Foresight

Infectious Diseases: preparing for the future

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T12: The Wildlife Trade and Global Disease Emergence

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Introduction

This paper examines links between the wildlife trade and the emergence of infectious diseases. Concern about emerging diseases has grown with the spread of the avian influenza A (H5N1) virus. As the possibility of a global pandemic is assessed, it is critical to re-examine the causes of the emergence of disease and to identify opportunities to mitigate the threat of disease. The wildlife trade, particularly the trade in wildlife for human consumption, poses a credible risk of disease transmission, and has been linked to the evolution and outbreak of diseases such as avian influenza, severe acute respiratory syndrome (SARS), Ebola, and human immunodeficiency virus (HIV). The wildlife trade should therefore be considered a security priority by governments around the world. Emerging diseases should be addressed through multifaceted, co-ordinated action at local, regional, national and international levels, as well as through reflection on our relationship with the natural world.

Emerging diseases

In 1980, the World Health Organization (WHO) declared the eradication of smallpox and the end of infectious disease was celebrated. This declaration of victory over the microbial world proved hasty. Since 1980, over 35 infectious diseases have emerged in humans (Karesh et al. 2005). In 1996, the WHO reported that infectious diseases accounted for 45% of deaths in low-income countries and up to 63% of deaths in children under four worldwide (Shetty and Shetty 2003). The WHO no longer seemed optimistic about the eradication of infectious disease:

> *Until relatively recently, the long struggle for control over infectious diseases seemed almost over … Far from being over, the struggle to control infectious diseases has become increasingly difficult … The result amounts to a global crisis: no country is safe from infectious diseases* (WHO 1996).

A distinction must be made between the terms 'infectious disease' and 'emerging disease'. Infectious diseases are pathological conditions spread by the interaction of two humans, or a human and another species. The six most deadly infectious diseases today are pneumonia, tuberculosis, diarrhoea, malaria, measles and HIV (Shetty and Shetty 2003).[1] By contrast, an emerging disease can be broadly defined as 'any disease that is currently spreading within the host populations' (Schrag and Wiener 1995). It may have been present before at low prevalence and now be increasing in incidence. Or it may be entirely new to a population, either recently evolved or spread from another human population.

[1] Most deadly, in terms of number of people that have died from the disease.

Disease sources

Disease sources are phenomena or biological events that cause emerging diseases. Vertebrate animals, including birds, are a common disease source (Table 1). Diseases transmitted from animals to humans are called zoonoses. Of 1,415 known pathogens that have infected humans historically, 62% were of zoonotic origin (Taylor et al. 2001). It is estimated that 75% of all diseases emerging during the last two decades have been zoonoses. These include SARS, avian influenza, Ebola, monkey pox, and the West Nile virus (Brown 1999; Hart et al. 1999). Diseases spread to humans from both domesticated and wild animals. Domesticated animals alone are known to be the source of at least 296 diseases (McNeil 1998). Wild animals have been the source of such devastating epidemics as the black plague and HIV. Stephen Morse of Rockefeller University describes the world's fauna as a vast 'zoonotic pool' with 'each species carrying within itself an assortment of microbes that might jump across species barriers under the proper circumstances to infect an entirely different type of host' (Garrett 1994). The wildlife trade provides both a source and a pathway for disease emergence.

Table 1: Examples of emerging diseases infecting humans. Diseases that have a vertebrate animal or bird host are listed in bold (Schrag and Wiener 1995).

Disease type	Disease name (taxon)	Distribution	Reservoir hosts
Virus	Influenza (*Orthomyxoviridae*)	Worldwide	**Aquatic birds**
	HIV (*Retroviridae*)	Worldwide	Humans **(originally primates)**
	Marburg, Ebola (*Filoviridae*)	Africa	Unknown
	Dengue (*Flaviviridae*)	Throughout tropics	Mosquitoes, humans
	Rift Valley fever (*Bunyaviridae*)	Africa	Mosquitoes, **ungulates**
	Oropouche fever (*Bunyaviridae*)	Brazil, Trinidad	Midges
	Junin (*Arenaviridae*)	South America	**Rodents**
	Hantaan (*Bunyaviridae*)	Asia, Europe, USA	**Rodents**
	Hantavirus (*Bunyaviridae*)	South-west USA	**Rodents**
	Seal plague (*Paramyxoviridae*)	Northern Europe	
	Canine parvovirus	Worldwide	**Canids**
	Legionnaires disease (*Legionella*)	Worldwide	Natural component of water flora
Bacteria	Lyme disease (*Borrelia*)	Worldwide	**Deer, rodents, birds**
	Toxic shock (*Staphylococcus*)	Worldwide	Human nasal passages
	E. coli 0157:H7	USA, Europe	**Cattle**
	Plague (*Yersinia*)	Worldwide, mostly south-east Asia	**Rodents**

Wildlife trade

The wildlife trade encompasses the domestic and international trade in animals, plants and products derived from them for uses including timber, clothing, ornaments, medicine, food and pets. Quantifying the global wildlife trade is difficult, as it occurs both legally and illegally, and on a local level and internationally. But it is thought to involve millions of individual plants and animals, and to have an annual turnover of billions of dollars. Approximately 40,000 live primates, 4 million live birds, 640,000 live reptiles and 350,000,000 live tropical fish are traded globally each year (Karesh et al. 2005). In 2001, 38,000 live mammals, 365,000 live birds, two million live reptiles, 49,000,000 live amphibians and 216,000,000 live fish were imported into the Unites States alone (Bell et al. 2004). Globally, the illegal trade in wildlife is estimated to be worth more than US$8 billion (Noreen and Claridge 2001). It contributes significantly to national economies. In Vietnam, the illegal trade in wildlife is valued at US$20 million per year (Bell et al. 2004).

The Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) regulates international trade in wildlife. While 150 countries are now signatories to CITES, law enforcement is often uncoordinated, scattered or ineffective (Noreen and Claridge 2001). The continuing illegal trade in wildlife results in unsustainable rates of extraction (Traffic 2004). The wildlife trade has long been criticised for contributing to the extinction crisis, but only recently has it attracted attention as a source of zoonoses. In October 2005, a parrot imported into the UK died in quarantine of avian flu, highlighting the fact that the wildlife trade poses worldwide disease risks (BBC 2005). Wildlife traded for human consumption has raised the greatest concern for disease emergence and has been associated with several disease outbreaks.

Bushmeat and wet markets

Wild meat is a major source of protein for people in subsistence economies. Hunting contributes up to 80% of the protein consumed by forest-dwelling families in the Congo Basin (Koppert et al. 1993). However, in many parts of the world, hunting has been transformed into a commercial trade, with meat sold to consumers through an extensive network of trappers, hunters and middlemen. The commercialisation of hunting has led to dramatic increases in wildlife extraction. In central Africa, it is estimated that 1–3.4 million tonnes of bushmeat are consumed annually.

'Bushmeat' is an African term for the meat of wild animals, which may include animals such as duikers, rats, porcupines, a variety of monkeys, great apes and elephants, as well as snails, turtles, snakes and crocodiles. Africa has often been referred to as the centre of the 'bushmeat crisis', but commercial hunting also occurs in other parts of the world. In the Amazon, 67,000–164,000 tonnes of wild meat may be harvested annually (POST 2005). In Sarawak, Malaysia it is estimated that 2.6 million animals are shot and 23,500 tonnes of wild meat are consumed each year (Sohdi et al. 2004). In Vinh City, Nghe An Province, Vietnam, 600kg of civet meat is consumed in four restaurants every month (Bell et al. 2004). Bushmeat has even been transported internationally to cities such as London (Kirby 2004). In 2004, it was estimated that 4,000–29,000 tonnes of illegal meat entered the UK per year from non-EU countries (POST 2005).

