Environment, climate change, social factors and the implications for controlling infectious diseases of poverty
We cannot rely on discovering more “magic bullets” to meet the infectious disease challenges of the poorest billion. A new paradigm is needed that recognizes the fundamental influence of environmental and ecological systems (including climate change), as affected by humans, and integrates across the fields of environment, agriculture, nutrition and social conditions.
Human activities are generating an ever-accelerating wave of change in the natural environment, while new technologies and globalization continue to alter economic and social patterns across the planet. We already know that global climate change and degradation of air, land and water in many areas are capable of profoundly endangering human health. In light of this, it is imperative that the best scientific minds examine the potential of these momentous changes to exacerbate the spread of infectious diseases, so that the world’s health systems are ready to respond.

The world’s poorest billion people tend to live in ecologically and socially risky environments, which are also where the prevalence of infectious disease is highest. Worldwide, nearly 900 million people do not have access to an improved water source, while an estimated 2.5 billion people − half of all people in developing countries − lack access to adequate sanitation (1, 2). Experience shows that the poor are more vulnerable than anyone when natural disasters strike. They are least able to advocate for sustainable ecological initiatives and will suffer most as the deleterious effects of environmental and climate change increase. And yet the world’s poorest billion are responsible for just 3% of the global carbon footprint (3, 4).

The impetus to act is at once moral, scientific and practical. For development to be sustainable, inclusive and effective in lifting people out of poverty, we need to find ways to address these inequities – particularly the links between environmental conditions and the infectious diseases that destroy so many lives and communities. Research can play a key role by informing the global community on the specific effects of climate change and other environmental drivers on infectious diseases and human health – helping us to anticipate what will happen in the decades to come. Such research may point to strategies for overcoming or at least mitigating
the effects of the infectious diseases arising as a result of environmental change. What is really needed is a new systems-based framework, drawing on interdisciplinary thinking and concepts that recognize the broader ecological dimension of infectious disease.

This chapter lays the foundation for a broadened paradigm of infectious disease research. We begin by analysing the core environmental and social drivers of infectious disease: drug and insecticide resistance, climate change, deforestation, urbanization, agriculture, hunger, conflict, migration and globalization. These drivers have complex links to infectious diseases of poverty (see Fig. 2.1) and need to be addressed within an integrative ecological framework, building on the definition of “One World, One Health” that is historically associated with the complex interrelationship between human health, animal health and the environment (5). To this nexus we add the eco-social determinants of health, recognizing that the infectious disease burden in human and animal populations is substantially influenced by changes in environmental and social conditions. To conclude, we list key questions for future research on links between the environment and infectious diseases.

**Understanding the microbial world – the inescapable starting point**

The impact of human activities on the environment is unparalleled (6). Every hour of the day, human activities clear another 1500 hectares of forests, release 4 million tons of the main greenhouse gas, carbon dioxide, into the atmosphere and cause the extinction of three species – a rate at least 1000 times greater than the historical norm (7).

These and other environmental changes are affecting the microbial world, resulting in new challenges for controlling infectious diseases. They influence the emergence of new diseases and further the persistence of older, well-established infectious diseases of poverty – including “neglected diseases” (8) such as filariasis, soil-transmitted helminthiasis, onchocerciasis and schistosomiasis, which together have a burden as large as that of tuberculosis and malaria combined. In 2008, nearly 70% of the 8.8 million deaths in children aged under five were caused by infectious diseases (9).

Most of today’s common infectious diseases entered human populations from animal or (less often) soil and water sources during the past eight millennia. The species barrier was crossed during repeated contact through activities such as land clearing, animal herding and domestication. Village life (which often featured exposure to rodents and other pests, including vectors), urbanization and increases in inter-group and inter-societal contacts via trade, conflict and warfare have enabled species jumps – zoonoses – and the spread of infectious diseases amongst human populations (12). In a recent analysis of 335 episodes of human infectious disease emergence from 1940 to 2004, researchers noted that 60% were zoonotic and that 72% of these originated in wild animals (13).

Human infectious diseases can be broadly grouped into four categories:

1. Diseases caused by infectious agents **newly recognized** as human pathogens that have probably long existed. These include Ebola in Africa and Nipah in south Asia.

2. Diseases that appear to be **genuinely new**, such as severe acute respiratory syndrome (SARS), bovine spongiform encephalopathy (BSE) and legionellosis.

3. Diseases that have **re-emerged**, such as malaria, tuberculosis (TB), dengue, Chikungunya, West Nile fever, Crimean-Congo haemorrhagic fever and Lyme disease. These maladies have spread beyond their usual geographic confines or have reappeared where once thought controlled. This may be due to the evolution of antimicrobial resistance by pathogens or due to insecticidal resistance by vectors, human migration, HIV/AIDS and changes in transmission strategies (12).
4. Diseases caused by infectious agents that are changing their modes of transmission, such as Chagas disease, which has recently been recognized to have significant oral transmission (13, 14), and Nipah virus infection, where there is airborne transmission of the virus between pigs and to their handlers (see Box 2.1).

