002 colonizing various species of trees and soil and has been recovered from water and air.

Response and Conclusions

Combined medical and veterinary investigations examining the life histories and activities of all the species involved quickly revealed that this disease had an airborne route of transmission. The fungus was found to cluster in the environment in a single biogeoclimatic zone, leading to speculation about the role of climate change in the emergence of this disease. Evidence sug-
gests that transmission of the disease on Vancouver Island occurred when the fungus was carried on inanimate objects such as car wheels and people’s shoes. Considerable public anxiety emerged as the first cases of deaths in humans were reported. As the disease gained national and international media attention, tourism and real estate sales dropped dramatically. Within a few years, the fungus was found in the lower mainland of BC, with cats being the first species to demonstrate disease. The pathogens as well as human and animal cases have now spread as far south as Oregon (USA).

The capacity to quickly mount an investigation that combined medical, veterinary, diagnostic, public health and environmental microbiology expertise resulted from a pre-existing professional social network which was facilitated by a research unit called the Animal Determinants of Emerging Disease Research Unit. This unit was housed at the CCH which has operated in the province for 14 years with the mandate to link human, animal and environmental health. The investigation touched on a breadth of issues from microclimate and fungal dispersion; managing a new environmental risk in a manner that balanced infection risk reduction with the benefits of outdoor activities; the use of animals as sentinels for regional spread of this agent; the discovery of new fungal virulence factors, the relationship between local environmental management and infection risks and the methods to link and integrate local needs for recreation and economy with the public fear of exposure to a relatively rare infection.

The detection and response to the outbreak of *C. gatti* on Vancouver Island underscores the importance and necessity of collaboration for a variety of reasons. Firstly, the emergence of this disease and its ecology was documented in detail and clearly elucidated by linking the human, animal and environmental data. This contributed significantly to the international literature on the epidemiology of *C. gatti*. More importantly, the collaborations increased the confidence of the public in public health messages. The teamwork used in this project helped trainees and established investigators develop an expanded view of how one could obtain and use the skills and knowledge of a diverse group of individuals in a real world outbreak scenario to achieve more rapid and effective public health outcomes.

*Key Policy Implications*

The history of past collaborations among the participants in these investigations created trusting relations between the investigators from both private and public sectors and allowed for sharing of information, and more effective decision-making. In the absence of these collaborations, the origins, mechanisms of spread, public communications and disease management could not have occurred as quickly, accurately or effectively as if each group had worked independently. All of the investigators in BC were linked to academic units and deployed graduate trainees in the investigation. This serves as a model for trainees and highlights the power and value of collaborative field investigations. Support for developing such networks should be enhanced through government, research, and private channels before crises occur.
Lyme Disease

The Disease

Lyme disease is the most prevalent vector-borne disease in the temperate zone. It is a zoonosis caused by species of the bacteria *Borrelia burgdorferi*. The bacteria are maintained in transmission cycles involving tick vectors and wild animal hosts (rodents, birds and medium sized wild mammals). Although it has a wide geographic distribution across the northern hemisphere, including Europe and Asia, much recent concern has focused on North America. *B. burgdorferi* causes little in the way of disease in wildlife populations, possibly due to its long co-evolution with wildlife hosts. Domesticated animals and humans may suffer fever, headache and a target-like skin rash where a tick has bitten; however, if untreated, the infection can to spread to the heart, joints, and nervous system. In the 1970s, an outbreak of the disease was identified by a group of mothers in Lyme, Connecticut, who were concerned about an unusually high rate of diagnosed rheumatoid arthritis in their community. As a result of a combination of parental persistence and scientific responsiveness, the ecology and extent of this re-emerging disease was uncovered in North America.

Animal-Human-Ecosystem Dynamics

Lyme disease is transmitted to humans by certain species of ticks from wildlife. Although the geographic range of the bacterium causing Lyme has spread and contracted for millennia with environmental change (i.e. interglacials) in Eurasia and North America, the Lyme epidemic in the USA was likely caused by changes in land use that were human-induced. For instance, farm land reverted to woodland as the result of changing economics and policy in agriculture. This caused increased deer and tick populations and a culture of outdoor recreational activity in these woodlands enabled greater interaction of people with infected ticks. Evolution of *B. burgdorferi* for different reservoir hosts has resulted in genetic variants that cause different disease entities in humans.

Changes to biodiversity are likely to have impacts on Lyme disease risk by affecting the abundance and range of reservoir hosts in any given locality. Although this has become a paradigm for conservation and infectious disease risk, the direction of effect is as yet unpredictable. Emergence of Lyme disease risk in North America is being driven by a warming climate, which enhances the survival of the tick vector.
Response and Conclusions

Understanding the environmental determinants of Lyme disease helps to predict the risk of exposure and assists public health professionals in making decisions. For instance, communication between managers of wilderness parks, the general public, hunters, dog owners and public health officials allows disease control to be put in place in advance of an epidemic in humans. Understanding links between ecological processes and disease entities allows more precise understanding of the links between animal, environmental and human health and prediction of effects of environmental changes. Mothers often notice unusual outcomes in their children well before official surveillance systems. The same is true for farmers and hunters noticing oddities in the animals they work with or hunt.

Key Policy Implications

Although the agents that cause diseases have evolved over many millennia, with minimal effects on human and animal populations, recent rapid changes in climates, landscapes, and how people interact with their environment have been associated with the emergence of more severe diseases. Thus populations who live near changes in land use (urbanization, encroachment into wilderness, abandonment of farms, intensification of agriculture) need to be monitored for changes in health outcomes. By involving local people in surveillance and response, and investigating their concerns seriously, policy makers are less likely to be surprised by new diseases, and will be more able to respond quickly and effectively.
Variant Creutzfeldt-Jakob disease / Bovine Spongiform Encephalopathy (vCJD/BSE)

The Disease

Bovine spongiform encephalopathy (BSE) belongs to a group of infectious brain diseases called Prion Diseases. The infectious agent is not a traditional microbe but rather an aggregate of misfolded protein (prions). Prions are very resistant to destruction, a characteristic that has had enormous medical, agricultural and environmental implications. Prion diseases can affect a number of species including humans (Creutzfeldt-Jakob disease, variant Creutzfeldt-Jakob disease), cattle, sheep and goats (scrapie), deer and elk (chronic wasting disease; CWD). The characteristics of the disease can vary from species to species, however, in all cases, prion diseases are characterized by long periods of infection (years to decades in humans). During the majority of the infection, the animal or human does not exhibit clinical symptoms until the end of the disease process; the disease causes the destruction of brain cells which ultimately results in death of the infected individual. The disease is always fatal; there is no treatment or recovery, nor is there a vaccine. In humans, prion diseases can be categorized into three forms. The most common (1 per million per year) are the sporadic forms that have not been linked to any external cause. Inherited forms (15% of human prion disease) are caused by having a defective copy of the prion protein gene. The third category is acquired (accidental) prion disease resulting from medical accidents, cultural practices (kuru, transmitted by ritualistic cannibalism) and consumption of BSE-contaminated foodstuffs.

The first cases of BSE were identified in United Kingdom in the mid 1980’s. Although the absolute number of cases of BSE is influenced by the amount of surveillance for the disease (Canada for example, tests more animals than the USA), the vast majority of BSE occurred in United Kingdom (approx. 200,000 documented cases). The disease has been detected in virtually every country in Europe (at considerably lower levels than United Kingdom), Japan and North America. In North America, there have been 19 documented cases of BSE (Figure 1), with the majority occurring or originating in Canada (two atypical BSE cases have been identified in the USA.).

One unfortunate characteristic of BSE is its ability to infect other species, including humans. Variant CJD (vCJD, “human BSE”) is clearly caused by BSE, presumably by consumption of BSE-infected beef. The number of cases of vCJD has been relatively low (fewer than 200 vCJD cases worldwide, the majority in United Kingdom) and declining (Figure 2). The average age of onset of the disease is roughly 29 years. These individuals were exposed to BSE many years ago. It is not clear why this age group is more susceptible to the disease or if the disease will start to appear in other age cohorts. There is, in addition, a strong genetic component to the disease. Victims of the disease have a specific genetic background that is present in about 40% of the healthy population.

Sheep scrapie, another prion disease, has been present in Europe and England for over 100 years and now has a world-wide distribution (with the exception of Australia and New Zealand). Although the disease remains a persistent agricultural problem, there is no evidence that scrapie causes disease in humans. Eradication efforts over the years have been largely
ineffective. Although the abundance of sheep scrapie in flocks is not high, the disease has proven extremely difficult to eradicate. Scrapie prions can persist in the environment for years and remain a source of future infection. Sheep scrapie is believed by many scientists to be the source of BSE infection as well as CWD. CWD is localized almost exclusively in North America (Korea had a brief outbreak of the disease, resulting from the importation of an infected elk from Canada\textsuperscript{5}). The disease occurs in elk, mule deer, white-tailed deer and moose. It is present in farmed cervids and in free-ranging animals. It is the most contagious of the prion diseases. Originating in Colorado and Wyoming in the mid 1960’s, the disease has now spread to 17 states as well as Saskatchewan and Alberta. The spread of this contagious disease has been exacerbated by the unintentional transportation of infected cervids in game farms. There is no means of controlling CWD. Although relatively little is known about the potential transmission of CWD to non-cervids, there is, currently, no evidence that it presents a human health threat.

*Animal-Human-Ecosystem Dynamics*

The vast majority of BSE (“classical” BSE) is caused by the inclusion of infectious prions in cattle feed. The source of this infectious material is meat and bone meal, a feed supplement originating from rendered (heat treated) cattle and sheep carcasses. This would appear from one perspective to have been an efficient recycling of otherwise wasted protein. The presence of scrapie in sheep, and interactions among changes in rendering processes related to economic and market incentives were important in the emergence of the disease. The heat treatment was not sufficient to inactivate prions in infected carcasses with the result being the unintentional feeding of huge numbers of cattle infected material.

*Response and Conclusions*

Recognition of this source of infectivity resulted in a two food bans, a ruminant to ruminant feed ban (implemented in United Kingdom in 1988 and in Canada and USA in 1997) followed by a more complete ban in which specified risk material (SRM) protein\textsuperscript{6} is excluded from any animal feed, including that for pets (implemented in Canada in 2007, USA 2008).

The increased surveillance for the disease has also identified “atypical forms” of BSE. These atypical BSE cases have only been identified in very old cattle and appear not to be caused by the consumption of infected material but rather be a spontaneous form. Much less is known about the characteristics of these atypical diseases, including the ability to transmit to other species.

*Key Policy Implications*

While the current management of BSE and vCJD through rigorously applied feed bans and targeted surveillance seems straightforward, our understanding and management of BSE and its human consequences has required systemic integration of information from basic researchers, practitioners, private businesses and policy makers from animal, human and environmental fields. This disease provides important lessons on how and why such a range of information can

\textsuperscript{5}The referenced manuscript is coauthored by Dr. Aru Balachandran, a CFIA prion disease scientist. Sohn et al., 2002 A Case of Chronic Wasting Disease in an Elk Imported to Korea from Canada. J Vet Med. Sci 64:855-858.

\textsuperscript{6}SRM is defined as the distal ileum of cattle of all ages; and the skull, brain, trigeminal ganglia, eyes, tonsils, spinal cord and dorsal root ganglia of cattle 30 months of age or older. The 2007 feed ban restricts SRM from being fed to animals and pets as well as being included in fertilizers. A summary of the Canadian regulations is presented at the CFIA website (http://www.inspection.gc.ca/english/animal/health/animal/bovine/srm/enhren/enhr/enhrene.shtml).
be managed to make policy and management decisions, and what the unintended consequences of other decisions in complex agrifood systems might be.

Figure 1. BSE by year in North America. http://www.cdc.gov/ncidod/dvrd/bse/

Figure 2. Variant CJD (“human BSE”) deaths in Great Britain. http://www.cjd.ed.ac.uk/figures.htm
Q Fever

The Disease

Q Fever is caused by a rickettsial-like organism, *Coxiella burnetii*, that invades mammalian cells and reproduces inside them. It may be carried by a wide range of non-human species, from cats and cattle to wild hares, but is best known for causing outbreaks of abortion (called "abortion storms") in sheep and goats. In between these outbreaks, it often appears to stay quiescent and causes no particular problems. The organism is shed in the birthing fluids at the time of parturition; the tissues then dry and the organisms are aerosolized. Human outbreaks can often be related to some combination of infected animals, dust, and wind patterns. Clinical signs vary from place to place, probably depending on particular strains of the organism. In the Maritimes of Canada, pneumonia seems to be the main disease; in other places, it is hepatitis, diarrhea, or general “flu-like” symptoms. As a chronic condition, *coxiella* can stick to heart valves and cause a debilitating endocarditis.

Animal-Human-Ecosystem Dynamics

The agent appears to occur nearly everywhere, and can infect a wide range of birds, mammals, and arthropods, some of which can spread it through their feces. Livestock rearing practices, climate, wind patterns, seasonal changes, human interactions with animals all influence when and where outbreaks occur. Human cases have occurred through drinking unpasteurized milk; outbreaks have occurred in hospitals where sheep were used for research, among people playing cards in a room where an infected cat gave birth, and at agricultural fairs, where infected but not clinically ill animals were brought for show. However, transmission of the infection from animals to people does not always require such close physical contact. In 1983, several hundred people in Switzerland became ill; they lived in a valley near a road along which sheep were being moved from mountain pastures to their home villages. An outbreak in the United Kingdom in 1981 was attributed to dust and manure from farm trucks driving through urban areas. Beginning in 2007, increasing numbers of human cases of Q Fever have been reported from the Netherlands. By 2010, several hundred people had become ill, and six have died.