The market value of bushmeat is significant, estimated at US$117 million per year in the Ivory Coast alone, and US$42 million in Liberia (Robinson and Bodmer 1999). In 1999, bushmeat's share of GDP on the Ivory Coast was higher than that of domestic beef production, tropical wood exports, bananas and pineapples combined (Bassett 2005).

Meat collected in rural areas is often transported to urban areas for sale in markets or restaurants. In Africa, the majority of meat may be smoked or dried, while in south-east Asia and China animals may be sold live in 'wet markets' (Peiris et al. 2004; Karesh et al. 2005). Wildlife commonly sold in Asian wet markets includes masked palm civets, ferret badgers, barking deer, wild boars, hedgehogs, foxes, squirrels, bamboo rats, various species of snakes, and endangered leopard cats, along with domestic animals. A three-year study of selected wet markets in Guangzhou and Shenzhen, south China, found 39 mammal species, 453 bird species, 154 reptile species and 31 amphibian species there (KFBG 2004). Over 90,000 snakes and 24,000 turtles were recorded in one visit alone (KFBG 2004).

Disease pathways

Disease pathways are mechanisms or routes by which disease organisms can transfer from one host to another. For a new zoonosis to emerge, an animal virus first needs the opportunity to infect a human. Then it needs to be able to replicate within the human, and finally it must spread between humans (Webby et al. 2004). Viruses may enter a new host through a variety of routes. The respiratory route is the most common pathway for virus entry into the human body. Other pathways for transmission include the oral–gastrointestinal route, cuts, bites or trauma to the skin, and sexual transmission (Phillips et al. 2001). In the long term, diseases that spread through the air have the greatest chance of becoming pandemics, while diseases that spread only through close contact are more controllable.

Once a virus has established contact with a new host, the virus must then replicate within the host's cells. This requires entry into an appropriate cell, the production of viral copies, which means overcoming the host's immune response, then exit and transfer to other cells (Webby et al. 2004). A virus which is virulent in birds, say, may elicit no illness in humans because it is not equipped to grow in human cells. A virus can gain the ability to grow in humans through mutation, reassortment or recombination, processes illustrated in Figure 1.

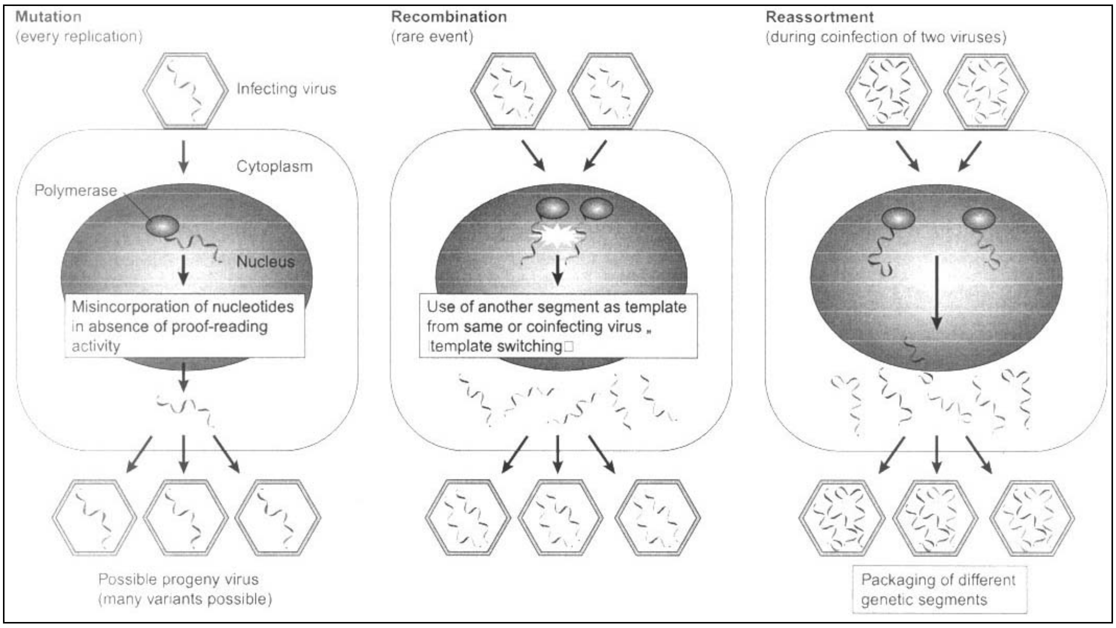

Figure 1: (Webby et al. 2004). Molecular mechanism for generating viral diversity. Viruses have evolved three main mechanisms for generating diversity: (a) during replication, single-point mutations are incorporated into one or more genomic positions; (b) during recombination, foreign genetic material is incorporated into the viral genome; and (c) during reassortment, which occurs during dual infection of a cell with different viruses, whole gene segments can be swapped.

Viruses are classified into a number of families, such as herpesvirus, retrovirus, adenovirus, based on differences in their structure and mode of replication. Some viruses are more effective at invading new hosts than others. Coronaviruses, for example, use a restricted range of host cells. Arenaviruses, on the other hand, exploit a broad range of host cells by making use of a host cell protein receptor that is widely conserved. RNA viruses are a particular concern for disease evolution because they are extremely mutable and have no proofreading mechanism to correct mutations. As a result, when they enter new environments, such as a new host, they are more likely to survive. Diseases that have resulted from RNA viruses include Nipah, Hendra, Ebola, H5N1 influenza A and SARS coronavirus, as well as HIV (Webby et al. 2004).

While animals involved in the wildlife trade may provide a source of zoonoses, the trade and markets themselves create the pathway for disease transfer and evolution. While butchering and dressing wild meat, humans are exposed directly to animal pathogens and have an increased likelihood of cutting themselves, thus opening a route of virus transmission. Wet markets provide opportunities for disease evolution. Though stalls selling live animals, fish or poultry may be separated, they are near enough to each other to allowing mixing (Webster 2004). Wild mammals, birds and reptiles come in contact with dozens of other wild species, domestic animals, vermin and pests, as well as countless people. Hygiene problems are common, including lack of storage space and refrigeration (Goldman et al. 1999).

These conditions provide easy opportunities for virus exchange and for virus evolution. For example, domestic ducks do not show signs of illness from H5N1 influenza, although they may excrete large quantities of the virus (WHO 2005b). A pig in a wet market, exposed to both humans and to ducks, could contract both human and avian influenza viruses (Figure 2) because pig cells have surface molecules that allow entry to both types of virus. If these two viruses were to reassort within the pig, the hybrid virus may be able to infect human cells while still carrying bird-virus genes that could evoke a deadly reaction in humans (Appenzeller 2005). Viruses may gain a selective advantage as a result of immunosuppression of both animals and people. Wildlife, particularly expensive species such as pheasants, often remain in the markets for several days. Individual animals kept in markets for long periods of time may experience immunosuppression as a result of stress and handling, while immunosuppression in people may result from HIV infection, or poor lifestyle and nutrition (Garrett 1994). Finally, the sheer volume of the commercial wildlife trade allows disease transmission on a large scale. Karesh et al. (2005) suggest that at least a billion direct and indirect contacts between wildlife, humans and domestic animals result from the wildlife trade each year. As these interactions increase, so do opportunities for pathogen exchange, mutation, recombination or amplification, increasing the likelihood of successful disease emergence (Wolfe et al. 1998; Peiris et al. 2004).