**Box 2.1. Changing Modes of Infectious Disease Transmission in an Evolving Microbial World**

Though not responsible for a heavy burden of disease, Nipah virus is of scientific interest in that it illustrates how complex ecological factors – including deforestation, intensive agriculture, and possibly climate change – have affected its transmission. This paramyxovirus was isolated in Malaysia in 1997 after the deaths of 105 humans who had been in close contact with domestic pigs (25). Increased deforestation and the intrusion of small-scale human livestock operations into forest areas appear to be cofactors for the emergence of the virus. The pigs probably acquired the virus through direct contact with the faeces or saliva of bats eating fruit around the pigsty. The pigs then developed a respiratory form of the disease and passed the virus on to their human handlers, who surprisingly did not develop respiratory symptoms but instead died of encephalitis. It was later recognized that Nipah virus also occurs in Bangladesh and West Bengal, India, and is also thought to be transmitted to humans directly by bats and indirectly via date or palm sap (16).

**Drug and Insecticide Resistance – Magic Bullets Will Not Suffice**

Most responses to infectious diseases of poverty have emphasized interventions requiring economic development – better housing, sanitation, public hygiene – alongside improved detection and drugs, insecticides and vaccines. Too often, biotechnological initiatives have not been accompanied by commensurate efforts to achieve environmental and social innovations that can ensure effective implementation. Regrettably, many health workers and poorly informed populations have used drugs and insecticides too readily, thus accelerating the evolution of drug resistance in many microbes and vectors. There have been recent reports suggesting that the parasite responsible for the most severe form of malaria (Plasmodium falciparum) has evolved resistance to artemisinin (17). It is also likely that the use of single insecticide-treated bednets will stimulate pyrethroid resistance in mosquitoes, as happened previously when bednets were treated with dichlorodiphenyltrichloroethane (DDT) (18, 19).

The response called for is two-fold. First, we cannot rely primarily on discovering more “magic bullets”. Rather, we need a new paradigm that integrates diverse fields – a paradigm that recognizes the fundamental centrality of environmental systems and processes, including climate change, to infectious diseases of poverty. Second, we need a more anticipatory approach in our decision-making for infectious diseases of poverty, one that accommodates the complexity and uncertainty inherent in a changing microbial world.

**Research Question:**

We need to better understand the “eco-social” factors which facilitate resistance. What strategies – biological, chemical, genetic, cultural and social – exist to better control pathogens and vectors?
CLIMATE CHANGE – NOT ENTIRELY TO BLAME

The Earth’s atmosphere has been getting considerably warmer over the past two centuries. During the last century the global temperature rose by 0.8 °C (20). Since entering the industrial age around the mid 18th century, we have produced a vast output of greenhouse gas emissions that now far exceed the planet’s capacity to absorb them. Most of the global temperature rise measured since 1950 is attributed to human activity (20).

However, climate change entails more than just warming. It includes atmospheric alteration which is driving significant changes in the Earth’s weather system, including shifts in rainfall patterns, seasonality and increasingly frequent and severe weather events.

The incidence of extreme weather events is increasing, and climate change is increasingly recognized as a contributory factor. Sixty years ago, there were an average of two weather-related disasters per year; by 2007, this rate had risen to slightly more than six per year. Today, nearly 70% of these events occur in regions of Asia, the Pacific, Africa and the Middle East, where the largest populations of the poor and vulnerable reside (21).

These changes affect human health in multiple and complex ways. For example, devastating floods in Pakistan in August 2010 displaced 22 million people. In the same month a prolonged and record-breaking heatwave in Russia, associated with countless fires, killed thousands of people. It also led to a spike in the world wheat price, which in turn contributed to a rise in global food prices and thereby an increase in malnutrition and disease. On another front, global warming is causing a rise in sea levels and increasing the acidity of the oceans as carbon dioxide is absorbed. These and other climate change-related phenomena, collectively and individually, influence the ecology and the life cycles, behaviours and survival of species everywhere.

The manifestations of climate change also influence infectious disease patterns. For instance, warmer weather permits vector survival at higher elevations, spreading malaria beyond its historical geographic range, as has been documented in eastern (highland) Kenya (22,23). Climate modelling predicts that further warming may make more areas suitable for malaria transmission. Fig. 2.2 presents data from Zimbabwe examining the geographical distribution of malaria over time. Sixteen climate projections were completed, and in the absence of constraints on malaria transmission imposed by human activity, in all scenarios, changes in temperature and precipitation were shown to alter the geographical distribution of malaria (24).

FIG. 2.2. Climate change and malaria: potential transmission in Zimbabwe. Climate modelling predicts that further warming may make more areas suitable for malaria transmission (see lower image for 2050 projection compared to upper baseline image). Source: reference (24).
Previously unsuitable areas – such as the central plateau where the majority of the country’s population is concentrated – were projected to become suitable for transmission. According to these projections, by 2050, most of Zimbabwe could have a suitable climate for stable malaria transmission (24).

Some aspects of climate change may actually benefit health in some areas. For example, warmer average temperatures and hotter extremes may reduce vector populations when conditions are too hot for vector reproduction. Heavier rainfall may wash away mosquito eggs and larvae (21). It should be remembered that heavier rains, especially those that lead to flooding, often aggravate malnutrition, diarrhoea and diseases such as cholera.