Response and Conclusions

Responses in the Netherlands have been targeted at culling tens of thousands of goats and sheep from flocks that tested positive for the infection, prohibition of breeding of sheep and goats, compulsory vaccination, and public education. There has been a shortage of vaccine, and consequently the vaccination program could not be fully implemented. Prohibition of breeding small ruminants results in a major hardship to those whose livelihoods is based on selling milk products from these animals. Furthermore, tests of sheep flocks and cattle herds in Canada and the USA have demonstrated that a high level of apparent infection in flocks is related to measurable clinical outcomes in the animals. In February, 2010, the Ministry of Agriculture, Nature and Food Quality in the Netherlands, together with the European Food Safety Authority and the European Centre for Disease Prevention and Control hosted a conference. The conference, titled “One Health in relation to Q-fever, in humans and animals”, brought together experts from
countries around the world. The explicit one health response to Q Fever in the Netherlands is remarkable, in that involved a wide range of stakeholders from a variety of disciplines and jurisdictions, and drawing on the best available global knowledge. What is missing from many of these efforts, however, is a full involvement of ecologists and environmental scientists; hence there is no acknowledgement that recurrent disease outbreaks may reflect underlying social-ecological systemic problems with the structure of livestock agriculture in many countries.

Policy Implications

The response to Q Fever in the Netherlands would benefit from involvement by ecologists, and could be used as a model of the kinds of sustainable organizational links that can respond to newly emerging situations. In this way, the response to Q Fever could help improve responses to other diseases. Specific cases of outbreaks should be viewed as models for developing general response capabilities, which would allow decision makers to respond efficiently to similar outbreaks. Furthermore, involvement of ecologists and systems specialists would enable governments to begin to understand the “epidemic of outbreaks” that appears to be occurring in industrialized countries, and how this related to the structure of the agrifood system overall.
Caribbean

Ciguatera Fish Poisoning on the North Shore of La Habana, Cuba
Food-borne and Waterborne Infections – Caribbean Eco-Health Program
Ciguatera Fish Poisoning on the North Shore of La Habana, Cuba

The Disease

Ciguatera fish poisoning (CFP) is caused by the bioaccumulation and biomagnification of naturally occurring biotoxins, produced by various genera of marine dinoflagellates (particularly *Gambierdiscus* spp.) that live symbiotically on any red, brown or green marine macroalgae. These toxins are some of the most potent known to humans; for example, ciguatoxins are 22,000 times as toxic as cyanide to mice and pose a health risk to humans at concentrations above 0.1 ppb. The diagnosis of CFP is complicated by the fact that more than one toxin is involved. Fat-soluble ciguatoxins and water-soluble maitotoxins are the most commonly referenced, although other as yet unknown toxins may also play a role. Ciguatoxins are odourless, tasteless and generally undetectable. The combination of toxins, which are not affected by heating, freezing, smoking or salting, provide the foundation for more than 150 different gastrointestinal, neurological and cardiovascular symptoms associated with the illness, which includes acute, chronic and relapsing phases.

CFP has been associated with the consumption of more than 400 species of fish. Inclusion on the list of suspect fish does not mean that a fish is always toxic, or toxic in all locations, it only means that it has a reputation for toxicity and may pose a risk. Species of concern in endemic locations such as the North Shore of Cuba, include higher order carnivores such as barracuda, jacks and snapper. In the last several decades reports of human poisoning and other adverse effects caused by marine algal toxins appears to be increasing. While part of this increase is no doubt linked to improved public health reporting systems in some areas, as well as the expansion of both international tourism and the commercial seafood industry, there is general consensus that it may also be linked to anthropogenic factors, local and regional environmental disturbances (including coastal eutrophication) and global climate change. Monitoring for the dinoflagellates that create these potent biotoxins is not necessarily helpful for surveillance, as the production of toxins appears to be strain-dependant and the trigger for their production is currently unknown. Because of the many human, animal (fish) and ecological interactions involved in the occurrence of ciguatera, the significant gaps in existing knowledge of ciguatera, and the systemic uncertainties, it has been referred to as “a problem in ecology par excellence”. That is, since there are no technical therapeutic or preventive measures, a resolution to the problem of ciguatera can only be found in a better management of human-ecosystem relationships.

Animal-Human-Ecosystem Dynamics

In Cuba, the increase in outbreaks of CFP during the Cuban Special Period in Peacetime (1989-1995+), in some communities but not others, was an issue of key concern for the Ministry of Public Health (MINSAP). Prior to the Special Period, CFP followed a relatively stable pattern of toxicity involving the larger carnivores in the area which caused low-level sporadic outbreaks of the illness. Following the collapse of the Soviet Bloc in 1989, and the subsequent economic challenges, the role of near-shore coral reefs as an easily accessible food resource became more important. There was a dramatic increase in fishing pressure from the community-at-large.
In addition, Cuban coral reef ecologists noted the link between coral reef degradation and an increased incidence of outbreaks of CFP on shore. Thus, the challenge of CFP not only involved the conditions of the near-shore reef ecosystem, but also the socio-economic conditions on shore. An interdisciplinary perspective was required, and MINSAP actively solicited assistance in researching this topic.

Response and Conclusions

Given the numerous areas of uncertainty in the chemical, biological, ecological, social, cultural and economic aspects of ciguatera, an interdisciplinary comparative case study research program was designed, focusing on three similar sized coastal communities located on the North shore of La Habana, Cuba. Epidemiological data from MINSAP was used to select communities with low, medium and high levels of reported illness during the Special Period. The theories of situated learning and social-ecological resilience provided the foundation for an examination of the social-ecological system related to CFP in each community. Semi-structured interviews with key informants and community members, community and national workshops, literature reviews and matrix timelines were among the methods used to collect data.

Participatory techniques, including community and a national workshop, enhanced the interdisciplinary communication between key stakeholders from different Ministries. Of particular significance was the information provided from other disciplines (for example, coral reef ecology) that was unfamiliar to both the fishing and health communities of practice. In one town, the representative of the local environmental office was invited to join the ad-hoc interdisciplinary group on CFP that was established when the increase in outbreaks was first noted. The study also provided information directly to affected community groups, school children and the public-at-large, primarily through the design and printing of poster and pamphlets on the topic. These posters were distributed nationally to all schools in partnership with a concurrent UNICEF project, and also were used as the backdrop for a new television spot providing information to the public about CFP.

Key Policy Recommendations

In the long run, and worldwide, this disease is best prevented by investing in measures to protect coral reefs from degradation, including addressing problems with overfishing, and better management of on-shore developments that result in sedimentation and local pollution. To be effective, such measures need to include a wide range of stakeholders, including members of the fishing communities, local health authorities, and land use planners.
Food-borne and Waterborne Infections – Caribbean Eco-Health Program

The Disease

Food-borne infections constitute a significant public health problem in the Caribbean. The movement of foods and people into and within the Caribbean region creates an ideal environment for the introduction and spread of bacterial, parasitic and viral pathogens associated with food-borne infections. The Caribbean, being the most tourist dependent region in the world, is especially sensitive to the economic implications of food and waterborne disease outbreaks. Climate change has exacerbated the frequency and impact of food and water-related infections on vulnerable population. For example, in 2005, flooding following heavy rains in Guyana contributed to a leptosporosis outbreak that is believed to have affected over 250 people and resulted in 23 deaths. Many of those affected came from poor low-lying communities where animal, rodent and human populations live in close proximity.

Animal-Human-Ecosystem Dynamics

Control of food-borne and water-borne infections requires input from public health, environmental health and veterinary public health practitioners, as well as regulatory authorities responsible for safe food and water. It is becoming increasingly clear that effective interventions also require a deep understanding of how social, economic, environmental and cultural factors interact with dynamics of disease transmission and the acceptability of control methodologies.

The control of food-borne infections requires targeted interventions at numerous ‘critical control points’ along the production pathway. Beginning on the farm and continuing until the food is ready for consumption, many players from different backgrounds contribute to the safe production and dissemination of food. The same holds true for the control of waterborne infections. A detailed understanding of the introduction, persistence and movement of pathogens and contaminants through the environment, animals and people is required before effective interventions can be implemented.

Response and Conclusions

The Caribbean Eco-Health Program is a large multi-agency initiative led by Canadian and Caribbean researchers and funded under the Global Health Research Initiative by the Canadian Institutes of Health Research. The program received funding in 2007. The key partners include the Public Health Agency of Canada, Laval University, Trent University, PAHO, the Caribbean Epidemiology Centre, the Caribbean Environmental Health Institute, the Caribbean Food and Nutrition Institute, the University of the West Indies and St. Georges University. The focus of the program is to closely examine the public and environmental health interactions in food and waterborne illnesses. By linking the academic community with the research needs of key regional institutions, the Caribbean Eco-Health Program has created a cadre of engaged professionals interested in the link between human and environmental health.
The key research themes in the program include the community burden of food-borne disease, microbial contamination of rainwater, zoonotic infections, persistent organic pollutants, pesticides and heavy metals, seafood safety, ciguatera, exotoxicology, bathing water quality and the indigenous environment and health. This program continues to develop and expand as new researchers are added to the network and additional funds acquired. In addition to research, the program has supported numerous training workshops for epidemiologists, microbiologists, veterinarians, nurses, toxicologists and other professionals. Some of the training programs have been conducted jointly with other global initiatives, such as the WHO Global Food-borne Infections Network. These specific courses have brought together epidemiologist, microbiologists, environmental health officers and veterinary health practitioners and involved them in a single training curriculum.

**Key Policy Recommendations**

Making research available for decision-making, and having political concerns incorporated into scientific research require active knowledge translation and exchange activities. These are a priority for the Caribbean Eco-Health program and will continue to expand as results are generated from its innovative research projects.
South America

Vampire Bat Rabies
Chagas Disease
Leishmaniasis
Leptospirosis
Jungle Yellow Fever
Vampire Bat Rabies

The Disease

Rabies is an infectious viral disease that affects the nervous system of humans and other mammals. Rabies is transmitted to humans through close contact with the saliva of an infected animal, most often via a bite or a scratch. Dogs are the main reservoir worldwide, especially in urban settings, while hematophagous (blood feeding) bats, raccoons and foxes are reservoirs for sylvatic human rabies.

The rabies virus infects the central nervous system, causing encephalopathy. Early symptoms of rabies in humans are nonspecific, consisting of fever, headache, and general malaise. As the disease progresses, neurological symptoms appear that may include insomnia, anxiety, confusion, slight or partial paralysis, excitation, hallucinations, agitation, hypersalivation, difficulty swallowing, and hydrophobia (fear of water). Death usually occurs within days of the onset of symptoms.

There is no specific treatment for rabies, however, thoroughly cleaning of the wound or bite site and post-exposure prophylaxis administered promptly after contagion can help prevent the onset of disease.

Animal-Human-Ecosystem Dynamics

In 2004, there were 79 reported cases of human rabies in South America that interrupted a 20-year decline in the incidence of the disease in the region. The decline was largely due to the Rabies Regional Elimination Program coordinated by the Pan American Health Organization (PAHO) that focused on the reduction of canine-transmitted rabies. Canine rabies has been linked to situations of poor living conditions and precarious dwellings in urban and peri-urban settings.

However, the majority of the cases in the 2004 human rabies outbreak occurred in remote areas of Brazil, Colombia, and Peru and they involved the hematophagous bat, *Desmodus rotundus*, as the animal reservoir. This supports a new set of interacting social and ecological conditions affecting the spread of the disease. Important ecological factors relate to the viability of colonies of vampire bats including the presence of adequate sources of food and the spread of the rabies virus in a population; social factors usually relate to changes in human activities leading to natural habitat modifications.

Specific conditions were identified as being present in the 2004 Brazil outbreak and in a similar outbreak in rural Peru in the 1990s. These were: 1) the communities affected were small populations living in remote areas; 2) livestock activities had recently ceased thus reducing the supply of food available for vampire bats and making them more likely to attack humans; 3) new economic activities had emerged (e.g., gold prospecting, that brought humans and bats into closer contact; 4) living conditions were poor and housing precarious; 5) there was lack of access to medical services which limited the possibility of administering post-exposure prophylaxis; 6) the population was not aware that a bat bite could cause rabies so it was unlikely that
they would have treated the wounds. Hence, through this type of analysis one can begin to appreciate the interrelatedness of social, cultural, economic and biological factors in the spread of sylvatic rabies.

Response and Conclusions

In the 1980s PAHO coordinated the Rabies Regional Elimination Program that helped reduce the cases of human rabies by 90% between 1982 and 2003. The success was primarily due to mass vaccination campaigns for dogs and improvements in the administration of post-exposure prophylaxis.

However, the 2004 outbreaks of bat-transmitted rabies meant that the institutional response needed to adapt to a new set of circumstances. In Brazil, the Ministry of Health organized teams of interdisciplinary experts to work collaboratively to consider health measures, such as prophylaxis campaigns, but also educational needs for human populations at risk, and ecological monitoring of vampire bats.

The role of inter-agency collaboration and community participation in responding to a crisis was clearly important. First, research efforts were directed towards improving the logistics of prophylaxis distribution, especially since the outbreaks occurred in remote villages, which involved seeking the participation of community-level health professionals who could identify bite victims and administer adequate treatment. Second, coordination between different health programs was promoted since many of the areas susceptible to rabies were also places with high incidence of malaria, yellow fever and other health risks with programs already under way. Third, wider community participation was sought to design educational materials that were culturally appropriate to the Indigenous populations and river dwellers that live in this region.

Key Policy Implications

Multidisciplinary approaches are more effective at pointing out the ecological, cultural, social and economic dimensions of disease and inter-programmatic approaches working across government departments and agencies allows for more effective use of resources and encourages learning, if the institutional incentives are set right.