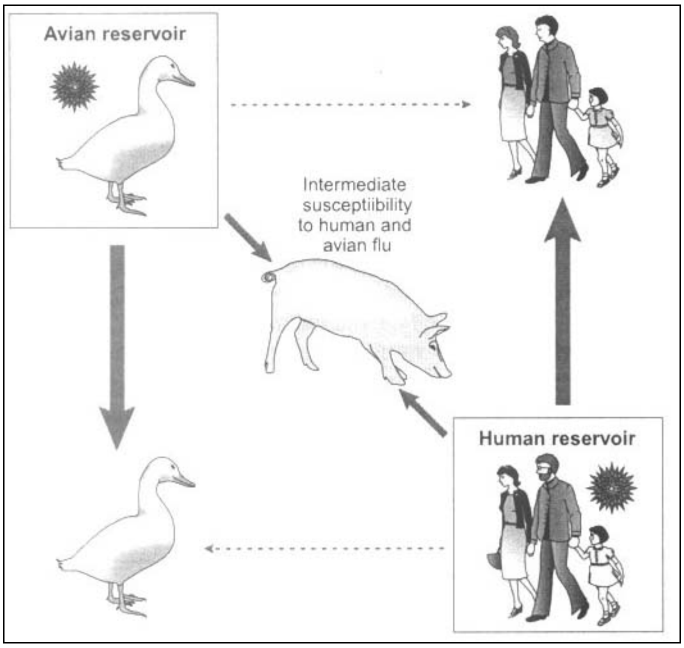

Figure 2: (Webby et al. 2004). The primary reservoir of the influenza A virus is the aquatic bird. Viruses adapted to humans form part of the human reservoir. Pigs may act as hosts to both avian and human viruses, providing opportunity for viral reassortment. The new virus can then get passed to humans though the avian reservoir or the human reservoir.

Past disease emergence and current risks

Evidence exists that the hunting and consumption of wild meat has already resulted in disease emergence. HIV is thought to have evolved from a family of primate viruses, possibly transferred to humans during hunting (Barre-Sinoussi 1996). In the past four years, 13 of 16 Ebola outbreaks in Gabon and the Republic of Congo have resulted from the handling of gorilla or chimpanzee carcasses (LeRoy et al. 2004). A recent study documents simian foamy virus (SFV) in individuals engaged in bushmeat hunting in rural Cameroon (Wolfe et al. 2004).

Markets have also spawned zoonoses. SARS may have emerged in humans from SARS-like coronaviruses (CoV) in Himalayan palm civets (*Paguna larvata*) and other small carnivores in the wet markets of Asia. Specimens collected from animals found in live wild-game markets in Guangdong in China yielded a SARS CoV-like virus with more than 99% nucleotide homology (Peiris et al. 2004). Several of the early SARS patients in Guangdong Province worked in the sale or preparation of wildlife for food (Bell et al. 2004). Five out of ten civet dealers at the market were found to have antibodies that cross-reacted with SARS (Bell et al. 2004). In turn, the disease may have jumped to civets from bats, which are also increasingly present in wet markets in southern China (Li et al. 2005).

SARS illustrates the interconnectedness of global populations. Hunters, farmers, market vendors and consumers experience the direct risk of disease transmission from wild meat and animals (Karesh et al. 2005). However, other individuals around the world are also at risk from human-to-human transmission of zoonoses, or from disease transmission from wildlife if emerging viruses establish themselves in wildlife populations. The SARS outbreak illustrates how quickly a local outbreak can turn into a global crisis. It initially affected individuals in Hong Kong and southern China. Through human air travel, SARS quickly spread to 25 countries in five continents (Peiris et al. 2004). With over 700 million people travelling by air annually, disease outbreaks can easily change into worldwide epidemics (Karesh et al. 2005). The probability of a disease outbreak spreading to a new population depends on the rate of introduction of infected individuals into the new population. This means that countries with significant air traffic and transport have an elevated likelihood of disease outbreak (Hufnagel et al. 2004). As a major hub for air traffic, London is a city at particular risk.

At the time of writing, the evolution of H5N1 avian influenza virus is generating specific concern. Avian influenza is a viral disease affecting the respiratory, digestive and nervous systems of many species of birds. Influenza viruses are classified into different groups, A, B and C, based on protein spikes on their outer surface. Certain types, such as influenza C, are widespread and only mildly pathogenic, while other forms of influenza, such as influenza A, are highly mutable and could present significant disease risk to humans. The 1918 pandemic may have begun after the adaptive mutation of an avian influenza virus. Pandemics in 1957 and 1968 are known to have been caused by the exchange of genes between avian and human influenza viruses (WHO 2005a).

It is believed that the current strain of H5N1 influenza began circulating in poultry in parts of Asia in 1997. The virus may have been introduced to poultry from wild birds and may initially have caused only mild symptoms. Infected birds shed virus in saliva, nasal secretions and faeces. Other birds become infected when they have contact with these excretions. In 1997, outbreaks of H5N1 were controlled in Asia by drastic poultry culls. H5N1 emerged in eight Asian countries during late 2003 and early 2004. Since that time, the virus has spread to other countries in Asia and to several countries in Europe including Turkey, Romania, and Croatia (CDC 2005). Over time, the virus has become progressively more pathogenic in poultry and is now killing wild migratory birds. The virus is also expanding its mammalian host range and has caused death in domestic cats and captive tigers (WHO 2005a). H5N1 infection in tigers was linked to feeding on chicken carcasses. Humans may become sick when exposed to sick or dying poultry. Transmission of the infection from person to person is rare and has not continued beyond one person (WHO 2005a). H5N1 has not yet therefore met all the pathway requirements for full disease emergence. However, the continued spread of H5N1 influenza is a cause for concern because it has been documented to pass directly from birds to humans, in whom it causes severe disease. Never before has a highly pathogenic avian influenza virus caused outbreaks in wildlife in so many countries at once (WHO 2005a).

While the disease ecology of influenza is complex, the wildlife trade plays a role in the evolution and spread of the disease. Wet markets, where poultry is exposed to ‘mixing vessels’ such as pigs, may have assisted viral reassortment. In turn, shipments of poultry and wild birds enable the continued spread of the virus (Webster 2004; Appenzeller 2005). Airport authorities in Belgium found two smuggled mountain hawk eagles from Thailand. Both tested positive for H5N1 in its highly pathogenic form (WHO 2005a).

Disease drivers

Diseases have emerged into the human population throughout history. Historical reflection suggests that epidemiological transitions occur as a result of changes in human lifestyle, changes in human interaction with the environment or wildlife, or changes in contact between different human populations (McNeil 1998). Levins (2000) summarises: ‘Diseases come and go when there are major changes in social relations, populations, the kinds of food we eat, and land use. When we change our relations with nature, we also change epidemiology and the opportunities for infection.’ Drivers of disease can be defined as social, economic or physical factors that change the behaviour of the disease source, the pathway or the receptor.

Major changes in disease abundance and distribution have been termed epidemiological transitions. Four epidemiological transitions can be identified in history. The first, a prehistoric transition, was associated with the human evolutionary process. As early hominids moved from tree dwelling to living in the savannah, they were exposed to different disease vectors, including mosquitoes and tick species. Growing reliance on the consumption of meat increased human exposure to animal diseases and sparked the evolution of new zoonoses (McMichael 2002). The second transition occurred between 5,000 and 10,000 years ago. Changes in health were precipitated by the development of agriculture and the rise of permanent communities. The impact of the agricultural revolution on health was probably mixed. Sedentary populations were less likely to encounter a wide range of zoonoses, and land clearance may have assisted with the elimination of other vectors (Cohen 1989). At the same time, other aspects of agricultural life were detrimental to human health. The proliferation of parasites was favoured by practices such as using stagnant water for irrigation, the application of manure and increased contact with domestic animals (Pedersen 1996). A third epidemiological transition occurred at the continental level, between Mediterranean and south Asian civilisations, and then between the Roman Empire and China, some 5,000 and 2,000 years ago respectively. Exchanges of diseases such as smallpox and bubonic plague resulted from contact between the different civilisations (McMichael 2004). The fourth transition occurred at a trans-oceanic level approximately 500 years ago. This resulted from European exploration and colonisation of the Americas, the Pacific and the Australasian regions (McMichael 2002). Unlike previous transitions, microbial traffic this time was relatively one-sided, from Europe to the Americas (Barnett and Whiteside 2002).