**RESEARCH QUESTION:**

*What is the most effective way to use existing, orphaned and potential datasets (e.g. epidemiological, social and climatic) to analyse and forecast infectious disease outbreaks?*

Overall, however, current evidence suggests that climate change is increasing the global burden of infectious diseases (25,26). This is happening in complex ways and in combination with other eco-social changes involving things such as migration, poverty and land use change. In addition, climate is likely to be contributing to the emergence of diseases in regions previously unaffected (including at higher altitudes) and to their persistence and changed seasonality in endemic areas. As described above, extreme weather events affect the incidence and prevalence of many infectious diseases, including cholera and other diarrhoeal diseases. Flood-associated outbreaks of leptospirosis have been reported in countries as diverse as India, Argentina, Australia, Brazil and Italy (27).

The precise causal relationship of climate change to infectious diseases, especially those that are vector-borne, remains uncertain. One way to reduce this uncertainty is to establish and support data “observatories”, especially in low-income settings. A good location for an observatory would be in a transitional zone between areas either free of, or having low prevalence of, diseases thought to be climate sensitive, and those that have a high prevalence of such diseases. Candidates include the highlands of east Africa and Papua New Guinea. Other good locations are in the slums of the world’s megacities. These observatories would gather and monitor social, health and environmental indicators, including those relevant to climate. However, care must be taken not to waste precious funds on indiscriminate data collection. It may also be prudent to build on existing “orphaned” data sets – that is, time series data collected in the past that may have been abandoned due to a lack of funds or for other reasons. To help accomplish this, an inventory of existing and incomplete datasets would be useful.

**DEFORESTATION – CUTTING THE BRANCH WE SIT ON**

The relentless growth of the human population during the past half-century has stimulated city-building, forest-clearing and the expansion and intensification of agriculture. Collectively, these have dramatically altered the global landscape. While they have brought numerous health benefits for the population at large, many critical “regulating” ecosystem services (28) have been damaged, including carbon sequestration, nutrient cycling, the regulation of floods and loss of important natural buffers such as mangroves and wetlands.

Deforestation and other forms of landscape transformation have increased the risk of infectious diseases in several other ways. Pathways include more frequent direct and indirect human contact with rodents, primates, bats and birds, thereby increasing the risk of old and new zoonoses. In the Brazilian Amazon region, 186 different arboviruses have been isolated, of which 32 are known to be zoonotic (29). The loss and displace-
ment of predators and competitors can alter the population density of both reservoirs and vectors in complex ways. For example, the extinction of the passenger pigeon, once the most common bird in North America, is thought to have increased the rodent population because acorns, formerly consumed by these birds, became more available for rodents to thrive on. In turn, this increased the habitat and population of Lyme disease-transmitting ticks because mice are one of the principal reservoirs for Lyme disease spirochetes (30).

Deforestation can also alter the distribution and population size of vectorial sub-species, many of which have differing capacities to transmit pathogens. The resultant change in vectorial biodiversity can thus alter human and animal epidemiology. This has occurred with onchocerciasis, a disease where it has been shown that transmission has been altered by changes in the density of the different sub-species populations of the blackfly *Simulium damnosum* (33, 34). Similarly, forest clearing in Peru has been shown to increase the rate at which *Anopheles darlingi* mosquitoes, the major vector of *Plasmodium falciparum* (one of the malaria parasites), feed on human blood (33). In Mexico, genetic changes in mosquito vector populations linked to deforestation affected the transmission of Venezuelan equine encephalitis virus, which resulted in epidemics in animal hosts (34). Other examples of human infectious diseases that have increased in prevalence following alterations in biodiversity include hantaviruses, schistosomiasis, West Nile fever and Chagas disease.

Finally, loss of biodiversity is destroying a vast “library” of potentially valuable species – those that could potentially have medicinal, nutritional or ecological value, for example. Artemisinin, ivermectin and quinine, three drugs crucial to infectious disease management, are derived from plant species. Some of this library has been catalogued through countless generations of indigenous experience; the rapid loss of indigenous languages, knowledge and cultures risks eroding it (35).

**URBANIZATION – IS WEALTHIER ALWAYS HEALTHIER?**

The world’s population is quickly becoming urbanized as growing numbers of people migrate to the cities. Today, around 3.5 billion people – about half the world’s population – live in urban areas; by 2050, this figure may exceed 6 billion (36). New cities are forming while many old ones are expanding. In 1975, only three of the world’s cities – New York, Tokyo and Mexico City – had populations exceeding 10 million. Today there are 21 such megacities and by 2025 this number will likely grow to 29. The majority of them will be in Asia, followed by Latin America and Africa (37).

Careful and far-sighted urban planning can enhance environmental conditions and health. But all too often urban growth is rapid and unplanned, thereby worsening the environment and generating crowding, poor sanitation and water and air pollution (see Box 2.2). These conditions, in turn, increase the risk of exposure to waterborne and respiratory infections, occupational hazards, heatwaves, pollutants and chemical wastes.

**BOX 2.2. THE EFFECT OF URBANIZATION ON LAKE TAI, CHINA**

Lake Tai (or the Grand Lake) is the third largest lake in China. In May 2007, human activity and pollution produced high levels of cyanobacteria (blue-green) algae that rendered the lake’s water unfit for human consumption. This affected 30 million people in the city of Wuxi and its region. Nearly 60% of the water in China’s seven main rivers has been judged unsafe for human consumption, harming public health and endangering social and economic development (38). Amid all of this, the price of bottled water has risen, further harming the poor.