The control of rabies has brought together international organizations (PAHO), national governments (Brazil Ministry of Health) and community health workers. Striking a balance between centralized and decentralized measures seems key to deliver health improvements to remote regions. Community participation was key to effective implementation.
Chagas Disease

The Disease

Chagas disease, also called American Sleeping Sickness, is caused by the parasite *Trypanosoma cruzi*, which is transmitted to animals and humans by blood-feeding triatomine bugs, popularly referred to as “kissing bugs”. The bugs are infected when they ingest blood of infected hosts, and the parasite enters the bloodstream when the bug later feeds on an uninfected host, through bite wounds, mucous membranes, or broken skin. Less common transmission routes include consumption of uncooked food that is contaminated with bug feces, congenital transmission, blood transfusions, and organ transplants. Most infected individuals are asymptomatic or present with mild symptoms that are not unique to Chagas, such as fever, fatigue, diarrhoea, and vomiting. However, up to 30% of infected individuals develop more serious symptoms related to diseased smooth muscle and cardiac muscle. These clinical syndromes (that is, constellations of clinical symptoms and signs), including chronic cardiac or intestinal complications, can lead to death. Those with immune deficiencies and young children are particularly vulnerable to complications, with a case fatality rate of 5%. Therapy can be life saving and includes anti-parasitic drugs or symptomatic treatment.

Despite a general decline in Chagas disease in Latin America, it is estimated that 8 to 11 million people are infected annually. Endemic areas include Mexico, Central America, Venezuela, and Columbia; however, the true distribution of Chagas disease in the Americas is unclear. The documented distribution is dependent on reporting, and, in some cases, on the presence of researchers with an interest in the disease, which could indicate serious under-reporting problems. Occasionally, the disease been reported in non-endemic regions, including Canada, Europe, the USA, and the Amazon. Although *T. cruzi* can infect many species of animals, in many areas the infection cycles have been related primarily to the co-localization of bugs and people living in poor housing. Thus, campaigns to reduce the incidence of Chagas disease focus on increased monitoring (e.g. surveillance) and vector control measures (e.g. indoor insecticide spraying). While these campaigns have been successful in some areas, the disease remains endemic in many poor rural areas of Latin America. The occurrence of animal reservoirs outside of urban areas means that the disease always has the possibility to re-emerge in human populations.

Animal-Human-Ecosystem Dynamics: An Amazon Example

Until recently, Chagas disease was considered rare in the Amazon; however, there have been over 500 cases reported in the area and the disease was declared emergent in 2001. While Chagas disease in the Amazon has a lower sero-prevalence (e.g. 2-13%), morbidity, and mortality than other endemic areas, efforts are underway to prevent the disease from becoming endemic in the region. If Chagas disease becomes endemic in the Amazonia region, more than 30 million residents will be at risk. To implement successful control measures, it is necessary to consider interacting biological (e.g. diverse hosts and vectors), ecological (e.g. uncontrolled deforestation, invasion of houses by adventitious vectors), technological (e.g. disease surveillance, medi-
cal treatment, vector control), political (e.g. intergovernmental support within, between, and among regions), and socio-economical (e.g. rural poverty, intense emigration out of endemic regions) determinants of Chagas disease. Climate change is also thought to be changing the range of triatomine bugs. Since the determinants of the disease encompass complex interacting factors, simple household level spraying will not successfully control the disease, and thus, a multi-faceted approach to disease control is necessary.

Response and Conclusions

The International Initiative for Chagas Disease Surveillance and Prevention in the Amazon was launched to prevent endemic vectoral transmission of Chagas disease in the Amazon region through heightened surveillance, vector and disease control, and regional epidemiological research. This intergovernmental commission has health representatives from each Amazon country, a Brazilian Pan American Health Organization technical advisor, a rotating executive technical coordination group, and research representatives that meet annually. Another program which is supported by the World Health Organization is the Communication for Behavioural Impact Program, which focuses on social mobilization, changes in urban planning and environmental services, and inter-sector collaboration. In principal these approaches move beyond household and community level spraying to include a broader involvement of actors to focus on addressing the disease through behaviour modification.

In addition to focussing on modifying behaviours, it is also important to focus on modifying environmental and social contexts to reduce disease transmission. Understanding how degraded ecosystems, vector biology, and socio-economic conditions interact to create health risks will assist in providing effective measures for disease control. Canada’s International Development Research Centre (IDRC) has supported several initiatives to explore in more detail the relationships among social, environmental and health outcomes. The IDRC supported intervention study in Guatemala is using improvements in housing, combined with pesticides, to pressure the bugs to feed on other animals, rather than on people. This novel approach may reduce the risk of human disease and the considerable risks associated with many eradication programs. While it is necessary to continue multi-stakeholder participation and transdisciplinary involvement, it is also fundamental to view Chagas disease as an environmental problem, and not only a behavioural problem, in order for interventions to be sustainable.

Policy Implications

Continuing to use participatory approaches to intervention programs will ensure that improvements are implemented.

Characterizing Chagas disease as an environmental problem will facilitate the ability to engage land developers, urban planners, and ecologists and biologists, as well as health professionals, to identify systemic, sustainable solutions. Modifying environmental and social contexts, which requires governmental (economic, business, health, agriculture etc), non-governmental, and business to work together, will enable the creation of healthy communities where Chagas and a variety of other diseases are minimized simultaneously.
Leishmaniasis

The Disease

Leishmaniasis is a disease caused by species of the parasite *Leishmania*. It is transmitted to animals and humans by the bite of female blood sucking sandflies (genus *Phlebotomus*), which have previously fed on an infected reservoir host (e.g. humans, rats, dogs, horses, and poultry). Other transmission routes that are not as common include congenital transmission, blood transfusions, and needle sharing. The phlebotomine sandflies are usually found in rural areas, but have been known to colonize in peri-urban and urban houses, with the highest *Leishmania* transmission rates in the rainy seasons. The sandfly lays its eggs in rodent burrows, tree bark, cracks in house walls, and animal shelters.

Cutaneous and visceral leishmaniasis are the most common forms of infection. Cutaneous leishmaniasis symptoms may appear within several weeks or months after the sandfly bite and include open or closed skin lesions, which can change in size and appearance over time. The sores typically progress from papules to nodular plaques, to open sores with a raised border covered with scales or crust. The sores may heal without treatment, but can last for months to years and result in scarring. Visceral leishmaniasis symptoms may develop years to decades after the sandfly bite. Symptoms include fever, weight loss, enlargement of liver and spleen, and pancytopenia (e.g. anemia, leukopenia, and thrombocytopenia). Drug therapy is available, but if visceral leishmaniasis is left untreated it is most often fatal.

It is estimated that there are 2 million new cases of leishmaniasis each year, with an estimated 12 million human infections worldwide; however, only 32 of 88 affected countries report cases, resulting in substantial underestimates of infection. While leishmaniasis is found in over 88 countries, more than 90% of visceral cases occur in the Indian subcontinent, Sudan, and Brazil, and more than 90% of cutaneous cases occur in Afghanistan, Algeria, Iran, Iraq, Saudi Arabia, Syria, Brazil and Peru.

Animal-Human-Ecosystem Dynamics

Despite the high prevalence, incidence, and morbidity of leishmaniasis, the disease is often overlooked and thus classified by the WHO as a neglected disease. While the mortality rate of leishmaniasis may be low, the social and economic consequences of the disease can be substantial. In particular, the sores and scars caused by cutaneous leishmaniasis can be seriously disfiguring and result in serious stigma and social prejudice. The prejudice against scarred women can leave them unmarried, unemployed, and outcast from communities. The disease burden is substantial at an estimated 2.3 million disability-adjusted life years.

Skin ulcer due to leishmaniasis. Hand of a Central American adult. Photo courtesy of Dr. D.S.Martin, Centers for Disease Control and Prevention. 2009
(DALYs) and disproportionately impacts women: 0.9 million in men and 1.4 million DALYs in women.

Leishmaniasis transmission is complex with a number of interacting risk factors including cultural practices and beliefs, migration, urbanization, deforestation, climate change and variability, water management practice, inaccessibility to patient care, lack of organized social involvement, insufficient use of information for decision-making, lack of treatment, and human-vector interactions. Considering these complexities, a transdisciplinary, multi-sector, equitable approach to disease control is necessary.

Response and Conclusions

Campaigns to reduce the incidence of leishmaniasis focus on increased monitoring (e.g. surveillance such as LeishNet), vector control measures (e.g. indoor insecticide spraying), animal control measures (e.g. dog testing and culling), and educational campaigns. While these campaigns have been successful in some areas, they are costly and are rarely maintained over the long term. For instance, in Brazil, despite 200,000 houses sprayed and 20,000 dogs culled per year, zoonotic visceral leishmaniasis continues to increase.

Relationships between physicians and veterinarians in control efforts could prove to be beneficial. For instance, an intervention trial in Iran found that the use of deltamethrine-treated collars reduced the risk of infection in dogs by 54% and consequently in children by 43%.

Considering the complexity of the interacting risk factors for leishmaniasis infection, it has been suggested in World Health Organization (WHO) publications that transdisciplinary research needs to be conducted to study the interactions between the environment, humans, vectors, and animals to improve control measures, as well as multi-sector and multi-national collaborations between health, education, urban development and planning, environment, and other sectors. Some WHO initiatives have indeed brought multi-national stakeholders together to discuss leishmaniasis control; however, most stakeholders invited to the meeting were only from the health and biology fields, neglecting other important perspectives (e.g. gender, social, and veterinary sciences) that are critical to addressing the disease.

Summary of Key Policy Implications

Leishmaniasis is a neglected disease that impacts poor, rural women disproportionately and needs to be recognized as a public health priority. The approach to disease control must be founded on transdisciplinary perspectives (e.g. biological, veterinary, medical, anthropological sciences) and multi-sector collaborations.
Leptospirosis

The Disease

Leptospirosis is a zoonotic waterborne infection caused by species of the bacteria *Leptospira* that affect the liver and kidneys. Contagion in humans occurs by coming into contact with water, vegetation or soil containing the urine of infected animals. There are a variety of possible animal reservoirs including livestock, dogs, rodents, and wild animals. Leptospires enter the body through contact with the skin and mucous membranes and, occasionally, via drinking water and the inhalation of urine droplets. Person-to-person transmission is rare.

Symptoms of leptospirosis include high fever, severe headache, chills, muscle aches, and vomiting, and may include jaundice (yellow skin and eyes), red eyes, abdominal pain, diarrhea, or a rash. Although it is hard to diagnose, it is treatable with antibiotics such as doxycycline or penicillin. If left untreated, the disease progresses to kidney damage, meningitis, liver failure, and respiratory distress. In rare cases, the disease is fatal.

Animal-Human-Ecosystem Dynamics

The occurrence of leptospirosis depends on a complex set of interactions between ecological and social factors that act at different scales to determine the viability of the microbial population and the probability of contact with humans. Although leptospirosis is present worldwide, it is more common in tropical and sub-tropical regions where abundant precipitation, regular flooding and high temperatures enhance the distribution and survival of leptospire. According to the World Health Organization, the incidence of leptospirosis ranges from 0.1 to 1 per 100,000 per year in temperate climates to 10 or more per 100,000 per year in the humid tropics. Where leptospirosis is endemic, outbreaks can be triggered when there is unusually high rain and flooding, paired with land use and land coverage changes, which mobilizes bacteria from the soil into waterways. For example, in the Caribbean, Central and South America, Southeast Asia and Oceania, incidences of leptospirosis are cyclical, coinciding with the rainy season in tropical climates, and the summer in temperate climates.

Leptospirosis is found in both rural and urban settings. In rural settings, infection is associated with particular crops, such as rice or taro, which grow in flooded and semi-flooded areas. Similarly, workers in direct contact with animal reservoirs (e.g. farmers, veterinarians and butchers) are considered higher risk. One study found that English dairy farmers were disproportionately affected by leptospirosis due to manual milking which exposed them to the animal’s urine. Similar findings occurred in Australia where leptospirosis annually affects 8.9 persons out of 1,000,000 and is considered mainly an occupational disease.
In urban areas, exposure coincides with crowded inner city locations prone to rat infestations, and with particular occupations, such as sewage and waste disposal workers. For instance, a GIS analysis of the 1996 leptospirosis outbreak in urban Brazil demonstrated that the disease had higher incidence in flood risks areas and waste accumulation sites.

More recently, there has been an increase in the incidence of leptospirosis in people engaged in recreational activities involving freshwater such as swimming, canoeing, boating and adventure travel.

*Response and Conclusions*

While there have been large-scale clinical trials of vaccines for people in Cuba, China and Russia, none of these are widely available or deemed sufficiently effective to market. The greatest barrier to antileptospiral vaccine development is the difficulty of developing a polyvalent leptospirosis vaccine for humans in endemic areas who may be exposed to several variants. Polyvalent vaccines are available for animals; however, there is some evidence that the field strains in dogs, for instance, are changing as the result of vaccination – that is, vaccination is putting selection pressure on bacterial populations but is not eradicating the disease. In many cases, the vaccine prevents against disease, but not infection and shedding.

An integrated approach was used in 2005 to explore the occurrence of leptospirosis in Hawaii’s “ahupua’a” region, characterized by a watershed ecosystem that extends from the uplands to the ocean and seawards to the barrier reefs. In Hawaii, it is estimated that the annual incidence of leptospirosis is 12.9 cases per million (same as Brazil) with the highest rates of infection occurring among taro farmers and tourists. In contrast, the annual incidence of leptospirosis in continental USA is 0.1 per million.

A multi-disciplinary group of experts met in Honolulu to attempt to examine the emergence of leptospirosis, considering the interaction of human and natural systems as determinants of disease. Major risk factors in Hawaii include the use of water catchment systems for taro farming, wild pig hunting and the presence of skin wounds. Taro farmers participated in the research from the onset, their views and concerns regarding leptospirosis formed the foundation of the research program. Input from the farmers was critical as they possessed in-depth knowledge about ecological factors affecting the spread of disease. For example, they confirmed the relationship between leptospirosis and stagnant water, the proximity of cattle to water bodies or the presence of rodents.