Today, authors such as McMichael (2002) have proposed that we are experiencing a fifth epidemiological transition. Drivers of the current epidemiological transition include the expansion of the human population, changing relationships with the environment, and globalisation (Brown 2004). The expanding human population influences agricultural development, urbanisation, deforestation and habitat fragmentation. This in turn influences disease emergence by changing the densities and ecology of disease vectors and pathogens, and altering human interaction with them (McMichael 2004). In *The Coming Plague*, Laurie Garrett (1994) says: ‘If an ecology had been entirely devastated and its eventual replacement species were of inadequate diversity to ensure a proper balance among the flora, fauna, and microbes, new disease phenomena might emerge.’ Habitat fragmentation and deforestation can result in the crowding of wildlife populations into increasingly small areas, or the fragmentation of populations into isolated groups. North American wild waterfowl populations have witnessed huge outbreaks of infectious disease such as fowl cholera. Their crowding into decreasing wetlands has led to the establishment of a critically large population for disease outbreak and can lead to immunosuppression through density-induced stress (Brown 1999). Growing human contact with wildlife caused by population pressure on remaining environmental resources increases the opportunity for pathogen exchange (Wolfe et al. 1998). Globalisation, in turn, has an impact on disease emergence as disease agents have the opportunity to move into new niches and meet new vulnerable populations.

Both expanding populations and globalisation can be considered as drivers of the trade in wild animals for consumption. Increasing human populations create additional demand on protein supplies, including wild meat, while globalisation helps to create and maintain markets for wild meat. Meat from Asia and Africa can be shipped abroad to centres of demand in Europe.

However, a variety of other factors also drives the bushmeat trade. The development of infrastructure, such as roads, assists the transport of meat and wildlife to urban areas and markets. Rural poverty perpetuates high-risk behaviours, including the slaughter and consumption of, and trade in, infected meat (WHO 2005a). In Laos, 53% of the rural population lives in poverty. The wildlife trade provides a means to obtain household goods, such as clothing, throughout the year, and a way to obtain rice during shortfalls in crop production (Nooren and Claridge 2001). Furthermore, wild meat may be the only source of protein available in rural and impoverished areas. In urban areas, alternative sources of meat are available. However, urban dwellers still like bushmeat (Robinson and Bodmer 1999). Wild meat is considered a delicacy, with consumers prepared to pay a price premium. In 1994 in Libreville, Gabon, bushmeat commanded 1.6 times the price of the most popular cut of beef (Steele 1994). In urban areas, increases in human welfare lead to greater demand for luxuries, such as bushmeat, a process illustrated in Figure 3. In Asia, consumer preferences for fresh food also play a role in the continued existence of wet markets, despite the existence of western supermarkets (Goldman et al. 1999).

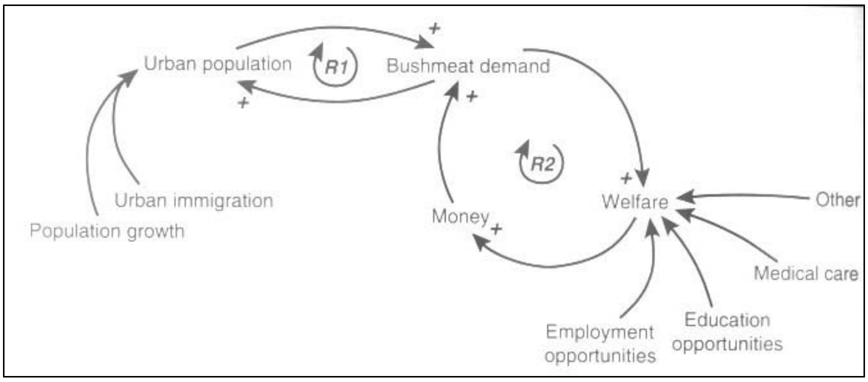

Figure 3: Causal loop diagram showing bushmeat demand cycle (Albrechtsen 2005)

Cause for concern

The emergence of new zoonoses is a cause for concern and has even been described as a national security threat (Brower and Chalk 2003). Zoonoses may result in significant loss of human life, may disrupt the economy, and may undermine social and political stability. Past outbreaks of diseases illustrate the potential impact of zoonoses. The influenza epidemic of 1918 killed more than 50 million people, three times as many as died in the First World War (Appenzeller 2005). As current fears about H5N1 avian influenza illustrate, zoonoses continue to spark global pandemics with high rates of mortality. The economic impacts of emerging diseases are also devastating. Exports from Thailand's industrial chicken farms collapsed after outbreaks of avian influenza. In 2004, Thailand's gross domestic product was estimated to have fallen by US$1.2 billion as a result of losses to poultry farming (WHO2005a).

In parts of Indonesia, 20% of workers in commercial poultry operations lost their jobs (Appenzeller 2005). During an outbreak of SARS in Toronto, Canada, commerce and travel were curtailed and businesses lost hundreds of millions of dollars (Weinstein 2004).

Diseases may also have long-term impacts. AIDS has negated half a century of development gains in Africa as measured by life expectancy (Barnett and Whiteside 2002). In nine African countries with HIV prevalence of 10% or more among adults, life expectancy by 2010–2015 will be 47 years on average, compared to 64 years without HIV (Seale 2000). Barnett and Whiteside (2002) describe the impact of disease on the structure of society: 'In the worst-affected countries economic growth may falter, provision of social services may become difficult and the epidemic may ultimately threaten political stability as the fabric of government is frayed.'

Response to disease threats

Preparations for and responses to threats from emerging diseases should occur in accordance with a discovery-to-control continuum (Murphy 1998). Several themes emerge. First, risk mitigation involves input from and co-ordination of a variety of actors at local, regional, national and international level (Ridley 2004). Second, knowledge and understanding of the factors that influence disease emergence need to be holistic. Murphy (1998) argues that, in order to fully address current disease risks, we need to build a cadre of professionals with an appreciation of several medical and biological sciences. Similarly, Pedersen (1996) argues that in order to understand diseases today, broader frames of analysis are needed: 'A new disease ecology must be translated into a new research agenda in international health involving ecologically-oriented health and social scientists aimed at improving understanding of reciprocal relationships between multiple causes and effects, constructing new paradigms and shedding light on the broader social, cultural and political issues influencing the health status and disease experience of large segments of the world population.'

Third, long-term planning and research are required. Wildlife samples should be archived for future reference. As the manufacturing of vaccines can be slow, stockpiles need to be established before a disease spreads globally.

Specific actions along the discovery-to-control continuum are described below.

Discovery of disease: In the first step, diseases must be identified and monitored. Disease surveillance should be considered a national priority. Countries that conduct disease surveillance of their wild animal populations are more likely to detect zoonotic diseases (Morner et al. 2002). Reports of illness in animals may provide the first warning of the presence of a new disease agent (Morner et al. 2002). Animal scientists, wildlife experts and diagnostic laboratories can all assist in the identification of new diseases. However, the community supporting zoonotic public health programmes is often small, poorly experienced at fieldwork, and scientifically fragmented

(Murphy 1998). For surveillance and disease identification to be effective, networks need to be developed among universities, government facilities, zoological institutions and non-governmental and private organisations.