The cyanobacteria that rendered the water of Lake Tai unsuitable for human consumption.

Photo: courtesy of C Bradshaw
Increased urbanization has been accompanied by rising urban poverty. In 2000, an estimated 128 million poor households were in urban areas; that number is expected to reach 380–455 million by 2020 (39). The urban poor are often homeless or survive in illegal, temporary and flimsy shanties. They are also at greater risk of substance abuse, undertaking sex work and suffering violence. Such activities present many challenges to the management and spread of diseases, including diarrhoea, respiratory illnesses, dengue fever, kala-azar, leptospirosis, TB and HIV/AIDS.

Vulnerable urban subpopulations, such as migrants, typically struggle to access health and human services (40). The successful implementation of infectious disease control in these settings thus requires addressing the physical and social determinants of transmission: poverty, exploitation and overcrowding. Research is needed to develop effective strategies that control the risk of infectious disease and improve social well-being and quality of life for the poor.

**RESEARCH QUESTION:**

How can infectious disease control campaigns be incorporated into broader policies to improve the wellbeing of the urban poor?

**AGRICULTURE – ALSO SOWING SEEDS OF SICKNESS**

The production of a sufficient amount of food for the global population is absolutely essential for human health and livelihood. The management of the agriculture-climate-health nexus is critical, as good nutrition boosts immunity and reduces infectious disease susceptibility. In this respect, agricultural innovations – such as improvements in farming methods, crop varieties and livestock management – can benefit human health by expanding production of safe, nutritious and culturally appropriate food. Improvements in irrigation techniques and waste treatment, food biofortification (see Box 2.3), inoculation of animals and targeted insecticide spraying offer ways in which agriculture can reduce infectious disease prevalence in humans and animals (41).

As with deforestation and urbanization, however, agricultural activities can also harm both health and the environment. Agriculture accounts for about 20% of global greenhouse gas emissions, especially through land clearing, livestock rearing and rice cultivation – thereby contributing to climate change and its deleterious effects on human health.

Intensive agricultural techniques can unexpectedly trigger infectious diseases. For instance, large-scale crop farming has led to a rise in the incidence of malaria (as a result of both irrigation and changes in forests and forest species) and of Japanese encephalitis (also associated with irrigation). Large-scale palm oil (Elaeis guineensis) plantations in Colombia and Venezuela have provided excellent habitats for Chagas vectors although, as yet, the effect on human health has not been evaluated (44). On the other hand, the increased wealth earned from cash crops can, if well managed, reduce infectious diseases. This has been documented in some locations for malaria and it is plausible that palm oil production in Colombia could produce the same effect.

Some agricultural activities can also result in overworking of the soil, contamination...
of the food chain with harmful pesticides and unwanted elements (such as arsenic and cadmium) and pollution of ground and surface water. The growing diversion of food crops for biofuels is harming both biodiversity – as is happening in south-east Asia – and human nutrition. In 2011, the global food price index was at a new record high, likely due in part to extreme weather events, rising energy prices and the diversion of food crops to fuel crops.

The raising of animals for meat and of crops for feed (which has increased as growing numbers and increased incomes of consumers in urban areas fuel the demand for higher-value products) is also problematic. As mentioned above, livestock production produces large quantities of greenhouse gases, including methane, carbon dioxide and nitrous oxide (45). Intensive farming releases many nutrients, especially in manure, that harm local and even regional ecological systems. Riverine and coastal eutrophication leads to harmful algal blooms and several oceanic “dead zones” that depress marine productivity and thus (again) threaten nutrition (46).

Changes in climate and patterns of land use have also influenced the susceptibility of non-human species to infectious diseases. This in turn affects human health and well-being. For the many infectious diseases affecting animals and plants that are not known to infect humans, the resulting loss of livestock, livelihoods, income and sources of food directly affects the social and economic determinants of human health (47). For example, foot and mouth disease, which is a very rare cause of human sickness and does not directly kill many animals, has resulted in losses to livestock farmers via trade restrictions and large-scale slaughter of healthy animals to curb the spread of infection (47). The fungus Phytophthora infestans, cause of the Irish famine in the 1840s, still remains the most significant threat to potato crops (48) and the fungus has recently reappeared as a risk to the global wheat crop (49).

Some modern agricultural practices also bring humans and animals into closer contact than ever before, facilitating the spread and emergence of zoonoses. In both the field and around and about the home, the risk of disease being transmitted to humans via contamination of food; direct skin contact with vectors; or contact with aerosolized animal droppings and urine has risen to new levels. Already, in Latin America, several arenaviruses (e.g. Machupo, Junin and Guanarito) have spread as humans and infected rodents have come into closer contact with each other in farming areas. Intensive animal farming may also alter viral evolution, as it enables viral mixing and the emergence of new strains, some of which may be more lethal for animals and humans.

As large numbers of agricultural workers migrate to pursue work opportunities, infectious diseases are carried into periurban environments where they can infect a greater number of people (see Box 2.4). Finally, the overuse of antibiotics, especially as growth promoters in animal rearing, can also lead to multiple antibiotic resistance in human pathogens such as salmonella (50).