At times, the farmers also disagreed with the views held by the experts. For instance, farmers held pigs in high regard culturally, whereas scientists tended to view wild pigs as major animal reservoirs. Similarly, the participation of taro farmers added an important cultural dimension to understand the efficacy and impact of disease prevention. For example, taro is a staple food of great significance for several groups of Pacific islanders. However, wet taro lots are considered a risk factor for leptospirosis and taro farmers disliked the association, as it would keep people away from traditional Hawaiian activities. Cultural dimensions such as this need to be considered in order to develop effective disease prevention and response strategies.
Policy Implications

The disease underlines the relevance of transdisciplinary approaches that integrate horizontally across the disciplines and vertically across different groups of stakeholders, community members, decision-makers, and scientists. It also underlines the serious challenges and opportunities in considering traditional ecological knowledge/indigenous knowledge alongside Western/biomedical knowledge.
Jungle Yellow Fever

The Disease

Zoonotic yellow fever virus is transmitted from infected primates to humans by tree-hole breeding mosquitoes (Figure 1). The virus can result in mild to severe hemorrhagic fever with jaundice – the symptom that the disease is named after. Approximately 3-6 days after exposure to the virus, acute symptoms develop and include fever, muscle pain, headache, shivers, loss of appetite, nausea and/or vomiting. These symptoms are not unique to yellow fever, and as a result the disease is often misdiagnosed as malaria, typhoid, arboviral infections (e.g. dengue), leptospirosis or viral hepatitis. Of those infected with yellow fever, more than 85% of patients recover from these symptoms and gain immunity to the virus. The remaining cases enter the toxic phase within 24 hours, where 50% of the adult cases and 70% of child cases result in death within two weeks. Toxic phase symptoms include jaundice, abdominal pain with vomiting, blood in vomit and feces, hemorrhagic symptoms, black vomit, nose bleeds, bruising, and deteriorating kidney function. The only treatment available for yellow fever is symptomatic relief.

The virus is endemic in many African and South American countries. Although a vaccine has been available for more than 60 years, the incidence of yellow fever has increased over the last
20 years. The World Health Organization (WHO) estimates that there are 200,000 new cases each year resulting in 30,000 deaths per year. Consequently, yellow fever is considered to be a public health emergency of international concern and is notifiable under International Health Regulations.

*Animal-Human-Ecosystem Dynamics*

Currently, most disease control programs rely largely, or solely on a vaccination program. The 17D single dose vaccine is effective in 95% of people for 10-35 years. An International Certificate of Vaccination for Yellow Fever is required to enter many endemic countries, or for travelers returning from an endemic country. In the 1940’s a mass vaccination campaign dramatically reduced yellow fever incidence; however, as the disease incidence decreased, so did vaccination efforts. In order to prevent epidemics of yellow fever, 60-80% of the population must be vaccinated; however, few countries at risk have this level of vaccination coverage. Furthermore, since the virus persists in mosquito and primates, vaccinating humans alone will be ineffective in eradicating the disease. Therefore, vaccination campaigns must reach and maintain high levels of vaccination to successfully control the disease over the long term.

Another intervention approach involves vector control. The Pan American Health Organization led a campaign to eliminate mosquitoes and destroy breeding sites with insecticide spraying. This campaign not only reduced the incidence of yellow fever, but also other vector-borne diseases including dengue. Despite this success, long term sustainability of such programs is difficult due to a variety of reasons (e.g. high financial cost, ecological implications, unintended health consequences). Consequently, mosquito populations have since increased to pre-campaign levels, and have resulted in re-emergence of yellow fever and dengue.

While low vaccination coverage and vector re-emergence impact yellow fever incidence, other important factors have contributed to a resurgence in the disease, including deforestation, urbanization, political unrest, population movements, and climate change. Thus, control strategies must consider these interacting factors and complexities to create sustainable interventions.

*Response and Conclusions*

The Yellow Fever Initiative is a preventive vaccination effort led by the WHO, supported by UNICEF and National Governments, and funded by GAVI Alliance (Global Alliance for Vaccines and Immunisation), ECHO (European Humanitarian Aid Office), Ministries of Health, and country-level partners. This program aims to reduce yellow fever “in striking and sustainable ways” through the vaccination of 48 million people and increasing stock piles of reserve vaccine.

The Pan American Health Organization emphasizes the importance of keeping vaccination coverage high; however, they also advocate for mosquito control by emphasizing community participation and health education as fundamental elements to yellow fever control.
Policy Implications

Due to complex interactions and mosquito and primate reservoirs, human vaccination will never completely eradicate yellow fever; thus, approaches that modify environmental and social contexts must be integrated into intervention plans to reduce risks.
Africa

Tuberculosis – The HALI Project
Canine Rabies
Zoonotic African Trypanosomiasis
Rift Valley Fever
Joint Animal and Human Health Services for Remote Rural/Pastoral Communities
Zoonotic Malaria
Ebola Virus
Zoonotic Schistosomiasis
*Taenia Solium* and Epilepsy
Tuberculosis: - the HALI Project

The Disease

Rapid land-use change and water scarcity is impacting Tanzania’s vast Ruaha landscape, an area of extraordinary conservation significance with an appropriate natural resource base for traditional livestock keeping (pastoralism). In addition to habitat degradation and economic hardship, increasing overlap among human, livestock, and wildlife populations for dwindling water resources may increase transmission of zoonotic diseases like bovine tuberculosis (BTB; *Mycobacterium bovis*), an emerging zoonotic disease agent in people and a disease of conservation concern for wildlife. Nearly 40,000 new cases of TB (human, bovine, or atypical strain) are diagnosed per year in Tanzania, with anywhere from 21% to 77% of Tanzanian tuberculosis patients also infected with HIV. The extrapulmonary form of TB in people, often associated with BTB infection from animals, accounts for 20% of the reported cases in Tanzania.

In 2006, the Health for Animals and Livelihood Improvement (HALI; http://haliproject.wordpress.com/) project was initiated to test the feasibility of the one health approach in rural Tanzania and to find creative solutions to these problems by investigating the impact of zoonotic disease on the health and livelihoods of rural Tanzanians living in the water-limited Ruaha ecosystem. Bovine TB became a focal disease for HALI due to its high livestock prevalence, wildlife data paucity, and the large, susceptible HIV infected human population living in close association with livestock and wildlife. Based on input from local stakeholders, the often neglected zoonotic waterborne diarrheal diseases and the cattle disease, brucellosis, were also assessed.

Animal-Human-Ecosystem Dynamics

Every day thousands of children and adults die from under-diagnosed diseases that have arisen at the human–animal–environment interface, especially diarrheal and respiratory diseases in developing countries. Explosive human population growth and environmental changes have resulted in increased numbers of people living in close contact with wild and domestic animals. Unfortunately, this increased contact together with changes in land use, including livestock grazing and crop production, have altered the inherent ecological balance between pathogens and their human and animal hosts. Nowhere in the world are these health impacts more important than in developing countries, where daily workloads are highly dependent on the availability of natural resources. Water resources are perhaps most crucial, as humans and animals depend on safe water for health and survival, and sources of clean water are dwindling due to demands from agriculture and global climate change. As water becomes more scarce, animals and people are squeezed into smaller and smaller workable areas. Thus, contact among infected animals and people increases, facilitating disease transmission. Water scarcity also means that people and animals use the same water sources for drinking and bathing, which results in serious contamination of drinking water and increased risk of zoonotic diseases.
Response and Conclusions

HALI is assessing the impact of water limitation and zoonotic disease by simultaneously investigating the medical, ecological, socioeconomic, and policy issues driving the system (Figure 1). This multilevel approach includes: testing of wildlife, livestock, and their water sources for zoonotic pathogens and disease; environmental monitoring of water quality, availability, and use; assessing wildlife population health and demography; evaluating livestock and human disease impacts on livelihoods of pastoralist households; examining land and water use impacts on daily workloads and village economies; introducing new diagnostic techniques for disease detection; training Tanzanians of all education levels about zoonotic diseases; and developing new health and environmental policy interventions to mitigate the impacts of zoonotic diseases.

HALI researchers identified BTB and brucellosis in livestock and wildlife in the Ruaha ecosystem and are using this information to identify geographic areas with varying water availability where risk of transmission may be highest. In addition, *Salmonella*, *Escherichia coli*, *Cryptosporidium*, and *Giardia* spp. that can cause disease in humans and animals have been isolated from multiple water sources used by people and frequented by livestock and wildlife. These data are being used to examine spatial and temporal associations between landscape factors and disease and to identify risk factors and health impacts that may be mitigated through policy changes and outreach. Preliminary findings also indicate that more than two-thirds of participating pastoral households do not believe that illness in their families can be contracted from livestock, and nearly half believe the same of wildlife. Furthermore, when the HALI project began, 75% of households did not consider sharing water sources with livestock or wildlife a health risk, illustrating the need for effective community education. In response, the HALI team is raising disease prevention awareness in local communities through outreach events, radio broadcasts, and novel educational materials.

Policy Implications

The HALI project has reinforced the importance of the one health concept and provided lessons for the development of a new approach to global health. First, it is crucial to recognize that zoonotic pathogens are present and emerging in rural communities. Most people living in high risk areas are not aware of the danger or what can be done to reduce it. In addition, disease transmission can be exacerbated by common animal husbandry and food and water handling practices. Therefore, data collection strategies should include spatial, temporal, and demographic patterns of pathogens and disease in human, domestic animal, and wildlife in likely hotspots for disease emergence. The underlying water and land use determinants of disease and the social, economic, and cultural barriers to control and prevention must be explored. Second, the role of water as a driver of disease transmission and zoonosis emergence should not be ignored. Water scarcity increases work stress, especially in women and children, and brings animals and people together more frequently, increasing the likelihood of water contamination and transmission of infectious diseases. Likewise, the manner in which water is used for agricultural and animal production affects worker health, food safety, and the health of those who drink and bathe in it. Finally, the determinants and consequences of zoonotic diseases, as well as the interventions to mitigate their deleterious effects, are all cross-sectoral.
Effective surveillance, assessments, and interventions are only possible by crossing the organizational gaps among institutions studying and managing wildlife, livestock, water, and public health.

Education in global health, especially emerging zoonotic diseases, is urgently needed at all levels from research institutions to pastoralist communities. While strong science is an excellent foundation on which to base recommendations, interventions can succeed only if stakeholders are involved in the characterization of the problem and are willing to make the tradeoffs necessary to balance short-term economic needs with those of the long-term health of the ecosystem. The donor community should be encouraged to transcend disciplinary conventions and invest in holistic health projects that have the best chance of affecting change.

Figure 1. Local and global influences impacting human health, including the interdependence of people, animals, plants, and the environment, and the associated food and water availability, safety, and security
Canine Rabies

The Disease

Rabies is caused by a virus which is most often transmitted by an animal bite. The disease may be the oldest known zoonosis, as it was described by the ancient Egyptians. In the Arabic language, the name for rabies means the disease of the dog (da’h al kelb), which is the main source of transmission to humans in Asia and Africa. Most human deaths from rabies occur in resource limited countries. In Africa and Asia, an estimated 24,000 to 70,000 people die of rabies each year.

Animal-Human-Ecosystem Dynamics

Worldwide, the domestic dog is the main source of exposure and a primary vector for human rabies. Rabies in humans can be prevented by appropriate post-exposure prophylaxis (PEP), which is an effective treatment after being bitten by a rabid animal, but which is not always available and affordable in resource-limited countries. Human rabies can also be prevented through vaccination of animal vectors. Evidence of successful and sustained vaccination programs to eliminate dog rabies is reported from South America, Mexico, and the Caribbean providing hope for similar efforts in Africa and Asia. Unfortunately, human resources, diagnostic capacity, and financial resources of most sub-Saharan African countries are less developed than those in South America and in most countries little is known about the real cost of mass vaccination of dogs. The main question is: Is it profitable to mass vaccinate dogs compared to human PEP in developing and transition countries?

Research and Intervention

Using a one health research approach, the cost-effectiveness of different rabies-control strategies was simulated by a mathematical model of dog-human rabies transmission in an African urban center, using as an example N’Djamêna, the capital of Chad. Based on earlier small scale studies, it was shown that sufficient numbers of dogs could be vaccinated if dog mass vaccination was free to the owner and if community participation and the operational capacity of the veterinary services were satisfactory.
The model allows comparison of the cost-benefits and cost-effectiveness of different interventions, in particular the trade-off between interventions in humans alone or in combination with interventions in the animal host. Under the current conditions in N’Djaména a single parenteral mass dog-vaccination campaign reaching 70% coverage is, on average, profitable after 6 years, and more cost-effective over a period of longer than 7 years when compared to PEP for exposed humans alone (Figure 1).

Policy Implications

In the case of urban rabies in N’Djaména, which may apply to many other African and Asian cities, rabies can be effectively controlled by publicly funded dog mass vaccination. Human health benefits are higher from combined dog vaccination and PEP than from PEP alone.

Figure 1. Comparative cost of human post exposure prophylaxis (PEP) alone versus Dog mass vaccination and PEP. Dotted lines represent 95% confident intervals.
Zoonotic African Trypanosomiasis

The Disease

Sleeping sickness (African trypanosomiasis) is a re-emergent and neglected tropical disease affecting people, livestock, and wildlife in sub-Saharan Africa. The designation of ‘neglected tropical disease’ reflects its impact on predominantly poor rural regions, as well as historically negligible international funding or advocacy. Trypanosomiasis is a vector-borne parasitic disease carried by tsetse fly vectors, and transmitted among humans and a range of animal species, predominantly cattle and other livestock. Some forms of the disease are restricted to people, others are restricted to animals, and still others are zoonotic. Sleeping sickness is the human form of the disease, so named because of the disrupted sleep cycles of affected patients. Early symptoms are non-specific and often mis-diagnosed as malaria or HIV. Late stage symptoms include progressive confusion, slurred speech, psychological disturbance, progressing to encephalitis and eventually death within weeks to years, depending on the form of disease. Sleeping sickness has a case fatality rate of 100%. High levels of under-reporting, focalized and epidemic occurrence, and limited drug development have meant that human disease burden is high in affected regions.