Preparation prior to disease spread: Once a disease has been identified, more data on it must be gathered and preparations for a possible outbreak made. Epidemiologists need to conduct risk assessments to determine the likelihood of a pandemic, while pharmaceutical companies can begin to develop and stockpile vaccines. The private sector must be integrated into overall public health efforts so that findings made by a biomedical research laboratory are also shared with national laboratories (Brower and Chalk 2003). At this point, it is also critical that public health authorities engage in interdisciplinary strategy development with veterinary and agriculture agencies (Murphy 1998). It is important to identify the roles and responsibilities of each agency in terms of wildlife and human disease control and management. Vaccine distribution protocols must be developed, together with measures ensuring the equity of supply of pharmaceutical products. At a local level, hospitals and emergency facilities need to develop appropriate emergency plans to accommodate large patient influxes, as well as ensuring that health facilities can communicate electronically for the rapid distribution of knowledge (Brower and Chalk 2003).

Hufnagel et al. (2004) suggest that the quarantine of cities, or of neighbourhoods within cities, is the most efficient way to prevent disease from spreading once an outbreak has began. Local governments need to develop quarantine strategies now, examining the legal, social and economic implications of such measures (Weinstein 2004).

Actions must also be co-ordinated internationally, because disease risks transcend national borders. The countries most at risk from disease emergence are often those least prepared for it (WHO 2005a). Many African and Asian countries are in desperate need of better surveillance and diagnostic systems and laboratory facilities for work at biosafety level 4 (Murphy 1998). Access to antiviral drugs and vaccines also remains a problem. The majority of developing countries would not have access to vaccines during the first wave of an avian influenza epidemic, and it would be prudent for western countries to provide them with support. Mutual aid agreements could assist preparations by including provisions for the sharing of biological intelligence, research, diagnostics and personnel (Brower and Chalk 2003). Global vaccine standards need to be developed to ensure quality and safety. Regulatory pathways for vaccine licensing need to be harmonised and support provided to vaccine makers in developing countries.

Control during disease spread: If the disease outbreak grows into an epidemic, it is necessary to contain or delay spread of the virus and reduce its impact in terms of morbidity, mortality, and economic and social disruption. Disease management efforts can include:

- target control – efforts to control the virus in the human population with no reference to the disease source

- blocking tactics – efforts to block the spread of disease between animals and humans
- source control – efforts to reduce infection in animals.

Target control should include both medical and non-medical intervention using the public health infrastructure. Medical intervention should include vaccination. As vaccine supply may be limited, vaccination cannot be considered an immediate solution. Antiviral drugs can be used to decrease the likelihood of individuals developing diseases such as influenza and to reduce the severity and duration of illness. Drugs need to be administered shortly after onset of the disease (WHO 2005a). Effective non-medical interventions include promotion of personal hygiene, the wearing of masks, the containment of the sick in hospitals, rapid case reporting, and community surveillance (Brower and Chalk 2003). Large-scale education campaigns locally and internationally can help raise awareness of the disease and how to slow down its spread. However, actions aimed at target control do not address the source of the disease. Blocking tactics and source control may be a more effective way to manage zoonoses.

Attempts can be made to limit opportunities for disease transmission in the wildlife trade and wildlife markets. If an outbreak occurs, important control measures include quarantining wildlife, or, if that is not possible, the rapid culling of infected animals, the proper disposal of carcasses, and restrictions on trade. The evolution of diseases can also be slowed. In response to past disease outbreaks, such as SARS, the management of wet markets is changing. The Guangdong government and Department of Public Health have banned the sale and slaughter of small wild animals such as civet cats (Zhong 2004). The Food and Agriculture Organization (FAO) recently developed a strategy to help reduce the risk of disease emergence, including measures such as vaccination of animals or birds, reducing contact between different species on certain farms, and greater control of animal and animal product movements.

However, these measures are not fully effective. Outbreaks of the H5N1 virus continue (Karesh et al. 2005). Closure or banning of the markets will put people out of work, while continuing demand will drive the markets underground, where they will be even harder to regulate (Webster 2004). Drivers of the wildlife trade need to be addressed. Education programmes can help change food preferences by communicating health risks to consumers (WHO 2005a). Rural African and Asian communities need to be provided with alternative sources of livelihood and protein.

Past lessons

Lessons can also be gleaned from past disease outbreaks. The 1918, 1957 and 1968 influenza pandemics showed that these outbreaks behave as unpredictably as the viruses that cause them. Variations are seen in mortality, illness and patterns of spread. However, one constant feature of all pandemics is the rapid surge in the number of cases. Public health structures must be prepared for this influx. Pandemics have also illustrated that there is a tendency for epidemics to emerge in waves, with later outbreaks becoming more severe. The interval between successive waves may provide time for vaccine production. In the past, vaccines have had little effect due to inadequate production levels. The 1997 outbreak of avian influenza in Hong Kong highlighted the need for disease surveillance in densely populated areas with risk factors such as large live animal markets (WHO 2005b). In Toronto, the outbreak of SARS illustrated the importance of communication with the public and of objective measures for risk assessment, as well as the need to re-examine public health laws and measures such as ‘cordons sanitaires’ (Weinstein 2004).

The SARS outbreak also illustrated that careful adherence to basic public health and infection control measures can control a disease effectively. Basic infrastructure measures can work well. Source containment, case management, contact investigation and infection control in health facilities led to the control of the SARS epidemic without a vaccine, standardised treatment or diagnostic test. SARS also illustrated that centres for disease control, the WHO, local agencies and different laboratories can work together. The SARS coronavirus was identified within weeks of the original outbreak (Weinstein 2004). It is important to continue to re-examine such disease outbreaks to identify sources of weakness and strength in public health infrastructure.

Response in the United Kingdom

In response to threats from emerging diseases such as avian influenza, the UK health and agriculture departments have released contingency plans. The Department of Health’s Influenza Pandemic Contingency Plan highlights some of the preparations made by the National Health Service for an outbreak of avian influenza (DH 2005a). Many of the measures it contains are also applicable to other diseases. The plan assumes that if an outbreak of avian influenza occurs and is transmissible from human to human, 25% of the population in the UK will develop clinical influenza over a period of 12 weeks. Consultations with general practitioners will increase, as will hospital admissions. Attack rates and their severity will vary between age groups, and an influenza pandemic could cause a total of 50,000 additional deaths. The Government’s response to such an outbreak will occur in phases. Preparations will occur before the outbreak. This was happening at the time of writing. Action will continue during the pandemic. The goal of any response will be to save lives, reduce the health impact and minimise disruption to health services, while reducing general disruption to society and the economy. Two key interventions will be used to minimise the impact of the emerging disease: immunisation and the use of antiretroviral drugs. As a vaccine cannot be developed effectively until an infectious influenza strain emerges, stockpiles of antiretroviral drugs are currently being amassed. The UK Department of Health will co-ordinate the health response, procure antiviral drugs, facilitate the development, manufacture and supply of an effective vaccine, and provide information to other government departments and the media. The Department of Health acknowledges that flexibility at the local level is important. It asks regional and local-level organisations, primary care trusts (PCTs) and strategic health authorities (SHAs) to develop, maintain and periodically test multi-agency plans. The plan also acknowledges the UK's international responsibility for supporting the efforts of the WHO.

The Exotic Animal Disease Generic Contingency Plan of the UK Department for Environment, Food and Rural Affairs (Defra) outlines strategies and systems that would be deployed in an outbreak of any exotic disease in the food and agriculture sectors (Defra 2005). The plan seeks to ensure improved surveillance of animal disease, prevent illegal imports of infected meat and improve biosecurity on farms. In the event of an outbreak, the Government will employ control strategies which aim to minimise the number of animals that need to be slaughtered, cause the least possible disruption of the food, farming and tourism industries, minimise damage to the environment and protect public health, and, finally, minimise the burden on taxpayers. Vaccination will be used as a primary control measure. Other approaches that may be employed include prohibition of the movement of animals, litter and vehicles into and out of the infected place, cleansing and disinfection of vehicles and premises, long-term controls to ensure that outbreaks do not recur, and compensation to farmers for animals slaughtered (Defra 2005). A variety of stakeholders will be involved, including local and regional government organisations. If necessary, the armed forces will provide assistance with logistic capacity. The plan calls for the immediate establishment of a permanent expert group with input from epidemiologists, veterinarians and virologists.