**BOX 2.4. AGRICULTURE AND KALA-AZAR IN NORTH-EAST BRAZIL**

In the semi-arid regions of north-east Brazil, periods of drought are associated with outbreaks of kala-azar. Small landholders are driven by food shortages to the cities to search for government assistance (51). This increases the incidence of this sandfly-transmitted disease in periurban areas and strains local health systems. Climate models forecast that in the next 25–35 years aridity in this part of Brazil will intensify, with increased average temperatures and less rain (52). These climatic changes will increase food insecurity and consequent migration – conditions conducive to kala-azar persistence and its possible emergence elsewhere in Brazil (52).
HUNGER AND MALNUTRITION – GETTING THE RIGHT FOOD TO THE RIGHT TABLE

For decades, the world has produced enough food to end global hunger and achieve the first MDG. However, the persistent maldistribution of food entitlement means that this goal remains out of sight. While migration in search of greater food security usually reflects an acute shortage of locally available food, diverse sociopolitical and cultural factors—including poverty, corruption, high food prices, food waste and ineffectual food storage and distribution mechanisms—also contribute. In fact, from 2007 to 2009 food insecurity was responsible for a 200 million increase in the number of people considered undernourished. Despite there being enough food available to feed everyone, today more than 1 billion people lack adequate nutrition. Natural disasters, poor agricultural infrastructure and over-exploitation of natural resources—all linked to global ecological challenges—are among the key causes of hunger and malnutrition.

Lack of food, malnutrition and poor hygiene interact to compromise immunity and increase disease vulnerability. Multiple infections or poly-parasitism are common, especially in children. A combination of malnutrition, diarrhoeal diseases, malabsorption and parasitic infections in the early years of life can have long-term negative health effects, including impaired physical and cognitive growth. For example, the average diarrhoea burden in malnourished children in the first two years of life is estimated to lead to a 17% loss in work productivity in later life due to impaired fitness and a loss of nearly 10 IQ points. Progress at school, physical health, and economic and social prospects are all diminished by this. Even the absorption of drugs (needed to combat diseases such as AIDS, TB and malaria, which often coexist with malnutrition and diarrhoea) is impaired.

It is predicted that climate change will exacerbate malnutrition, especially in low-income countries, by depressing agricultural productivity in many low-latitude countries. There are multiple pathways to this projected outcome, including heat stress, intensified rainfall events and more severe droughts. These threats will be increasingly amplified by sea level rises, particularly in highly productive river deltas such as the Mekong and the Nile. We need better data to more accurately predict the effect of climate change on food production, as well as its potential for exacerbating food shortages, malnutrition and vulnerability to infectious diseases—and the long-term effect on people and development.

CONFLICT – ANOTHER MAN-MADE DISASTER, AMPLIFYING INFECTIOUS DISEASE

Shortages of resources such as food, water or oil can interact with divergent claims over access, rights and entitlements to create political instability and, in some cases, outright warfare. The resulting conflicts can amplify existing environmental crises, further undermining the social fabric of communities. There are numerous political “hotspots” where climate change has, or will, amplify existing tensions and conflict. Further, these tensions often cause significant rates of migration and internal displacement while placing additional pressure on the resources of those nations where people go to seek asylum and refuge. Conflict also increases the prevalence of infectious diseases and reduces the availability of health services and their capacity to cope in crisis zones.

In Sudan, conflict has been linked to desertification and shortages of water, food and oil.
It has led thousands of people to leave their homes and seek refuge, often in settings with a higher burden of infectious disease, resource shortages and the other challenges of complex emergencies (60). Epidemics of leishmaniasis (visceral and cutaneous), dracunculiasis and African trypanosomiasis have intensified as a result, spreading to neighbouring countries including the Democratic Republic of the Congo (8).

Similar situations have been observed in other areas of unrest. Examples include outbreaks of malaria in Pakistan, Afghanistan (see Box 2.5), Tajikistan and Cambodia (8). Moreover, evidence from refugee and emergency camps in Africa, Asia and Latin America consistently reveal poor sanitation, disruption of food and water supplies, unhygienic living conditions, substandard housing and poor health care. These can nurture epidemics including cholera, dysentery, diarrhoeal disease and malaria, while concomitantly increasing hunger and malnutrition.

**Box 2.5. Malaria and Conflict in Afghanistan**

Recent conflict and population displacement in Afghanistan have been implicated in the introduction of malaria into the Bamiyan valley in the central highlands – at an altitude of 2250–2400 metres, the area used to be malaria free. Researchers found that of 215 peripheral blood smears analysed, 63 were confirmed to show infection by a malarial parasite (90% *P. falciparum* and the remainder *P. vivax*). Mortality rates were high as the area has poor health infrastructure and services (60). The fact that the local community had reduced natural immunity to malaria may also have contributed to the high mortality rate.

Conflict also harms health infrastructure and capacity. Many health personnel flee conflict zones, leaving people to manage with fewer resources under greater stress. Relief teams working in conflict and disaster zones may overlook infectious diseases such as Chagas disease, sleeping sickness, dracunculiasis and Buruli ulcer, even though conflict and trauma create heightened vulnerability to infectious diseases (61).