Animal-Human-Ecosystem Dynamics

The concurrent impact of the animal form of the disease, ‘nagana’, means that the disease has significant integrative zoonotic burden. Nagana’s impact is predominantly economic, with livestock (usually cattle) suffering chronic disease and reduced productive capacity. Indeed, the distribution of livestock livelihoods and livestock development in Africa is inversely correlated with the distribution of the tsetse fly vector. All forms of trypanosomiasis re-emerged in sub-Saharan Africa in the 1960s and 70s in association with newly independent governments, widespread civil conflict, and re-allocation of finances to other health and political priorities. This re-emergence has occurred predominantly in Sudan, Angola, Uganda, and the Democratic Republic of the Congo, but the disease affects more than 30 countries in sub-Saharan Africa.

Given the strong social, cultural and economic value associated with livestock in many affected regions, the impact of trypanosomiasis encompasses physical as well as social, cultural, and economic health of those dependent on livestock-based livelihoods. The occurrence of zoonotic sleeping sickness has been found to coincide with periods of social disruption or conflict associ-
ated with compromised health and veterinary services, changing vector habitat, and unchecked parasite transmission through movements of cattle and internationally displaced populations. Similarly, agricultural change, land use, and urbanization contribute to the changing availability of suitable habitat for the tsetse fly vectors.

Response and Conclusions

Control measures vary between forms of the diseases, and include vector habitat clearing, veterinary intervention through animal treatment, tsetse-focused farming practices, active human surveillance, and poverty reduction. Trypanosomiasis and its resurgence and control thus reflect a complex reflection of ecological, social and political determinants of human and animal health.

Diseases such as trypanosomiasis, with zoonotic cycles involving humans and multiple animal species, mean that interventions must focus on both human and veterinary health. The additional complexity of vector-borne diseases illustrates the importance of insect populations and associated vector habitat factors such as agriculture and land use. Dominant control measures include active case finding and treatment, meaning that social disruptions (such as political instability or conflict) and the health of health systems must also be considered.

Intervention activities have recognized the need for integrated and pan-African programs to address trypanosomiasis control. PAAT, the Program Against African Trypanosomiasis, and PATTEC (the Pan-African Tsetse and Trypanosomiasis Eradication Campaign), for example, have attempted to integrate a number of initiatives, including standardization of surveillance data and mapping and support for public-private partnerships to promote development of new and field-friendly diagnostic tools and novel drug treatments. Funding for these initiatives has come from a wide range of resources, including the World Health Organization (WHO), the Food and Agricultural Organization, national international development agencies (e.g. Department For International Development, UK), global financial institutions (e.g. African Development Bank), and non-governmental organizations (e.g. Médecins Sans Frontières ). There have been initiatives to develop feasibility programs for integrating Sterile Insect Technique approaches for vector eradication in combination with active surveillance and animal treatment. At the local level, funding has predominantly targeted improved surveillance, diagnosis, and treatment provision.

The zoonotic and vector-borne nature of some forms of trypanosomosis has meant that the disease is extremely difficult to control, with total eradication likely unfeasible. The necessity of
sustainable control systems means that trypanosomiasis is even more reflective of the need for integrative and self-sustaining management strategies. Recent global commitments, particularly by the WHO and public-private partnerships, have dramatically improved provision of drugs to cash-strapped national health ministries, and more recently led to the development of new drug treatment options. Incidence has begun to decline in continental Africa, largely aided by stabilization of long-standing conflicts in affected countries such as the Democratic Republic of the Congo. Many intervention measures, however, remain subject to shifting funding priorities at the international and national levels, without convincing establishment of nationally-funded and sustained prevention and control programmes in individual nations. Aspirations for technological fixes based on costly vector eradication strategies have in some cases overshadowed the lack of basic disease surveillance and treatment provision.

Policy Implications

Trypanosomiasis and the complexity of its transmission, determinants, and impacts, are not well suited to vertical programs designed at eradication. Alternatively, the disease requires approaches to sustained and decentralized control which integrate cooperation of multiple sectors and jurisdictions. Effective control of trypanosomiasis is likely to be dependent on the more general status of health systems and poverty indicators in sub-Saharan Africa. Indeed, the disease is prevalent exclusively in poor rural regions, and usually in locations and during times of weakened health systems and/or social or political instability. While targeted interventions have been successful when implemented, the long-term sustainability of control programs remains a concern. Ultimately, successful, sustained, and effective trypanosomiasis control is likely to remain elusive until it is mainstreamed into more generalized poverty reduction and health capacity strengthening in affected nations.
Rift Valley Fever

The Disease

Rift Valley Fever (RVF) is a zoonotic disease affecting mainly sheep and cattle in the Rift Valley. It is caused by a mosquito-borne virus of the Bunyaviridae family, which also includes Crimean-Congo hemorrhagic fever virus. All of the viruses in the Bunyaviridae family, except for hantaviruses, are transmitted by arthropod vectors. The severity and degree of clinical signs may vary according to age or breeds of the animals affected, with infections usually unapparent or mild in adults but with high mortality rates in newborn animals and abortions in pregnant animals. The majority of animal infections result from infected mosquito bites, while most human infections are caused by direct or indirect contact with the blood or organs of infected animals. RVF in humans is usually asymptomatic or characterized by an acute self-limited febrile illness. The virus infects the vector at every stage of its life cycle, and virally infected eggs can lie dormant in the ground for long periods of time in semi-arid areas. Hatching is stimulated by wet weather, and the local flooding that follows allows water to accumulate in pools that provide an ideal mosquito breeding ground. Most species of the *Aedes* mosquito rarely feed on humans but when large numbers of animals become infected through mosquito bites, this can lead to direct transmission to humans via infected blood and tissue and also mass transmission by secondary mosquito vectors that become infected by biting livestock. Although 99% of infections are subclinical (that is, people are infected with the virus but are not clinical ill), the numbers of deaths can be high because of the sheer numbers of people infected.

Animal-Human-Ecosystem Dynamics

Identified in the 1930s in Kenya, RVF virus now circulates in many other African countries, as well as on the Arabian Peninsula, where epizootics and associated human cases have been reported. Larger epidemics appear to occur about every decade. Climate change could have a major impact on the occurrence and distribution of the disease due to more frequent extreme weather events and the impact of these events on the biology and geographic distribution of the arthropod vectors. Additionally it is argued that the international trade of livestock and large-scale human movements, which have both expanded during the past 40 years, are important contributory factors. An outbreak in Egypt in 1977 resulted in infection in 200,000 people, 600 of whom died, and the first outbreak in Saudi Arabia and Yemen in 2000 led to around 250 fatalities. RVF, being a trans-boundary zoonotic infection associated with large losses of human...
and livestock assets, is complicated by current trends in climatic changes commonly affecting vulnerable resource poor African communities. Poor pastoralists, already facing increased climate-related hazards such as droughts and floods, and lacking adequate support policies, are perhaps most seriously affected.

Response and Conclusions

Prediction of outbreaks of RVF can be made using satellite imaging since vegetation growth responds to increased rainfall, and variations in vegetation can be easily measured by satellite.

In East Africa, vegetation index maps have been used together with ground data to monitor vector populations and RVF viral activity, and a correlation between these two parameters has been established. Vegetation measurements can be used in a more proactive way to forecast RVF before cases reach epidemic proportions.

Such predictions can improve the timeliness of action to identify, prevent, and/or control the disease by implementing vector control. Several steps can be taken to prevent amplification of the virus in livestock—vector control, public health advice to people not to handle infected animals and tissue, and targeted mass vaccination of animals with the highly effective vaccine that is already available. These interventions can do much to prevent human infections and in countries, such as those in western and southern Africa, and continents, such as Europe, where the disease has never been reported should increase vigilance and raise their awareness of RVF. Strengthening global, regional, and national early warning systems, and coordinating subsequent prevention and intervention measures will be crucial.

After a major epidemic in the Horn of Africa in 2005-2006, the International Livestock Research Institute (ILRI) came together with International Centre for Insect Physiology and Ecology (ICIPE), Kenya Medical Research Institute, Kenya Agricultural Research Institute, Kenya Wildlife Service, Ministry of Health, DVBD, Kenya, Ministry of Public Health, Kenya and the Department of Veterinary Services, Kenya. This group, termed the Arbovirus Incidence and Diversity (AVID) group, developed a phased risk-based contingency planning tool (developed with all stakeholders), a National RVF emergency fund (MoLD) and a communication plan and guidelines.

In Madagascar, a one health approach was employed during the 2008 outbreak of RVF by the Ministry of Health; disease surveillance had been intensified since February 2007 because of the risk of RVF from East African countries. Risk assessment of the neighboring areas was done and surveillance heightened. An integrated approach was employed by both the Ministry of Agriculture and the Ministry of Health in collaboration with the FAO and OIE. This helped to predict and map the distribution of the outbreak of RVF and reduce the number of human cases.

Policy Implications

RVF should be one of the diseases integrated into extension programs directed at both human and animal health workers, and livestock owners in high risk areas, with advice on how to recognize the disease, where to report it, and how to manage risks to people and animals through
vaccination, handling of sick or dead animals, and restriction of animal movements from affected areas into unaffected areas.
Joint Animal and Human Health Services for Remote Rural/Pastoral Communities

The “Disease” (Problem)

Vaccinating persons and livestock in hard-to-reach rural communities remains a serious challenge and calls for innovative, specially designed strategies. In Africa, the ability of human and veterinary health systems to deliver services is constrained by decreasing public-sector budgets; loss of confidence by community members in government services due to unmet demand; a severe shortage of human resources, especially qualified personnel; inadequate infrastructure and equipment; and weak monitoring and information systems.

Animal-Human-Ecosystem Dynamics

One of the 4 strategies of the World Health Organization (WHO) and the United Nations International Children’s Emergency Fund to achieve their vision of equitable, sustainable, and high-coverage immunization among children and women by the year 2015 is the provision of vaccination services linked to other health interventions. To achieve common health goals, the cross-over benefits of integrating other interventions in public health such as distribution of vitamin A, selling of insecticide-treated mosquito nets, and deworming and malaria treatments of children are increasingly being acknowledged. For children and for women of childbearing age, immunization provided through the National Expanded Program on Immunization (EPI) is considered one of the most cost-effective public health interventions and society’s best healthcare investment, especially in developing countries. National and global efforts aim to substantially increase vaccination coverage in general, particularly for those who have so far not benefited. Vaccination coverage among rural settled communities in many African countries is very low and among mobile pastoralists virtually nil. How can a high vaccination coverage among such communities be achieved?

Response and Conclusions

Using a one health, integrated research approach, a mixed team of physicians and veterinarians visited remote pastoral communities in Chad. They observed that, while a considerable number of cattle were vaccinated against anthrax and other animal diseases, the vaccination coverage of children and women with the vaccines of the EPI was zero. The Chadian Ministries of Health and
of Livestock Production (hosting the veterinary services), together with the nomadic communities, recommended testing the feasibility of joint human and livestock vaccination campaigns. The goals of these joint campaigns were to make the best use of visits by professionals in nomadic communities, reduce costs of services by sharing of infrastructure, and increase vaccination coverage. In this way children and women could be vaccinated who would otherwise not have access to health services and the service was highly appreciated by all partners involved. Providing joint health services also saved money by sharing transport and the cold chain, that is, the chain of refrigeration facilities required to keep vaccines cold (and hence effective), from the places where they are produced, to where they are delivered.

Policy Implications

Sustained vaccination programs are essential tools for both the public health and veterinary sectors. Combined human and livestock vaccination reduces operational costs of interventions requiring costly transportation and is adapted to livestock holders who highly value the approach that considers the health both of the family and of the animals that contribute to their livelihood. In Chad, a common policy agreement between the 2 sectors on cooperation in rural zones should also define a cost-sharing scheme. By optimizing the use of limited logistical and human resources, public health and veterinary services will be strengthened, especially at the district level, and, in turn, will be more prepared and operational in responding to endemic and epidemic diseases.
Zoonotic Malaria

The Disease

Malaria is caused by infection with protozoan parasites belonging to the genus *Plasmodium*, which are transmitted by female *Anopheles* species mosquitoes. There are four types of human malaria: *Plasmodium (P.) vivax, P. malariae, P. ovale* and *P. falciparum*.

*P. vivax* and *P. falciparum* are the most common with *falciparum* being the most deadly type of malaria infection. *Falciparum* malaria is most common in Africa, south of the Sahara, accounting in large part for the extremely high mortality in this region. Malaria symptoms appear about 9 to 14 days after the infectious mosquito bite, although this varies with different plasmodium species. Typically, malaria produces fever, headache, vomiting and other flu-like symptoms. If drugs are not available for treatment or the parasites are drug resistant, the infection can progress rapidly to become life threatening. Malaria can kill by infecting and destroying red blood cells (anemia) and by clogging the capillaries that carry blood to the brain (cerebral malaria) or other vital organs.

Today malaria is found throughout the tropical and sub-tropical regions of the world and causes more than 300 million acute illnesses and at least one million deaths annually. Ninety % of deaths due to malaria occur in Africa south of the Sahara mostly among young children. Malaria kills an African child every 30 seconds. Many children who survive an episode of severe malaria may suffer from learning impairment or brain damage. Pregnant women and their unborn children are also particularly vulnerable to malaria, which is a major cause of perinatal mortality, low birth weight and maternal anemia.