These two contingency plans include positive features such as co-ordination at national, regional, and local levels and multi-stakeholder involvement. The plans aim to control any disease outbreak by initiating both target control and blocking strategies. However, neither plan discusses source control or the need to address the driving forces behind the emergence of disease. Aid should be provided to help introduce and maintain hygienic practices in wet markets in Asia and to enforce legislation to limit the illegal bushmeat trade. Funds to support public health infrastructure and disease monitoring in developing countries could help control a disease outbreak before it reaches the UK. More basic research into zoonoses and wildlife epidemiology would be sensible. The WHO highlights three urgent research needs. It points to the need for more understanding of the potential of viruses, such as H5N1, to reassort and mutate, for more knowledge of the role of animal diseases in the emergence of human pandemics, and for better methods of vaccine production.

Future risks

There is no way to predict when or where the next important new zoonotic pathogen will emerge or what its importance will be (Murphy 1998). As the editors of *Nature* commented with reference to the BSE crisis, 'Never say there is no danger. Instead, say that there is always a danger, and that the problem is to calculate what it is …' (Murphy 1998). While the future can never be certain, reflection on different scenarios is useful to help decision makers take the necessary precautions.

Theories, such as the epidemiological transition theory, suggest that if modernisation continues, infectious diseases may decrease while chronic diseases increase. The Global Burden of Disease (GBD) Study, commissioned by the WHO and the World Bank, estimated worldwide and regional cause-of-death patterns in 1990 for 14 age/sex groups. The study divided causes of mortality into three groups. Group 1 consisted of infectious diseases, maternal and perinatal and nutritional disorders; Group 2 consisted of non-communicable diseases; Group 3 consisted of all intentional or unintentional injuries. Worldwide, deaths from non-communicable diseases vastly outnumbered deaths from infectious diseases. However, there were regional variations. For developing regions as a whole, Group 1 causes accounted for 40% of deaths, while Group 2 causes resulted in 50%. For countries with established market economies, only 6.25% of deaths resulted from Group 1 causes, while 85% resulted from Group 2 causes (Murray and Lopez 1997). These results appear to indicate that infectious diseases decrease as a result of economic development. Salomon and Murray (2002) examined worldwide mortality data from 1950 until the present in order to determine whether causes of death were changing with increases in income and standard of living. Diseases were classified according to the three groups set out by the GBD. Salomon and Murray (2002) concluded that increases in income *per capita* are associated with increases of Group 2 and Group 3 causes of mortality.

While economic development may reduce mortality from of infectious diseases, other factors may ensure that they continue to emerge. If pathways of disease emergence proliferate, new diseases will emerge in future, while the rate of their emergence will also increase. For example, if the wildlife trade increases in volume, it can be assumed that opportunities for disease transmission, or pathways, will also increase, resulting in new zoonoses. Further, if viruses such as H5N1 influenza become endemic in wildlife populations across continents, disease risks will not diminish even if the wildlife trade is halted or if standards of living rise.

In the Global Environmental Outlook 3 (GEO 3), the United Nations Environment Programme (UNEP 2002) presents four qualitative scenarios of change over approximately the next 30 years. Scenario analysis provides the opportunity to explore the combined impact of change in a variety of driving factors. Driving factors considered in the GEO 3 report include demography, economic development, human development, science and technology and environment. Each of the four scenarios in GEO 3 presents different outcomes for 2032.

The scenarios are:

1 *Markets First*. This scenario envisions a world that adopts market-driven development. The wealth of nations and the optimal play of market forces dominate social and political agendas. Globalisation and economic liberalisation continue. The impacts of these policies include continued population growth, predominantly in developing

countries. Population growth slows over time, as more countries pass through the demographic transition.[2] Urbanisation increases in Asian and Africa. Economic development is assumed to lead to social improvement, but economic inequality increases. The percentage of the world population living in hunger decreases (Figure 4), but this does not counterbalance population growth in regions such as Africa. The overall number of people living in hunger changes little.

2 *Policy First*. In this scenario governments take decisive action in an attempt to reach specific social and environmental goals. Environmental and social costs and gains are factored into policy measures and planning processes. The resulting policies speed up the demographic transition. The world achieves slightly lower levels of population growth. Global economic integration persists but is tempered by new policies. Income rises among the poor. Dramatic reductions occur in the percentage and total number of people affected by hunger (Figure 4).

3 *Security First*. This scenario assumes a world of great disparities, where inequality and conflict prevail, brought about by social, economic and environmental stresses. Wealthy groups focus on self-protection, with enhanced security and economic benefits, excluding the economically disadvantaged. Income growth is slow and unequal between world regions. Slower economic and social development slow demographic transition. Higher population levels result. Trends towards global integration continue for some parts of the economy, yet come to a halt in other areas. Sharp increases in the number of people living in hunger occur in most regions of the world (Figure 4).

4 *Sustainability First*. This scenario pictures a world in which a new development paradigm emerges in response to the challenge of sustainability. Sustainable policy measures and accountable corporate behaviour are encouraged, with collaborative decision making between governments, citizens and other groups. Values of simplicity, co-operation and community begin to displace those of consumerism, competition and individualism. Behavioural changes speed up the demographic transition. This scenario involves the least economic globalisation of the four, while the convergence of *per capita* incomes is the greatest. Emphasis is placed on meeting basic needs, and groups outside the public sector are involved in development initiatives. This scenario has the greatest decrease in the number of people living in hunger (Figure 4).

[2] The demographic transition is a model that explains the demographic transformation of a country from high birth/high death rates to low birth/low death rates. In the final stage of the demographic transition, countries have stable low birth/low death rates.

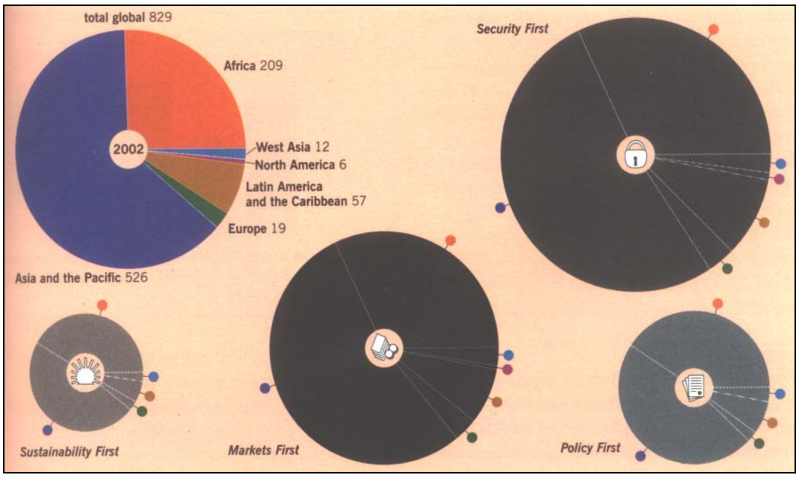

Figure 4: (UNEP 2002). Population living with hunger (million persons) in 2002 and in 2032. The top-left pie chart shows the population living in hunger in 2002, divided by region. The other four pie charts reflect population predicted to live in hunger in 2032, under each of the four scenarios. The size of the pie chart reflects the size of the population living in hunger. The *Security First* scenario has the largest population living in hunger while *Sustainability First* has the smallest population living in hunger.