**Migration and Globalization – Disease, A Worldwide Traveller**

In a globalized world, migration offers both the possibility of improved socioeconomic opportunities and also the spread of infectious diseases to non-endemic areas, facilitated by increased travel by air, rail, road and even ship. Growing trade volumes also facilitate the spread of disease. A case of “airport malaria” – whereby mosquitoes infected in a malaria-endemic country are inadvertently transported to a non-endemic region – occurred recently in France when a food parcel imported from Cameroon contained mosquitoes that bit and infected the recipient (62). On a larger scale, human migration has spread Chagas disease (with its prominent chronic component) from Latin America to countries outside the region. This places an additional pressure on health systems, including those with little experience of such diseases (63).

The mass gathering of peoples from different parts of the world for religious, sporting and cultural events also presents challenges to the control and global spread of infectious diseases. For example: Hajj, the annual pilgrimage to Mecca in Saudi Arabia, attracts 1.6 million foreign visitors from 160 countries every year (64), making it one of the largest temporary mass migrations today. Documented infectious diseases associated with the Hajj include meningococcal meningitis, gastroenteritis, hepatitis A, B and C, various respiratory tract infections and, most recently, H1N1 influenza (65). Lowering the spread of these diseases and other environmental and public health hazards requires coordination and planning from all government sectors of the host country, often years in advance. This includes development of quarantine facilities, vaccine requirements and screening procedures at entry, as well as the upgrade of health services to deal with
additional demand – initiatives which are essential for effective health system functioning and response to infectious disease.

The movement of humans, animals, plants and foods all contribute to “pathogen pollution”; that is, the introduction of a (potentially) pathogenic parasite into a new or native species, population and environment (66). A number of parasites have “travelled” to other parts of the world with their human and animal hosts. *Taenia solium* (pork tapeworm) endemic in Latin America, most of Asia, eastern Europe and large parts of Africa, has also recently been found in North America and Europe as a result of migration, tourism and the global sale of pigs and pork products (67).

A worldwide trade in wild game and exotic species parallels the global trade of domesticated animals. Nearly 500 million kilograms of meat from free-ranging animal species are consumed in the tropics alone, more than six times the sustainable rate (68). The hunting, consumption and sometimes farming of exotic animals, including bats, civet cats, primates and raccoon dogs, is intensifying the likelihood of new infections emerging and being spread effectively via migration and globalization (also see Box 2.6).

Risks also arise from the transport of pathogens (including fungal spores) in fresh produce, plants, livestock and products that use wood, nuts, fibres and roots, as well as certain medicines. In 2011, a rare strain of *Escherichia coli* bacteria, linked to the consumption of contaminated foods, caused a large number of cases of bloody diarrhoea and haemolytic uraemic syndrome in Germany, which then spread to France, Sweden and other parts of Europe (72).

The increased global circulation of blood and blood products, human tissues and organs, also contributes to pathogen pollution. Further, when pathogens cross borders they rarely do so alone; poly-parasitism is an important issue, and reflects the interconnectedness and clustering of biological, social and environmental risks in the emergence and spread of infectious diseases.

**Infectious diseases, the environment and poverty – a time bomb in the making?**

Today, over one-quarter of the world’s population, approximately 1.75 billion people, experience multidimensional poverty (73). They have poorer health, inferior education and lower living standards than other humans. The poor tend to live in ecologically and socially risky environments characterized by inadequate sanitation; unsafe and irregular supplies of drinking water; absent or intermittent electricity; and use of dirty cooking fuels such as dung, wood and coal. Not surprisingly, the prevalence of infectious diseases is high in these conditions (73). Even in wealthy nations there are many vulnerable groups: elderly people, children, and the rural and urban poor (74).
Gender is a major determinant of the distribution of infectious disease, including the risk of transmission, health-seeking behaviour and patterns of care. For example, in southern Ghana, women who are engaged in fishing and trapping of shrimps in the mangrove swamps have greater exposure to the mosquitoes that transmit filariasis, contributing to the higher prevalence of lymphoedema in women in this region (75). Water contact is linked with the different social roles and practices of men, women, boys and girls in particular locations and this affects the spread and control of schistosomiasis (76). In many cultures in disease endemic countries, girls have less access to food and medical care. Many girls and women also experience a disproportionate risk of HIV/AIDS. Less well understood are the links between gender and other social and economic variables such as age, ethnicity and socioeconomic status and further research is needed into these areas (77).

The causal relationship between infectious diseases and poverty is often two-way, as outlined in Chapter 1. Infectious diseases affect the poor disproportionately, especially children and women, while chronic or recurrent infectious disease can create or exacerbate poverty. Illness may lead to loss of livelihood and the treatment itself may prove economically disastrous. In some cases the poor have their funds wasted by medical treatment that is of marginal benefit, or even fraudulent (78). Whole families can sometimes be impoverished as a result of disease.

Infectious diseases affecting livestock pose additional threats to community well-being and health through lost income, status, livelihood and food. The poorest one-tenth of the world’s population (around 700 million people) is predominantly made up of subsistence farmers, many of whom are livestock-dependent (79).