Animal-Human-Ecosystem Dynamics

Malaria, once generally considered to have lost its devastating impacts on societies, has re-emerged as a major disease. In rural Africa, child mortality due to malaria is estimated to have doubled during the 1980s and the early 1990s. Factors contributing to the increase in malaria include resistance of parasites to commonly used anti-malarial drugs, breakdown of control programs and health services and resistance of mosquito vectors to insecticides. Similar factors, plus unstable political and economic conditions, have contributed to large malaria epidemics in Azerbaijan and Tajikistan, and smaller epidemics in Armenia, Georgia, Kyrgyzstan and Turkmenistan (WHO and UNICEF, 2005, 43). The movement of settlers into forest zones of Brazil contributed to a ten-fold rise in malaria cases between 1970 and 1990 (Martens and Hall, 2000).

While malaria has not been historically considered a zoonotic disease, the roles of livestock agriculture in promoting or preventing the disease have been explored, and a zoonotic strain of the
parasite has been identified in Southeast Asia.

Response and Conclusions

There is no doubt that some targeted interventions, such as pesticide-impregnated bed-nets, can have important impacts on the occurrence of malaria. However, longer-term, more sustainable responses require broader one health perspectives. In 2000, the System-wide Initiative on Malaria and Agriculture (SIMA) was created by the Consultative Group on International Agricultural Research (CGIAR). Associated with the International Water Management Institute in Sri Lanka, and based in South Africa, SIMA has investigated the ways in which agricultural activities, including livestock, affect the occurrence of malaria.

Recently, a zoonotic form of malaria has been documented in Asia. Using new molecular tools, researchers discovered that the simian malaria parasite, *P. knowlesi*, which is morphologically identical to the human *P. malariae* was present in human populations. *Knowlesi* malaria is a zoonosis that is widely distributed in Southeast Asia and can be fatal. A complete emergence of *P. knowlesi* into the human population could be overwhelming and, although challenging, the prevention of this situation deserves serious consideration. Several information gaps on the risks related to human-animal-environmental interactions require clarification. What is the risk of *P. knowlesi* among humans in known areas of transmission? Do other simian malarias infect humans in Southeast Asia? What is the prevalence of *P. knowlesi*, *P. cynomolgi*, and *P. inui* among Southeast Asian macaques? Can humans transmit simian malarias to other humans, can monkeys harbor human species of plasmodia and thus serve as reservoirs of human malaria?

Policy Implications

Better and freer integration of data from various disciplines and departments can identify connections between what appear to be separate issues such as simian and human malaria. The clarification of the roles of people, animals and ecology can enable the creation of more effective, better targeted, and more efficient responses. Initiatives such as SIMA can help transcend some of the barriers that arise when policy and action focus too exclusively on particular aspects of a disease to the exclusion of others.
Ebola Virus

The Disease

Ebola haemorrhagic fever (EHF) is caused by a virus of the family filoviridae (same family as Marburg virus). The disease in people ranges in severity from a mild to fatal illness. Case fatality rates in outbreaks may be as high as 90%. Initially the virus causes weakness, muscle pain, headache, fever and sore throat, followed by vomiting, diarrhea, rash, limited kidney and liver functions, and both internal and external bleeding. Symptoms appear 2 to 21 days after infection. To date, there is no vaccination. The only means of treatment is general supportive therapy and quarantine. Forest duikers (antelope species) and great apes are sensitive to lethal Ebola virus infection. The natural reservoir of the Ebola virus is believed to be in fruit bats, as they are capable of having asymptomatic infections. According to the World Health Organization, Ebola haemorrhagic fever is one of the most virulent viral diseases in the world. The Ebola virus was discovered in 1976 in Sudan and the Democratic Republic of Congo (DRC) after epidemics in Nzara, southern Sudan and Yambuku, northern Zaire (now known as the Democratic Republic of the Congo). Of the five different types of the Ebola virus - Bundibugyo, Sudan, Zaire, Côte d’Ivoire and Reston – only the first three types have caused sizeable outbreaks. Ebola-Reston has been a concern in the Philippines, and in captive primate colonies, but is not considered a serious human concern. Pigs in the Philippines were recently shown to have antibodies.

Ebola haemorrhagic fever is transmitted via direct contact with an infected individual’s (people or animals) blood, body fluids or tissues. Most outbreaks have spread through hospitals, family members taking care of ill people, or hunters of bush meat (primarily primates such as gorillas and chimpanzees, but also fruit bats). These groups, in addition to people living or traveling to areas where there is an Ebola outbreak, are considered vulnerable populations.

Animal-Human-Ecosystem Dynamics

Bats comprise 20% of all mammalian species and are essential for the functioning of the biosphere. Fruit bats in particular are essential for the pollination of flowering trees, and, through the carriage of seeds, the sustainability and diversity of tropical forests. Many fruit bats live in caves or mines. The mines, often in remote areas, and which are extracting some of the immense mineral wealth present in African soils for use in industrial products in developed countries attract poor people in search of work and income. Wild primates and duikers, exposed to Ebola virus from fruit bats, get very sick, and are therefore easy to hunt as bushmeat. Bushmeat is eaten by poor people living in those marginal areas, with poor access to agriculturally-based foods, poor understanding of the nature of infectious diseases, and where medical care is poor to nonexistent.

Response and Conclusions

In many cases, rapid responses have been mobilized by some combination of the World Health Organization, United Nations Children’s Fund (UNICEF), Médecins Sans Frontières and other medically-oriented non-governmental organizations, the Global Outbreak Alert and Response
Network (GOARN), the United State Centers for Disease Control, European epidemiology programs, and the Health Protection Agency in the United Kingdom. Social mobilization, which involves working closely with anthropologists and local community groups, is now recognized as an important component of these responses. The Wildlife Conservation Society (WCS) has worked with hunters, villagers and local health care professionals to detect Ebola virus and report disease and death in wild primates, who are often the first point of contact for disease outbreaks. They have also developed a non-invasive test of feces for Ebola in these primates.

Research to develop Ebola vaccination has been underway for years, but has yet to bear results. Wildlife groups such as WCS are hopeful that vaccines used in people might be used in related primates, as the disease is a serious threat to these endangered populations. This would have the double benefit of reducing the risk for human populations, in the way that vaccinating animals against rabies protects human populations.

Policy Implications

Development of vaccines for wildlife may have health benefits for people as well – and vice versa. Policy makers and corporate leaders might consider how some of the economic benefits enjoyed by mineral-importing countries and business could be more effectively invested in hospital, education, agriculture and road infrastructure in the countries where the minerals are being mined. This would be a win-win situation for both companies and exporting countries, enabling the creation of healthy, supportive communities. Furthermore, the continued collaboration with wildlife agencies working with non-human primates can help both with prevention and early reporting.
Zoonotic Schistosomiasis

The Disease

Schistosomiasis, sometimes called bilharziasis in the medical literature, ranks high among parasitic diseases in terms of socioeconomic and public health importance in tropical and subtropical areas.

Schistosomiasis infections are often asymptomatic, and if there are symptoms, they may be difficult to discern from concurrent diseases. The invasion, migration and maturation of the parasite induce acute schistosomiasis. Acute urinary schistosomiasis may lead to fever, dysuria and haematuria, whereas intestinal schistosomiasis may cause fever, abdominal pain, bloody diarrhoea and tender hepatosplenomegaly. If not treated, symptoms of chronic schistosomiasis may emerge after 5-15 years.

The major forms of human schistosomiasis are caused by 5 species of flatworm, or blood flukes, called schistosomes. Urinary schistosomiasis, caused by *Schistosoma haematobium*, is endemic in 54 countries in Africa and the Eastern Mediterranean. Intestinal schistosomiasis, caused by the mansoni worm, occurs in 53 countries in Africa, the Eastern Mediterranean, the Caribbean and South America. In 41 countries, both parasites are endemic. Another form of intestinal schistosomiasis caused by *S. intercalatum* has been reported in 7 central African countries. Oriental or Asiatic intestinal schistosomiasis, caused by the *S. japonicum* group of parasites (including *S. mekongi* in the Mekong river basin), is endemic in 7 countries in the Southeast Asia and the Western Pacific region.

Animal-Human-Ecosystem Dynamics

Transmission of schistosomiasis is the result not only of the interplay between humans, snails and parasites, but also of complex demographic, environmental, biological, technological, political, socioeconomic and cultural processes. At least one form of schistosomiasis is now endemic in 74 tropical developing countries. It is estimated that over 200 million people residing in rural agricultural and peri-urban areas are infected, while 500-600 million more run the risk of becoming infected as a result of poverty, substandard hygiene in poor housing, and inadequate public infrastructure.

Africa is estimated to account for 85% of all schistosomiasis transmission globally and there is a growing discrepancy between sub-Saharan Africa and the rest of the world.
of the world in terms of transmission and control. Schistosomiasis is mainly a rural occupational disease that affects people engaged in agriculture or fishing. In many areas, a large proportion of children are infected by the age of 14 years; in other areas, women face the highest risk because of domestic and occupational contact with fresh water. Increased population movements help to propagate schistosomiasis, as evidenced by its introduction into an increasing number of periurban areas of north-eastern Brazil and Africa and among refugees in Somalia, Zimbabwe and Cambodia. In sub-Saharan Africa, prevalence levels, particularly of *S. mansoni*, have increased due to water resources development projects, population increase or displacement, migration and competing priorities in the health sector. A country-by-country analysis is provided by Chitsulo et al. (2000) and Engels et al. (2002).

In China, *S. japonicum* which affects over 40 species of wild and domestic animals and bovines, mostly water buffaloes, are an important source of infection for people. Over a million people are infected and 59 million are at risk.

**Response and Conclusions**

Schistosomiasis is a complex phenomenon that cannot be addressed with technical fixes alone. Interventions need to shift from being centered on product-based interventions with social support to knowledge-based interventions within which technologies can be targeted.

An intervention trial in China demonstrated that treatment of both bovines and people had greater impact than treatment of people alone. In other parts of the world, where animal reservoirs are less important, different strategies are needed.

Understanding the dynamic interactions and roles of human occupations, the development of marshlands and irrigation, economic status, and the presence of zoonotic hosts are essential to developing effective and sustainable responses that do not create more problems than they solve.

**Policy Implications**

The research in China demonstrates that using simultaneous treatment of people and cattle is an effective intervention for schistosomiasis control. However, the intervention was also labour-intensive and further cost-effectiveness studies need to be performed in order to determine the impact of such a proposed strategy as part of an integrated control program that includes people, animals and the ecosystems they share. These studies would determine which combination of ecological management and human and animal treatment might be most effective.
**Taenia Solium and Epilepsy**

*The Disease*

*Taenia solium* is an intestinal tapeworm that infects people and which occurs in most parts of the world. In the most common form of the life cycle, up to 50,000 eggs per day pass out in feces of an infected person, and are ingested by pigs, where the larvae do not live in the intestine, but form cysts in the meat. People may be re-infected either when they consume undercooked, cyst-infected meat, or when their foods or hands are contaminated by feces containing tapeworm eggs. In the latter case, that is, if people infect themselves directly rather than by eating contaminated meat, they can become an intermediate host, taking the place of the pig in the life cycle. In this case, the parasite larvae may migrate to the brain, leading to clinical epilepsy, chronic headaches, blindness and/or sudden death. This is termed neurocysticercosis, and is an important preventable cause of adult-onset epilepsy in developing countries in Africa, Asia, and Latin America.

*Animal-Human-Ecosystem Dynamics*

The occurrence of cysticercosis is related to pig husbandry practices, availability and use of toilet facilities, knowledge of the disease among farmers, and agricultural and health extension workers. In some communities of Western Kenya, especially those where pigs are not confined, the prevalence of cysticercosis in pigs is more than 10%. Human taeniasis is very high, and mis-diagnosed epilepsy caused by the larvae is not uncommon.

Although cysticercosis has been declared by some experts to be an eradicable disease, achieving this requires a combination of changes in pig rearing, availability and use of hygienic facilities, availability and use of diagnostic tests and drugs for treatment of both pigs and people, and an understanding by farmers, health workers and animal health workers of the nature of the disease. Despite efforts to produce and market a vaccine, the underlying drivers and poverty of many of the affected people make this solution problematic.

*Response and Conclusion*

Researchers in Western Kenya demonstrated that at least 10% of households and 6.5 - 14% of pigs were positive for porcine cysticercosis. In the same area, interviews with the farmers, livestock, veterinary and public health officers, nurses and the pharmacists indicated that they were not aware of the life cycle of *T. solium* nor did they know the association between the parasite and epilepsy. Preliminary research also indicated that farmers were not aware of the tapeworm.
An integrated one health research and development initiative, supported from multiple sources, brought together investigators and practitioners from the affected communities, the University of Guelph, the University of Nairobi, the International Livestock Research Institute, and Veterinarians without Borders/ Vétérinaires sans Frontières – Canada. Training workshops and training-of- trainers workshops were held for farmers and butchers, veterinary and crop extension workers, veterinarians, public health and social workers and adult education specialists.

The farmers were taught about the financial expenses the butchers experience when running their business. The butchers were taught about the costs incurred to purchase, feed and house a pig to market weight. Both groups were taught the concept of a sustainable industry – the industry can only be sustained if both the pig farmer and the pig butcher have a profit for some proportion of the pigs. In response to the focus group meetings held in 2007, part of the meeting was devoted to discussing HIV/AIDS, as this has been a serious issue in the region, and many households include children orphaned by AIDS.

The farmer training included a session on building groups to enhance the sustainability of the local pig industry. Farmers worked with a government social worker to determine who wanted to be part of a group and the overarching objectives of the group. The plan was to introduce the concept at this meeting and then encourage the farmers who were the leaders to initiate the first meeting of the group.

The integrative, inclusive approach taken in these communities resulted in measurable improvements in pig husbandry and understanding of the disease.