Demographic, economic and development drivers have different trajectories in each of these scenarios. These may have different impacts on emerging disease and the wildlife trade. The *Markets First* and *Security First* scenarios present increasing population growth and urbanisation, continued globalisation, and consistent or increasing levels of hunger. The drivers of the wildlife trade described above therefore continue to grow in strength. Environmental disruption occurs in both scenarios (Figure 5), again with impacts for the wildlife trade and the emergence of disease. In *Security First*, the worldwide infrastructure network, including roads and airports, sees dramatic expansion in the next 30 years. The introduction of such infrastructure leads to increased resource exploitation such as hunting, with an increase in opportunities for disease transmission (UNEP 2002). As human populations grow, people will live in closer proximity to wild animal populations, generating greater human–wildlife interaction and greater opportunities for disease spread. At an extreme, environmental degradation may reduce the abundance of wildlife, affecting the source of the zoonoses, and may limit supplies for the wildlife trade, thereby restricting the disease transmission pathway. By contrast, in *Policy First* and *Sustainability First*, drivers of the wildlife trade, such as population growth and poverty, are reduced. As additional wilderness areas are designated as protected, contact with wildlife may decrease, reducing the risk of continued disease transmission.

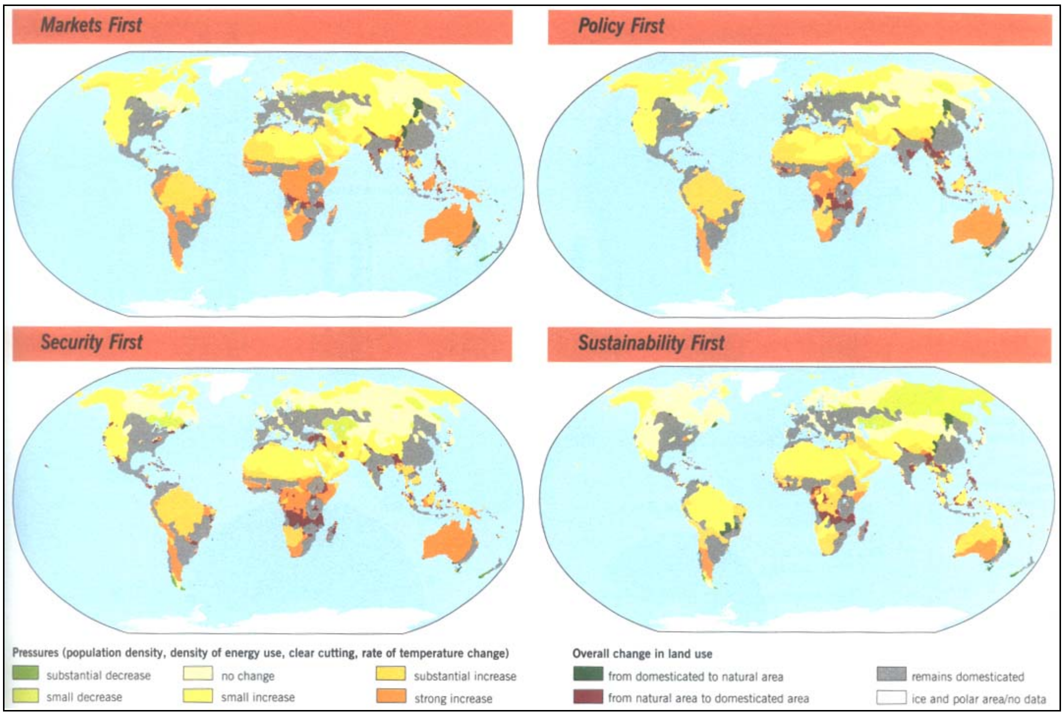

Figure 5: (UNEP 2002). Change in pressures (population density, density of energy use, clear cutting, and rate of temperature change) on natural ecosystems in each of the four scenarios. Maps picture the combined effect of change in 2032, relative to 2002. The *Security First* scenario predicts the conversion of natural land into agriculture, particularly in the southern hemisphere. The *Markets First* scenario also sees strong increases in environmental pressures in the southern hemisphere, but sees some conversion of domesticated land into natural areas. The *Policy First* scenario predicts slightly less pressure on the ecosystems than in the *Markets First* scenario. The *Sustainability First* scenario sees a slight decrease in pressures on certain ecosystems.

In the long term, climate change may have an important impact on disease emergence. The Special Report on Regional Impacts of Climate Change of the Intergovernmental Panel on Climate Change (IPCC) predicts that climate change will affect the sources, pathways and drivers of infectious diseases (McCarthy et al. 2001). Altered wind patterns, changes in rainfall and humidity, and changes in vegetation patterns will result from rising temperatures. This will alter the ecology of microbes as well as their vectors (Garrett 1994). It may affect the geographical distribution of humans and of animals species, exposing them to new pathogens.

Epidemics of Rift Valley fever illustrate the impact of climate on disease. Rift Valley fever is pathogenic for ruminants but can also be transmitted to humans by mosquitoes. It is associated with periods of heavy rainfall because mosquito populations increase during this time (Brown 1999). Furthermore, increases in extreme weather events will worsen food security in parts of Africa, potentially increasing demand for the wildlife trade (McCarthy et al. 2001).

In *Markets First* and *Security First*, above, carbon dioxide emissions continue to rise, though, over time, emissions decrease in the *Security First* scenario due to economic and political turmoil. In the *Policy First* and *Sustainability First* scenarios, carbon dioxide emissions decrease, most rapidly in *Sustainability First* projections. Climate response to different emissions scenarios occurs slowly, and is only significantly noticeable in the year 2050 (UNEP 2002). In each of the scenarios, the impact of climate change will be highly variable in different regions of the world. Therefore it is hard to make exact predictions about the impact of climate on disease emergence.

The WHO concludes that the only certainty in the future is that diseases will continue to emerge. Their emergence may be slowed by the adoption of sustainable policies and equitable development strategies, or be accelerated by market forces and globalisation. However, disease emergence can never be eliminated fully. The effects of the next zoonosis will be influenced by the properties of the virus involved, which cannot be known in advance (WHO 2005a). It is known, however, that if a pandemic occurs, health systems will be confronted by a sudden increase in demand for healthcare. Perhaps it is better to focus efforts on preparation for disease outbreaks and on improving health systems and standards of care than on seeking to predict what diseases will emerge.

New outlook

Ultimately, we need to rethink our assumptions about our relationship with the natural world. Throughout the 20th century, human beings were tantalised by the notion that advances in scientific and medical knowledge would eliminate infectious disease. The emergence of diseases such as AIDS raises doubts about this assumption. In 2001, approximately 36 million individuals were living with HIV/Aids. Assuming that each case directly influences the lives of four other individuals, a total of 180 million people are affected by the disease (Barnett and Whiteside 2002). As Susan Sontag (1991) comments, AIDS illustrates the hubris of medical practice: 'The advent of AIDS has made it clear that infectious diseases are far from conquered and their roster far from closed.' And Carolina and Gustavo (2003) observe: 'Disease is one of the conditions of existence of our species, which, despite its achievements, is unable to escape from its biological basis.' It is time to engage in extensive exploration of the relationship between the natural world and ourselves, and to seek to establish relationships of respect.

Action points

The following action points emerge from this paperThe risk of diseases emerging from the wildlife trade is significant and will persist. Diseases that have been linked to trade or consumption of wildlife include Ebola, HIV, SARS, and avian influenza. It is likely that outbreaks of these diseases will continue in future. New diseases may also emerge if contact with the wildlife trade continues, and if factors such as globalisation, poverty, environmental change and degradation are not addressed.