High levels of national capacity and wealth certainly impede the diffusion and persistence of infectious diseases, but they cannot entirely prevent their spread, the best strategy for reducing risks in wealthier societies would be to improve health in disease endemic countries. It is also the most equitable course of action. WHO’s Commission on Social Determinants of Health has persuasively argued that there is an urgent need to close the gap in health inequities and tackle social injustices (80). The socio-ecological drivers we have discussed in this chapter reflect the material and ecological conditions faced by households and policymakers in disease endemic countries.

How populations are fed, cities built, conflicts resolved and globalization managed profoundly influence the prevalence of infectious disease. This link ought to be a prominent part of the global development discussion. Policy and planning decisions should reflect the need to avoid the harm of adverse environmental change, including that which is caused by the spread of infectious diseases. We need to plan for more integrated, far-sighted and collaborative ways for the world to develop, while at the same time working to reduce the risk and impact of infectious diseases.

**Approaches for future research – three tracks to explore**

The unprecedented scale and intensity of human activity in the world today, and particularly its environmental effects, presents us with an array of research challenges. Basic research remains essential, but it needs a rich superstructure of more integrated interdisciplinary and systems-based research. The biggest challenge is how best to apply this enlarged and more complex conceptual frame and the attendant analytic strategies and methods to our research.

Research within this context is unlikely to yield much in the way of categorical “yes-or-no” answers – and that has implications for decision-making under conditions of uncertainty and unpredictability. We argue that there are three essential approaches:

1. to better understand the microbial world;
2. to expand and better utilize existing data sets and resources: and
3. to work towards a unified agenda.

It is imperative that future researchers integrate these concepts into their programmes if their work is to have a real hope of controlling infectious diseases of poverty in the long term. As advances are made in science and technology, people (especially in disease endemic countries) are going to be increasingly vital to managing their local environments and reducing the effects of disease. Communities must be involved in the implementation of research interventions designed to minimize the disruptive effects of environmental change.

BEETR UNDERSTANDING OF THE MICROBIAL WORLD

The relationship between the ecology of microbes and the broader environment needs further study aimed at gaining important insights into the biology of microbes and their potential evolutionary adaptations. There may be various natural barriers to the spread of some infectious diseases, but the functions, vulnerabilities and strengths of these barriers are not well understood. For example, why has yellow fever spread from Africa to the Americas but not to Asia? Why are trachoma and rheumatic fevers less prevalent now than 40 years ago, despite having received little to no attention? What are the macro-ecological factors that facilitate the spread of dengue from Indonesia to Saudi Arabia? If these natural barriers and salutogenic (health-promoting) forces can be identified, then efforts can be concentrated on maintaining and enhancing them. Conversely, if there are particular ecological vulnerabilities to disease, preventative efforts such as targeted insecticide spraying can be strengthened and health systems better prepared to respond to an increased number of cases.

However, microbes are highly diverse in their evolutionary pathways and lifecycles, and in their pathogenic adaptations that facilitate spread and persistence in human popula-

**"Invest in research which investigates the natural barriers and facilitators of the emergence, spread and persistence of infectious diseases in order to better control them."**

EXPAND AND BETTER UTILIZE EXISTING DATA AND RESOURCES

GIS and bioclimatic monitoring offer ways to measure, anticipate and plan for infectious disease outbreaks (see Box 2.7). Satellite-derived datasets have been used to predict the risks posed by malaria, Rift Valley fever, visceral leishmaniasis and tick-borne encephalitis (82). However, the full potential for infectious disease control from these datasets is yet to be used. Existing datasets such as HealthMapper, the Global Health Atlas (both WHO) and the TREES Project (Tropical Ecosystem Environment Observation by Satellites) from the European Commission offer useful tools to improve infectious disease management and control. Such technologies and systems may also be used to improve infrastructure and capacity in disease endemic countries.
Mobile phone technology also offers new ways of implementing telemedicine and disease surveillance. Prototypes with phone-mounted light microscopes have been used to detect *P. falciparum*-infected and sickle red blood cells, and *M. tuberculosis*-infected sputum samples (87). While such technology is still under development – and must be affordable, durable and usable to have wide reach – it illustrates an exciting possibility.

**“ONE WORLD, ONE HEALTH”**

The need for intersectoral collaboration is now urgent. Funding priority should be given to research that adopts inter-disciplinary approaches; encourages collaboration between government ministries and agencies; and better incorporates ecology into disciplines – including public health, medicine, social sciences, veterinary sciences and agriculture. The health sector is increasingly struggling to cope with the consequences of poor management of climate change and environmental damage, yet there are many intervention points that governments can use to prevent the loss of human life and livelihood. It is only through closer collaboration between government, private sector, civil society and communities – in areas such as agriculture, technology, education, social welfare, transport and health – that the complex socio-ecological drivers which contribute to ill-health can be mitigated.

The “One World, One Health” model offers such an integrated approach. As contact between humans and animals becomes more frequent, there are more opportunities for infectious agents to cross the species barrier. Domesticated species (especially pigs) can serve as viral mixers, combining and recombining influenza viruses of human, porcine and possibly avian origin (87, 88).

**BOX 2.7. GIS, LOA LOA AND MINIMIZING ADVERSE REACTIONS TO IVERMECTIN IN CAMEROON**

In 2004, an experience in Cameroon demonstrated the public health value of GIS as a means of reducing the risk of severe, sometimes fatal, reactions to ivermectin (the drug used in mass community-directed treatment of onchocerciasis).