Policy Implications

One of the five strategic elements of “Contributing to One World, One Health. A Strategic Framework for Reducing Risks of Infectious Diseases at the Animal–Human–Ecosystems Interface” is to better address “the concerns of the poor by shifting the focus from developed to developing economies, from potential to actual disease problems, and through a focus on the drivers of a broader range of locally important diseases”. By focusing on the livelihoods and related knowledge base of the many stakeholders in this agro-ecosystem, this initiative was able to improve the livelihoods and reduce the disease risk of the people in these Kenyan communities.
Asia

Brucellosis
H5N1 (“Avian Influenza”)
Severe Acute Respiratory Syndrome (SARS)
Nipah Virus
Hydatid Disease/ Cystic Echinococcosis
Brucellosis

The Disease

Brucellosis is one of the world’s major zoonoses, alongside bovine tuberculosis and rabies. *Brucella* infection is endemic in humans and livestock in Mediterranean countries. It is also present in Asia, sub-Saharan Africa, and Latin America. The importance of brucellosis is not known precisely, but it can have a considerable impact on human and animal health, as well as wide socioeconomic impacts, especially in countries in which rural income relies largely on livestock breeding and dairy products. Human brucellosis, a long lasting debilitating disease, is caused by exposure to livestock and livestock products. The most important causative bacteria are *Brucella melitensis* (small ruminants) and *B. abortus* (cattle). Infection can result from direct contact with infected animals and can be transmitted to consumers through raw milk and milk products. Human-to-human transmission of the infection does not occur. In animals, brucellosis mainly affects reproduction and fertility by mass abortion and reduces milk yield.

Animal-Human-Ecosystem Dynamics

Except for some of the Mediterranean countries, industrialized countries have controlled or eliminated brucellosis and other zoonoses by massive state interventions including, mass vaccination and test-and-slaughter campaigns. These operations were successful when veterinary services were performed well and when farmers were compensated financially for culled animals. Many developing countries lack, despite reasonably well performing veterinary services, the financial means to engage in such operations. The question is, can zoonoses control, like brucellosis or rabies be profitable and cost-effective in low income and transition countries?

Response and Conclusions

In Mongolia and central Asian countries after democratic reform and the shift from dependence on the former Soviet Union in 1990, human brucellosis reemerged as a major, but preventable, disease. After consultations with experts, the World Health Organization (WHO) raised the question whether mass vaccinations of animals saved money for the public health sector. A one health conceptual approach (without an environmental component) was taken including a cross-sector economic analysis and an animal-to-human transmission model to estimate the economic benefit, cost-effectiveness, and distribution of benefit (to society and the public health and agricultural sectors) of mass brucellosis vaccination of cattle and small ruminants. The intervention consisted of a planned 10-year annual livestock mass vaccination campaign of small ruminants and cattle. Estimated intervention costs were US $8.3 million, and the overall benefit was US $26.6 million. This results in a present net value of $18.3 million and a benefit-to-cost ratio for society of 3.2. If the costs of the intervention were shared between the various
sectors in proportion to the economic benefits each sector received, the public health sector would contribute 11% to the costs of the vaccination program (Figure 1).

**Policy Implications**

If costs of vaccinating livestock are allocated proportionally to all benefits, the intervention is cost-saving and cost-effective for the agricultural and the public health sectors. With such an allocation of costs to benefits per sector, brucellosis control becomes one of the most cost-effective interventions (<$25 per disability-adjusted life year (DALY) gained) in the public health sector, comparable to cost-effectiveness of vaccinating women and children or treating tuberculosis.

![Distribution of Benefits](image)

*Figure 1. Synoptic view of intervention cost and benefits*
H5N1 (“Avian Influenza”)

The Disease

Wild waterfowl around the world are the ultimate evolutionary source of all influenza viruses. Although influenza viruses are genetically unstable and evolve rapidly, they have not, historically, been considered to cause serious disease in waterfowl. Then, in the late 1990s, the H5N1 strain of avian Influenza (AI) was first recognized as a serious disease of poultry in southern China and Hong Kong. Within a decade, the virus was known to be causing die-offs of some species of wild birds, as well as domestic chickens and a variety of other species. The disease was (and remains) rare in people, but among those who get sick, between 30-80% die. It was also spreading rapidly, through some combination of trade and bird migrations, to all parts of the globe.

Animal-Human-Ecosystem Dynamics

Because of the rapid growth of poultry production and trade throughout the world in the 1990s, the H5N1 strain of AI, and how governments and international agencies reacted to it, clearly had not only human, animal, and ecosystem health impacts, but also economic and policy implications. These type of impacts varied depending on the types of species reared and types of farms (subsistence, small scale commercial, large scale commercial), local and regional economies and trading networks, domestic and export markets, deeply engrained cultural practices, and interactions with wildlife. Many governments initially reacted, understandably, by focusing on controlling the animal disease and preventing its transmission into the human population.

Response and Conclusions

While H5N1 certainly presented political difficulties for all involved, probably the major challenge for those wishing to understand and manage the rapidly changing H5N1 situation has been how to transcend the institutional, disciplinary and conceptual boundaries that separate the researchers and practitioners who deal with human, animal and ecological health. Without an integration across these boundaries, it is difficult for governments to develop policies that can respond to the multiple, often conflicting, demands being placed on them.

The Asian Partnership for Avian Influenza Research (APAIR) was established as a network of multi-country, multi-institutional teams from China, Thailand, Vietnam, Cambodia, and Indone-
sia, guided by a committee of national science advisors and leading researchers. As it became clear that the issues raised by Al were common to a range of other infectious diseases, APAIR transformed itself into APEIR, the Asian Partnership for Emerging Infectious Disease Research. APEIR investigates issues of disease emergence, wildlife, agricultural practices, human health, economics and policy development. The network is exploring the roles of wild birds and the ecological features of animal agriculture in the spread of epidemics; economic, cultural and policy influences on subsistence and commercial animal rearing and management of disease; social and economic impacts of disease and disease control; and, improving science and policy interactions. The International Livestock Research Institute (ILRI) and Veterinarians without Borders/ Vétérinaires sans Frontières - Canada (VWB/VSF) recently initiated complementary programs to promote research (ILRI) and to build capacity in ecosystem approaches to health (VWB/VSF) which will enable the consolidation and extension of APEIR. Much of this organizational development in Asia has been funded by Canada’s International Development Research Centre and by AusAID. These networks are creating regional and global synergy among researchers, academics, private sector actors and government policy makers to make one world one health a reality.

Policy Implications

While APEIR and similar networks provide a good basis for developing research and policies to respond to complex, changing situations with multiple stakeholders, they require leadership, funding and support at the highest levels. Leadership at the highest political levels can demand of researchers and practitioners that at least some of them work together to provide integrated knowledge and guidance, and can offer support when they do. In this way, political and business leaders will be enabled to make difficult decisions based on the best evidence available.
Severe Acute Respiratory Syndrome (SARS)

The Disease

Severe Acute Respiratory Syndrome (SARS) usually presents as a lower-respiratory disease in humans. The incubation period between infection and signs of illness is between 2 and 7 days but can be as long as 10 days. The disease is caused by the SARS Coronavirus (SARS-CoV) and is spread by infected droplets. It was first recognized as an infectious atypical pneumonia in Guangdong Province, China, in late 2002. SARS came to the world’s attention through a pandemic which occurred between November 2002 and July 2003, with 8,096 known infected cases and 774 deaths listed in 37 countries worldwide. The fatality rate for the 2002-2003 SARS outbreak was an average of 9.6%. The highest fatality rate was individuals over 65 years of age (fatality rate over 50%); the lowest case fatality rate was in individuals younger than 24 (less than 1%).

Much of what transpired during the early weeks of the epidemic occurred because of the unknown nature and origin of the agent, and the fact that the incubation period for the disease was longer than the time it took for an infected person to travel around the world. The spread of SARS by infected droplets is the now known to be the most common mode of transmission. Because of its highly infectious nature, relatively high case fatality rate, unknown origin and rapid spread in China, Hong Kong, Toronto, Singapore and Vietnam, the SARS epidemic created panic and huge economic losses in the countries involved. Nevertheless, as the result of concerted and coordinated international efforts, and wide-ranging, intensive scientific studies, the epidemic was brought under control within months.

Animal-Human-Ecosystem Dynamics

Within record time, investigations by Chinese zoologists, medical specialists, and molecular biologists, and their international colleagues, described the clinical disease, identified and isolated SARS-CoV, characterized its genome, and devised diagnostic tests. SARS-CoV-like viruses were isolated from Himalayan palm civets (Paguma larvata) in a live animal market in Guangdong Province. Seroprevalence of SARS-Co-V was higher in people involved in wild animal trading, and highest in those who traded primarily in palm civets. A ban on wild-game markets resulted in an abrupt cessation of new cases acquired from animal sources. Intensive zoological and virological investigations, combined with evolutionary and phylogenetic studies of viruses, determined that the virus had probably infected, and evolved in, civets and people separately, from a third source. Because bats comprise some 20% of all known mammalian species, and through
processes of analogical reasoning from Hendra and Nipah viruses, some Chinese investigators focused on several species of fruit bats as potential reservoirs. Armed with the latest techniques of genetic characterization, Chinese Horseshoe bats (*Rhinolophus sinicus*) were identified as the probable reservoir for the original SARS-CoV. In China there is considerable pressure to produce large quantities of low-cost food that may result in ecosystem disruptions, changing patterns of human exposure, and the emergence of new pathogens, which can lead to population pressures and local food demands. With advancements in modern transportation, trade and commerce, SARS spread quickly and easily spread around the world.

The systemic elements in the emergence of SARS thus included a rapidly growing urban population in China and the equally rapid expansion of traditional eating and marketing practices to meet the food demands, as well as the transmission, evolution and adaptation of particular viruses across species barriers.

*Response and Conclusions*

Although the Chinese response was clearly within the mindset of one health approach, the international response was less clear. Because the disease had emerged from ecological, social, and animal interactions in China, the Chinese investigators and regulators rapidly adopted a one health approach. Outside of China, SARS-CoV appeared as a virus already adapted to people, and to human- to- human spread. Hence, it was seen primarily as a problem of medical management, with very large social and economic impacts.

In Canada, the severity of the SARS outbreak in Toronto revealed gaps in public health (as differentiated from the public delivery of health care) management. This led directly to the creation of the Public Health Agency of Canada in September of 2004. According to its website, PHAC’s primary goal is to strengthen Canada’s capacity to protect and improve the health of Canadians and to help reduce pressures on the health-care system. Its primary function is preventive, and, for a great many health issues, this means that it must, by definition, take an integrative, holistic approach to promoting health in a modern, complex society, and, as well, to link its efforts to global understanding and activities from which new disease threats may emerge.

In British Columbia during the SARS outbreak in March 2003, a unified multi-stakeholder approach was used. Approximately five groups (University of British Columbia, Occupational Health and Safety, BC Center for Disease Control, governmental health authorities and Worker’s compensation) gathered to brainstorm, compile and publish a report to ensure standards of care and precautions for health care workers. Focus groups were held to review the document, followed by train-the-trainer sessions to educate front-line workers.

In the PHAC report, *Building Capacity and Coordination: National Infectious Disease Surveillance, Outbreak Management, and Emergency Response* (Chapter 5), the metaphor of firefighting is used as a comparison to a successful emergency continuum. While it is important that a fire is detected as soon as one starts, it is even more important to prevent the fire. Fires need to be understood, and preventative measures need to be put in place so that fewer fires break out, and when they do, the fire doesn’t spread like wildfire. Similarly, the most important compo-
nent to emerging infectious diseases (EID) is prevention addressed on the international stage. Fires may start deep in the forest, but quickly spread to cities many miles away. In the same way, infectious disease may originate in far away lands, but quickly travel around the world.

EIDs, such as SARS, are traditionally approached in a highly specialized, focused way with microbiology and epidemiology spearheading research and innovation. A new transdisciplinary approach, “all hands on deck” is explored by an international group of researchers from a variety of fields. The idea behind their vision is to vertically and horizontally integrate people, programs and sectors to ensure collaboration and innovative thinking. This will reduce the reliance on “magic bullet” EID interventions (Parkes et al. 2005).

It is important to take a transdisciplinary approach and have collaborations linking different knowledge groups and linkages across knowledge perspectives (Figure 1). As highlighted by the examples from China, the collaboration of ecologists, agri-food system specialists, health professionals, lay people (restaurateurs, farmers, marketers, general public) and policy makers are fundamental to a quick response. The aim for these interactions would be to plan proactively, so that reactive planning is not required. This would lead to explicit, clear communication between groups to learn from each sector.

**Key Policy Recommendations**

Possibly use the “all hands on deck” method when planning for, or responding to, infectious disease outbreaks. In addition to consulting academics and specialists, encourage community participation and the involvement of non-academic groups to promote the collective intelligence of society. This transdisciplinary approach may not be as effective as specialized methods for producing drugs and vaccines, however if emerging infectious diseases are to be prevented, thinking about infection in a holistic manner is the best long-term solution.

Medical collaboration after an outbreak has occurred serves an important purpose to minimize the negative effect of the disease. However, reactive planning is neither effective nor sustainable. Sustainable solutions require collaboration across a much wider spectrum of investigators, and an increased understanding of the dynamics between wildlife, food preferences, food
markets, viral evolution, and international travel and trade. The task seems daunting, but the rewards of such collaborations will be well worth the effort, and extend well beyond specific diseases.
Nipah Virus

The Disease

Human infection with Nipah Virus (NiV) was first recognized in Malaysia in late 1998. Over 35 weeks, 265 people suffered severe febrile encephalitis; 115 died. Most of the victims worked in the rapidly expanding pig-rearing industry. It was at first diagnosed as Japanese encephalitis, which can be carried by pigs and transmitted by mosquitoes. It now appears that several species of fruit bats (Pteropus sp.) are the natural reservoir hosts. The virus was spread through the saliva of infected bats, which remained as a residue on partially consumed fruit and dropped into swine pens. The fruit was eaten by pigs. In retrospect, an outbreak of respiratory disease and encephalitis in pigs was described prior to the human disease. The outbreak was stopped by the culling of more than a million pigs, at a cost of half a billion US dollars.