- Vertebrate animals and birds are a source of zoonoses. Throughout history, disease has spread to humans from both domestic animals and wildlife. Disease may spread from wildlife to domestic animals and then to humans, or directly from wild animals to human populations. Past sources have included primates, poultry, rodents and canids. As long as humans interact with animals, diseases will continue to spread.
- In 2015, it is likely that disease sources will remain the same and will include both wild and domestic animals. By 2030, if populations of wildlife are depleted by human activities such as the wildlife trade, disease reservoirs may have shifted to domestic animals such as poultry and pigs.
- Reports of illness or mass mortality in animals may be an initial alert to the presence of a new disease agent. Early investigation of unexpected disease outbreaks in animals is critical. Both live and dead animals should be sampled, and both quantitative and qualitative data collected, including biological data about the animal's behaviour, clinical findings, and pathology. Samples should be carefully stored and archived. If diseases are investigated regularly, basic knowledge about what kinds of diseases occur within certain geographical regions will be achieved (Morner et al. 2002). Given only limited funds, monitoring programmes could focus efforts on species, such as primates, from which numerous diseases have emerged. Physiological and genetic similarities between humans and other primates ensure that they are susceptible to many of the same viruses, bacteria, fungi, protozoa and ectoparasites, and that these may be transferred easily between species on contact (Wolfe et al. 1998). Monitoring could also focus on species with which humans have significant contact, such as poultry.
- The hunting and wet markets associated with the wildlife trade offer pathways for disease to travel from wild animals to humans, as do the preparation and consumption of the wild meat involved. For a disease to spread, it must not only infect a human, but it must then grow within that human, and spread between humans. These biological requirements act as filters, preventing the evolution of pandemics. However, genetic changes within the virus may enable diseases to spread. A new disease itself may emerge as a result of a reassortment event in which genetic exchange takes place between a human virus and an animal virus, or as a result of adaptive mutation, in which the capacity of the virus to bind to human cells increases during subsequent human infections. Genetic change may take place in third-party animals, such as pigs, which can act as amplifiers, assisting the evolution of diseases. Human actions can also act as filters and amplifiers. For example, the separation of species in wet markets could diminish the risk of disease transmission, while poor hygiene practices amplify the possibilities for virus reassortment.
- In 2015 and 2030, disease pathways are likely to remain similar to those we observe today. However, changes in driving factors may influence disease pathways. If factors driving the wildlife trade – such as poverty – decrease, bushmeat hunting may also decrease, and this pathway for disease transmission will decline.

- Pathways that could have a significant influence on disease risk include those that bring a large variety of animals and humans into contact, such as wet markets, and high-intensity, high-volume activities, which increase opportunities for disease transfer and mutation, such as commercial bushmeat hunting.
- Population growth, globalisation, infrastructure development, rural poverty, urban demand and consumer preferences are some of the drivers of the trade in wild meat, and therefore of disease emergence.
- Future projections of interactions among drivers are provided by scenario analysis. If policies based on market or security priorities are promoted, the global population will continue to grow, accompanied by continued globalisation, environmental destruction, and poverty. Under these scenarios, the impact of harmful infections is likely to remain significant in 2015 and 2030, especially in underdeveloped parts of the world. If *Policy First* or *Sustainability First* policies are adopted, drivers such as population growth may slow, environmental resources will remain secure, and poverty levels may decrease. By 2015, the impact of this change may not yet be significant. But by 2030, significant differences will exist between the scenarios. In the long term, climate change may also influence the drivers of the wildlife trade, and may affect the distribution of humans and animals, exposing them to new pathogens. However, a significant impact from climate change may only be felt in the middle of the century.
- Assessing the specific influence of a driver on disease risk is complicated. Several drivers may act together to influence a pathway of disease transfer or affect the disease source. New theories of epidemiology, such as eco-epidemiology, may offer tools with which to assess the influence of a driver on disease risk. During the past decade, the eco-epidemiology paradigm has been proposed to allow the examination of complex causal pathways. Three different theories have been advanced: eco-epidemiology, the social-ecological systems perspective and the ecosocial approach (Krieger 2001). At the core of each of these approaches are concerns with scale, levels of organisation, dynamic states and the understanding of unique phenomena in relation to general process (Krieger 2001). Eco-epidemiology theories examine disease at the social, ecological and biological level – levels that impact on disease emergence. The theories have much to offer in enhancing our understanding of the interaction between drivers of disease and disease emergence.
- The threat of disease emergence reminds us of the linkages between human and animal disease silos, and should force us to reevaluate our relationship with the natural world**.** Activities such as the bushmeat trade, which may be driven by poverty, change our interaction with the environment and have led to the emergence of diseases such as HIV. In turn, HIV, for example, increases poverty, which produces large numbers of immunosuppressed people, further assisting the emergence of new viruses. We should no longer assume that science and technology will enable us to eliminate infectious disease or that we can sever our link with the natural world.

- The specific evolution of viruses cannot be predicted. Further, it is difficult to predict which viruses will cause global pandemics. However, airborne viruses and RNA viruses may be particularly difficult to contain. The emergence of airborne or RNA viruses can be considered as red flags for the spread of disease. Disease emergence in areas of high population density, or in transportation hubs, can also be considered a red flag for a global pandemic.
- Preparation for disease emergence must occur along a discovery-to-control continuum. Resources must be invested in wildlife monitoring and in research on emerging diseases. Disease outbreak among wildlife, in the UK and overseas, should be considered an early warning for a potential human disease threat. Once a disease has been identified, interagency co-ordination is needed, as well as dialogue between local, regional, national and international agencies. If a pandemic occurs, vaccination and antiviral drugs may be used to limit disease spread. But these must be distributed equitably to achieve effective control. As vaccine production is slow, disease control measures must also seek to prevent disease transmission to humans and to control disease in the animal source. Wildlife may be vaccinated to reduce incidence of the disease in the disease source. Contact between wildlife and humans, and wildlife and domestic livestock, should be prevented.
- Critical inflection points are points along the discovery-to-control continuum where action can significantly reduce disease spread, and where investment in detection and identification can make a significant difference. Control of disease in wildlife acts as a critical inflection point. If diseases can be prevented or controlled in the animal source, the likelihood of spread to humans is greatly reduced. Disease control efforts in the original country of the outbreak also act as a critical inflection point. If the disease can be controlled at a local level, before it spreads regionally or internationally, pandemics can be averted. Resources should be spent to support disease monitoring systems in countries with extensive bushmeat trade or wet markets.
- Disease detection can be improved by establishing widespread wildlife monitoring and epidemiology programmes. However, detection will be made difficult by the complexity of disease ecology. Disease may appear seasonally, or may provide an inconsistent disease threat. It may exist in a variety of reservoirs, many of which are inaccessible. It is easier to monitor species that live in large populations, or that are farmed commercially, than scattered individuals or animals on rural and subsistence farms. Viruses may be noticed initially as a result of die-offs in commercial populations and, despite being eliminated from commercial populations, may persist undetected in rural populations that have not been monitored. Comprehensive monitoring is one of the greatest challenges in disease identification and prevention. Another challenge is the global nature of the problem. For efficient disease detection, countries around the world must institute appropriate monitoring programmes. Presently the early warning system is weak, particularly in countries that are most at risk. If financial and technological support is provided now, this challenge may be

eliminated by 2015 and 2030. Continued co-operation between countries will remain a challenge that always needs to be addressed.

- Significant uncertainty exists in the identification and detection of disease. Often the source of the disease is unknown and is therefore difficult to control. While Ebola has spread to humans as a result of the consumption of other primates, the actual reservoir of Ebola is unknown, despite thorough investigation (Peters and LeDuc 1999). Further, it is difficult to predict which diseases will produce pandemics and which will simply result in local outbreaks. Greater research into wildlife diseases and viral evolution is critical. Research into new models of epidemiology would help reduce uncertainty of disease risks.
- It is clear that, in the long term, decision makers can influence the emergence of diseases. Implementing sustainable policies with a focus on social justice and environmental preservation will provide health benefits by reducing the global impact of diseases and possibly slowing disease emergence. Decision makers can address challenges in disease detection and identification by working together at local, national, and international levels to co-ordinate monitoring efforts, and should include scientists, healthcare professionals and wildlife experts in their consultations.

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