It was known that individuals with high *Loa loa* microfilarial counts were at greater risk of dying from ivermectin treatment (83). Because this parasite is co-endemic with the onchocerciasis transmitting nematode *Onchocerca volvulus* in many parts of central Africa, it was recognized that mapping *Loa loa* distribution would identify areas where the greatest risk of severe adverse ivermectin reactions was highest. A spatial model of *Loa loa* risk was therefore developed, integrating prevalence with geospatial data for altitude, forest cover and soil type. This information was incorporated into the African Programme for Onchocerciasis Control (APOC) planning for community-directed ivermectin treatment (84). This was then refined by WHO/TDR studies that developed a field applicable, community-based rapid assessment procedure – RAPLOA – based on community recognition of ocular *Loa* infections (85).

**Use and expand existing datasets and new technologies to map disease prevalence and to identify areas for intervention and control.**
It is critical that research findings, clinical experience and learning from both human and veterinary domains be connected. Areas needing research include effective ways to build capacity among human and veterinary pathologists; integration of disease-surveillance, shared animal-human epidemiological studies; and best ways to develop health services able to deal with animal and human health (89). The socio-economic impact of zoonotic diseases on livestock production and the consequences that control of such disease (such as the condemnation of carcasses) have for the livestock trade need to be studied, as does how zoonotic diseases impact on wildlife populations and biodiversity. How social variables (gender, ethnicity, culture) influence human-animal interactions, the transmission of disease, cultural aetiologies of disease and patterns of health-seeking, as well as the social and mental health consequences of disability caused by infectious disease (e.g. social stigma, fear), are also areas needing further inquiry.

Collaborative approaches work. Rinderpest was a disease that once devastated livestock and wildlife and destroyed rural livelihoods and food supplies. This was eradicated from cattle through vaccination and surveillance efforts under The Global Rinderpest Eradication Programme (GREP), spearheaded by the Food and Agriculture Organization and with support from the World Organisation for Animal Health, the African Union, the South Asian Association for Regional Cooperation and other donor agencies (90). During the 2009 H1N1 influenza pandemic, good research and rapidly shared information led to clear clinical protocols and appropriate vaccines, which in turn enabled effective containment (91).

Communities also have an important role to play in preventing the spread of infectious diseases of poverty. In the Democratic Republic of the Congo, the Wildlife Conservation Society has established a network of hunters and other local people to report sightings of dead primates showing signs of Ebola. Researchers then test the faeces of the reported animals to see if they are infected. In Ebola “hotspots,” researchers also monitor great ape health, collect diagnostic samples and teach Ebola prevention awareness in at-risk communities. Local people are provided with information on how to prevent contamination and minimize the spread of the virus. In these parts of central Africa it is the Wildlife Conservation Society field veterinarians who deliver education and information to communities about Ebola and other zoonotic diseases (5, 92, 93).

If we are to achieve a more unified agenda, investment is required in human capital and knowledge systems. Interdisciplinary research and action are only possible when there is a common meeting ground. The education sector, especially universities, has a role to play in building capacity and fostering interdisciplinary learning in a new generation of scientists and policy-makers. This is part of shifting the paradigm of how research is conceptualized and practised, through encouraging interdisciplinary work.

Stronger collaboration between government ministries and agencies is needed to fund interdisciplinary approaches to research on human-animal health.
Conclusion: a big picture requiring intelligent investment and interaction

Increasing recognition of the interplay between demographic, social and environmental factors in infectious disease occurrence is leading to a more integrative, ecological, approach to studying, understanding, preventing and responding to infectious disease risks and outbreaks. This has important consequences for the repertoire of required research – topics, methods and interpretation – and for the social application of research findings.

A tantalizing inverse law often seems to apply to the conduct of research – the larger the frame of the research question and the more complex its constituents, the less precise and certain is the research result. Yet that result will often help us to understand the upstream determinants of vulnerability, risks, behaviours and exposure patterns that influence the probabilities of infection occurring or persisting.

It is becoming increasingly apparent that large and growing forces impede the control and eradication of infectious diseases. These dimensions of “causation” must be more purposefully studied and better understood, otherwise we face the continuing prospect – already clearly evident in the generally slow and partial achievement of many of the United Nations’ MDGs – of making welcome downstream advances in local disease control and treatment, but failing to address simultaneously the larger-framed upstream loci of intervention. In general, those larger-framed interventions will provide the key to finding sustainable solutions – solutions that entail wiser management of the natural environment (and its multiple microbial sources); wiser and fairer commercial practices; and social policies that reduce poverty, disadvantage and inequity.

Sustainable solutions to the specific causalities of the infectious diseases of poverty will also come from interdisciplinary research. A continued research focus on the downstream effects of these diseases, resulting in more effective therapies, may not be enough to break the cycle in which it appears the affected populations are now trapped.

Ultimately we must learn how to think more widely and in a more socially and ecologically sophisticated manner about how we undertake human activities: how we produce our food; undertake travel and trade; encroach upon and manage the natural environment; construct our cities; and interact with each other and other forms of life.
References – Chapter two