Since the initial outbreak, the human disease has been recognized in Bangladesh and India, although the transmission patterns from bats to people are different.

Animal-Human-Ecosystem Dynamics

A variety of theories has been suggested for the original emergence of Nipah virus infections. The elements of these theories include increased intensification of swine production in response to regional and global market pressures, changes in bat feeding behaviour driven by the availability of fruit trees near the pig farms, and smoke haze from forest-clearing affecting vegetation in the traditional feeding areas. The bringing together of infected bats, domestic animals, and people into close quarters led to the disease being transmitted across species. The events of 1998 suggest that the disease emerged as a result of migration of the bats from forests to cultivated orchards and pig farms which correlated with fruiting failure of forest trees during the El Niño-related drought and forest fires in Indonesia during 1997-1998.

Since the initial outbreak, transmission of Nipah virus from bats has occurred through direct ingestion of contaminated raw date-palm sap, exposure to people climbing trees where infected bats have rested, and occasionally person-to-person. In West central Bangladesh, date palm sap is harvested from December to March. The tree trunk is sliced and sap is slowly collected over-night into an open pot. Infrared cameras have shown fruit bats visiting the uncovered pots, and contaminating the sap with virus-infected urine.

Response and Conclusions

Understanding and integrating knowledge of the behaviour, ecology and infection status of the fruit bats, and the ways in which they interact both directly and indirectly with humans, have been essential to developing reasonable and effective responses. This has required work by human, animal and ecosystem health researchers at all scales, from the microscopic to the landscape level. In some cases, effective responses are simple. For instance, transmission via date palm sap can be prevented by putting in place simple bamboo “skirts” that prevent fruit bats from excreting into the pots. Managing the more complex social and ecological interactions
that led to the initial outbreak requires integration at much higher policy levels, where changes in animal husbandry, landscape alterations through fire, forestry or agriculture, and recognizing and sharing human and animal medical data quickly across jurisdictions, and development of vaccines are all relevant. Furthermore, the effects of the disease and its control through culling have also been felt through complex social and ecological pathways. As with all serious diseases that elicit dramatic responses, one might also ask questions regarding the mental health and social lives, and the short and long term socioeconomic effects of culling and reduced livelihoods on survivors, families and community members.

Policy Implications

An examination of the social-ecological systemic impacts of agricultural developments on human, animal and ecosystem health and well-being may lead to more balanced assessments of the value of changes in one sector, and possible unintended consequences that need to be guarded against.
Hydatid Disease/ Cystic Echinococcosis

The Disease

*Echinococcus granulosus* is one of several small tapeworms of dogs and other canids, such as wolves or foxes. The infected canids excrete tapeworm segments containing eggs, which are then consumed by other species, usually sheep, but sometimes other domestic species such as water buffalo, or wild ruminants such as deer or moose. People are infected when they are exposed to dog feces. In some areas, the domestic (e.g. dog-sheep) and wild (e.g. wolf-moose) cycles intersect. In dogs, the parasite has no discernable effect. In the intermediate species, cysts containing proto-tapeworms are formed in a variety of tissues such as the lung, liver and sometimes the brain. The cycle is completed when dogs eat the cysts. The clinical illness, which in people is usually called hydatid disease, is chronic and, in the long run, debilitating. Surgery is the only viable treatment option.

Animal-Human-Ecosystem Dynamics

Hydatid disease occurs worldwide and depends on human attitudes toward, and interactions with, both housed and free-running dogs, animal rearing and slaughtering practices, carcass disposal, dog control, environmental contamination, and availability and cost of treatments for the dogs. These are all embedded in cultural, ecological, and economic systems that vary from place to place. It is often not economically feasible for a country to develop a program specifically targeted at this one disease, hence there is a need to integrate control of this disease into more systemic goals. After more than a century of aggressive control programs in countries such as Iceland, New Zealand, Argentina and Chile, the disease appears to be making a come-back in all parts of the world, and even spreading to new areas.

Response and Conclusions

In the 1990s, after reports of a 20% case-fatality rate of patients undergoing surgery with hydatid disease, an intensive research and community development project was initiated in Kathmandu, Nepal. In the 1980s, various independent research and development activities targeted at improving slaughtering practices and investigating the disease dynamics generated a wealth of information with sometimes conflicting implications, such as the realization that dogs served as community police as well as sources of disease, and livestock generated both solid waste and economic wealth. Given these complexities, no changes occurred until representatives of Kathmandu City (KMC), Department of Drinking Water Supply Corporation (DDWSC), Ward Committees and chairs, Local Clubs, Ward Clinics, Schools, a couple of other local NGOs (Lumanthi and ENAPHC); representatives of Butchers, Street Sweepers, Street Vendors, Hotel Owners, business owners and squatters were mobilized into an integrated one health. With facilitation by two Nepalese non-government organizations - the National Zoonoses and Food Hygiene Research Centre, and Social Action for Grassroots Unity and Networking - and the University of Guelph, community-led transformation included changing slaughter facilities and practices, improved environmental hygiene, increased public awareness and better management of street dogs. The economic and social benefits extended well beyond the cost of the disease itself.
In 2008, a young girl in a northern Canadian aboriginal community was diagnosed with cerebral hydatid disease. Subsequent investigations revealed that free-roaming dogs, and hunting of wild moose and deer, were common in the community. Unused portions of hunted animals, including those infected, were often left in places where dogs could scavenge them. Although the disease is rare in Canada, the conditions in this community are not unusual among remote indigenous communities; and programs to address the issue must encompass not just infection in people and wild and domestic animals, but also the variety of ecological and cultural conditions that characterize their interactions and livelihoods. As in many economically disadvantaged and remote communities, this disease is one of many problems associated with free-running dogs, which also serve positive roles as waste scavengers and companions. Given the severity of the outcome, some response is called for, however, given the rarity of the disease, control programs must encompass multiple outcomes if they are to be sustainable. Currently a range of non-governmental and governmental organizations, including those representing First Nations, are working to develop sustainable strategies to resolve these complex issues.

Policy Implications

A 2005 World Health Organization (WHO) report on neglected tropical diseases noted that “so far as possible, an intervention for one disease should be designed in such a way that it can also be used as a vehicle for one or more interventions in relation to one or more other diseases.” This was clearly demonstrated in the one health case in Nepal, with hydatid disease, and indicates the possibility for justifying, economically and institutionally, the ways in which otherwise “marginal” diseases can be effectively dealt with under conditions of financial constraint.
Australia

Hendra Virus
Hendra Virus

The Disease

In September 1994, a well-known race-horse trainer and 14 of 21 clinically ill horses died, in Queensland, Australia, of acute respiratory disease of unknown etiology. Within a very short time, researchers from Australia's Commonwealth Scientific and Industrial Research Organisation (CSIRO) identified the virus involved, characterized it genetically, and developed diagnostic tests. Hendra virus, as it is currently known, is classified as a member of the genus Henipavirus, a new class of virus in the Paramyxoviridae family.

Although rare, it is now known that human and equine infections can range from fevers and muscle pains (influenza-like symptoms) to severe neurological and respiratory disease. The time from infection to disease ranges from 5 to 14 days. The case fatality rate in horses is about 75%. People acquire the infection through close contact with infected horses.

Since 1994, more than a dozen clusters of the disease have been identified in horses, and three people (a farmer and two veterinarians) have died.

Animal-human-ecosystem Dynamics

Since the original investigations, researchers have demonstrated that this virus is closely related to Nipah (see case study). The natural reservoir for the Henipavirus are fruit bats (family Pteropodidae, particularly Pteropus sp.), in whom the virus causes no apparent disease. Knowledge of the reservoir enabled further more directed investigations which have uncovered evidence of Henipavirus infection in Pteropus bats from Australia, Bangladesh, Cambodia, China, India, Indonesia, Madagascar, Malaysia, Papua New Guinea, Thailand and Timor-Leste, as well as in related fruit bat species in Africa. Transmission to horses is likely through bat urine, and to people, from horses, through close physical contact with infected fluids. Understanding the geographic extent of the infection and the modes of transmission have implications for ecological sustainability, human health, and the management and care of domestic horses.

Response and Conclusions

Scientists have been studying bat ecology and immunology, how Hendra-type viruses maintain themselves in bat populations, and the mechanisms of spill-over into people and other animals. Work is also continuing on developing vaccines for animals and people. An understanding of bat...
behaviour and initial understanding of transmission have already resulted in recommendations for horse owners and horse stables, and reflect similar recommendations for pig-rearing facilities.

The initial Hendra virus outbreak in 1994 in Australia seemed to be a small, isolated outbreak connected to horses. However, through a concerted effort by scientists, ecologists, human and animal health specialists, a much clearer picture has emerged of the ecology of infections associated with fruit bats in general. This has stimulated thinking about, investigations into, and implications for, our understanding of Nipah virus (in 1998-99), SARS (in 2002-2003), and even other, unrelated emerging diseases such as Ebola and Marburg. This understanding has resulted in recommendations as to how human behaviour and animal management can be modified to reduce the risks of transmission.

Policy Implications

The mixture of fundamental, ecological, human and animal research, as promoted and supported by the CSIRO clearly had unexpected, positive results well beyond the original problem being investigated and generated more general recommendations that will foster one health. This should be emulated by other research agencies and governments.
Acknowledgements and Contributors

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Introduction


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Websites of learning networks and supportive organizations:

Canada’s International Development Agency: www.idrc.ca

Community of Practice for Ecosystem Approaches to Health- Canada: www.copeh-canada.org

Community of Practice for Ecosystem Approaches to Health- Latin America: http://www.insp.mx/copeh-tlac/eng/inf/index.php

Community of Practice for Ecosystem Approaches to Health- Middle East and North Africa: http://www.copeh-mena.org/

Community of Practice for Ecosystem Approaches to Health- West Africa (francophone): http://www.copes-aoc.org/

Resilience Alliance: http://www.resalliance.org/
North America and Europe

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World Health Organization (WHO). Consultation on potential risks of pandemic (H1N1) 2009 influenza virus at the human-animal interface: Meeting Report (updated June 3,


**West Nile Virus**


**Anti-Microbial Drug Resistance and Integrated Surveillance in Canada**


Hantavirus


Waterborne Diseases: An Outbreak of Escherichia coli in Walkerton, Ontario, Canada


The Emergence of Neotropical Cryptococcosis in British Columbia

University of British Columbia. Cryptococcus gattii research publications: http://www.cher.ubc.ca/cryptococcus/new/topics.htm#publications

Lyme Disease


**Variant Creutzfeldt-Jakob disease/ Bovine Spongiform Encephalopathy**


SRM is defined as the distal ileum of cattle of all ages; and the skull, brain, trigeminal ganglia, eyes, tonsils, spinal cord and dorsal root ganglia of cattle 30 months of age or older. The 2007 feed ban restricts SRM from being fed to animals and pets as well as being included in fertilizers. A summary of the Canadian regulations is presented at the CFIA website: [http://www.inspection.gc.ca/english/anima/heasan/disemala/bseesb/enhren/enhrene.shtml](http://www.inspection.gc.ca/english/anima/heasan/disemala/bseesb/enhren/enhrene.shtml)

Websites:


Chronic Wasting Disease: [http://www.cwd-info.org/](http://www.cwd-info.org/)


Europe has established NeuroPrion Network with participation of researchers from more than 20 countries: [http://www.neuropriion.org/en/home.html](http://www.neuropriion.org/en/home.html)

PrioNet Canada is a Network of Centres of Excellence for research into prions and prion diseases: [http://www.prionetcanada.ca/](http://www.prionetcanada.ca/)

**Q Fever**


Q Fever in Netherlands (current) check Promed etc.: [http://www.promedmail.org/pls/otn/www_flow.accept](http://www.promedmail.org/pls/otn/www_flow.accept)
Caribbean

Ciguatera Fish Poisoning on the North Shore of La Habana, Cuba


Food-borne and Water-borne Infections – Caribbean Eco-Health Program


South America

Vampire Bat Rabies


Chagas Disease


Websites:

Center for Disease Control and Prevention (CDC). Chagas Disease General Information: http://www.cdc.gov/chagas/


Leishmaniasis


Websites:


Leptospirosis


**Yellow Fever**


Websites:


Pan American Health Organization 2000. Update on Yellow Fever in the Americas: [http://www.paho.org/English/sha/be_v21n2-yellowfever.htm](http://www.paho.org/English/sha/be_v21n2-yellowfever.htm)


Africa

Tuberculosis – The HALI Project


Canine Rabies

in dogs, Chad. Emerging Infectious Diseases. 14: 1650-1652.


Zoonotic African Trypanosomiasis


Rift Valley Fever


**Joint animal and human health services for remote rural pastoral communities**


**Zoonotic Malaria**


Ebola


Schistosomiasis (Africa and East Asia)


**Taenia Solium and Epilepsy**


**Asia**

**Brucellosis**


**H5N1 (“Avian Influenza”)**

The journal Nature for many years kept an excellent summary of the latest science in the field in a special page titled Nature Reports Avian Flu. The final posting on that was in February 2009: [http://www.nature.com/avianflu/index.html](http://www.nature.com/avianflu/index.html)


Several Organizations and Programs have promoted integrated one health types of approaches to emerging infections such as H5N1. These include:

Asian Partnership for Emerging Infectious Disease Research (APEIR): [www.apeiresearch.net](http://www.apeiresearch.net)
**Severe Acute Respiratory Syndrome (SARS)**


**Nipah Virus**


**Hydatid Disease/ Cystic Echinococcosis**


**Australia**

**Hendra Virus**

Websites:
