FORESIGHT

Infectious Diseases: preparing for the future

Future Threats

OFFICE OF SCIENCE AND INNOVATION

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Future Threats

Joe Brownlie
Catherine Peckham CBE FMedSci
Jeffrey Waage
Mark Woolhouse OBE FRSE
Catherine Lyall
Laura Meagher
Joyce Tait CBE FRSE
Matthew Baylis
Angus Nicoll

This report is intended for:

A wide range of professionals, researchers and people in business, whose work relates to infectious diseases in humans, animals and plants. The report takes an international perspective, and will therefore be of interest to governments and non-governmental organisations across the world.

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Executive Summary

The Foresight project: Infectious Diseases: preparing for the future, looks 10–25 years into the future to consider infectious diseases in humans, animals and plants. It particularly focuses on the UK and sub-Saharan Africa as examples of developed and developing regions. Its primary aim is to produce a vision of new systems for disease detection, identification and monitoring, and to assess how they might transform our capabilities in managing future risks. It follows that a starting point is necessarily an appreciation of the evolving threat, and the factors driving changes in risk.[1] Both of these are the subject of this report.

The project reviewed the present-day burden of diseases in humans, animals and plants, and also considered the importance of infectious disease in meeting the Millennium Development Goals.

Based on analysis of future disease risks, the project identified and analysed eight categories of diseases that were considered to be particularly important in the future:

1 Novel pathogens: there is a concern that, over the next 25 years, humans, animals and plants will be threatened by completely new infections, as well as continuing to suffer from those that are already known.

2 Pathogens acquiring resistance: the acquisition of antimicrobial resistance, which occurs across the spectrum of human, animal and plant pathogens, is a growing and serious threat to the treatment and control of infectious diseases.

3 Zoonoses: the majority of the human pathogens that have been reported within the last 25 years have had zoonotic origins. The risk of zoonotic infection shows no sign of diminishing and could increase in the future. Both domestic and wildlife reservoirs of infection are considered important.

4 HIV/AIDS, tuberculosis and malaria: these will remain the most important infectious diseases in Africa in coming decades. Indeed, models forecasting the future risks and burden of HIV and tuberculosis also concluded that these infections would continue to increase unless current control efforts were greatly stepped up. The resurgence of tuberculosis is attributable to the rising prevalence of HIV.

[1] 'Risk' is defined here as the product of the probability of an event occurring, and its impact (measured in deaths, DALYS, costs etc). This value may be further modified by social factors, including the different ways the public may perceive risk, independent of any risk calculation. A public sense of outrage or dread may also influence risk values and the level of risk deemed acceptable by the public.

5 Epidemic plant diseases: plant diseases are characterised by extreme diversity of hosts and diseases. This makes it difficult, in contrast to human and animal systems, to identify a handful of key global plant disease threats. However, four staple food crops – rice, maize, wheat and potatoes – make up half of the global supply. Epidemic diseases that affect these crops can pose global threats.

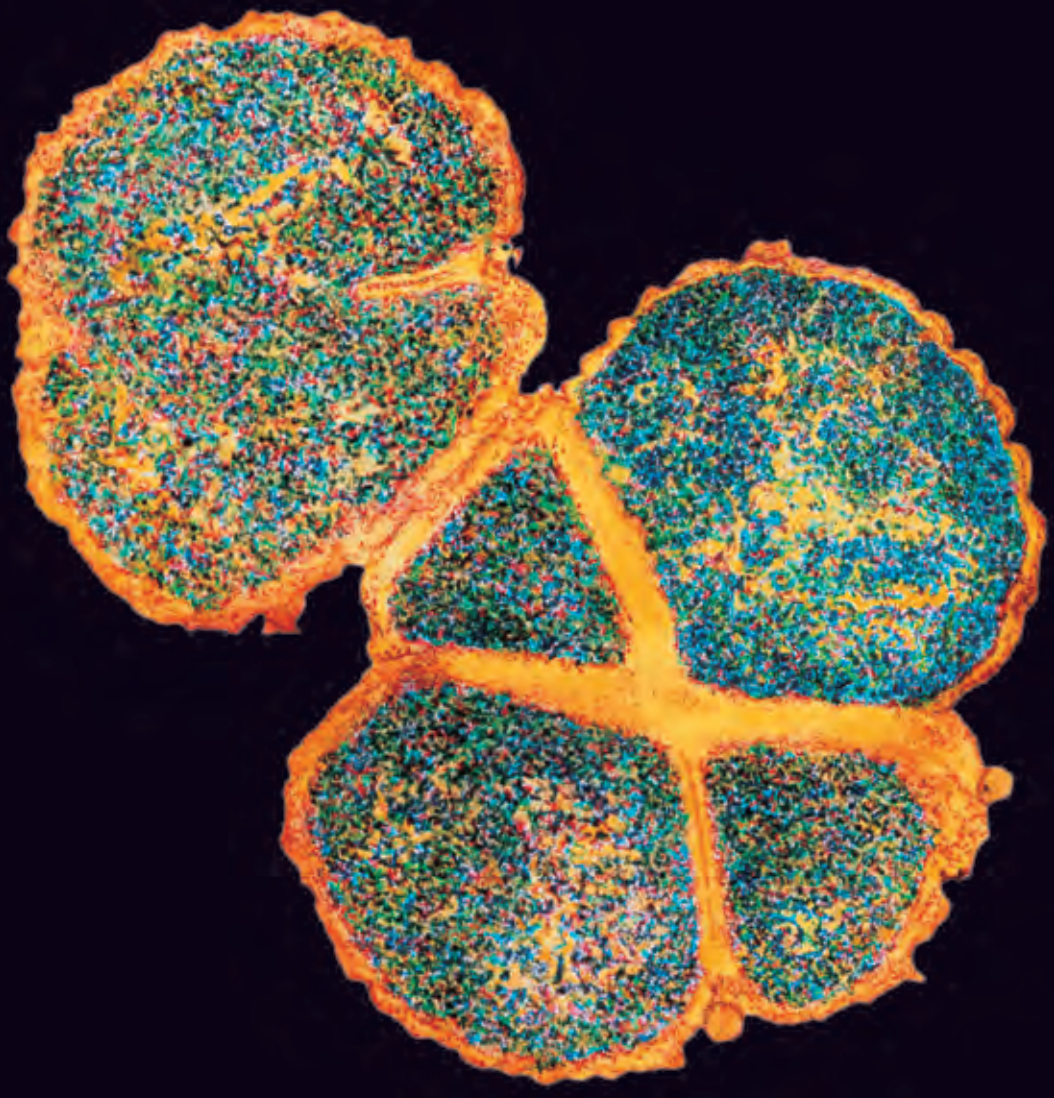
6 Acute respiratory infections (ARIs): The ARIs of greatest concern are those causing diseases of the lower respiratory tract, pneumonia, bronchitis and bronchiolitis. These diseases are associated with a range of endemic and epidemic viral and bacterial pathogens.

7 Sexually transmitted infections (STIs): STIs including HIV are increasing in prevalence throughout the world and constitute a large and growing infectious disease problem in the UK. In Africa, the prevalence of STIs is high and most infections are undiagnosed. The problem is exacerbated by the fact that STIs substantially increase the risk of HIV transmission, particularly when associated with ulcerative lesions.

8 Transboundary animal diseases: these are epidemic diseases that move across national boundaries. In some cases – for example, rinderpest – control has been highly successful. However, major epidemics are expected to continue to circulate across wide areas of the world. An important factor contributing to failure of control is the increasing transboundary movement of people and trade.

These disease threats, together with state-of-science reviews, identified the need for future detection, identification and monitoring systems. These systems were subsequently analysed in four broad classes termed "user challenges".

The Foresight programme is run by the UK Office of Science and Innovation under the direction of the Chief Scientific Adviser to HM Government. Foresight creates challenging visions of the future to ensure effective strategies now.



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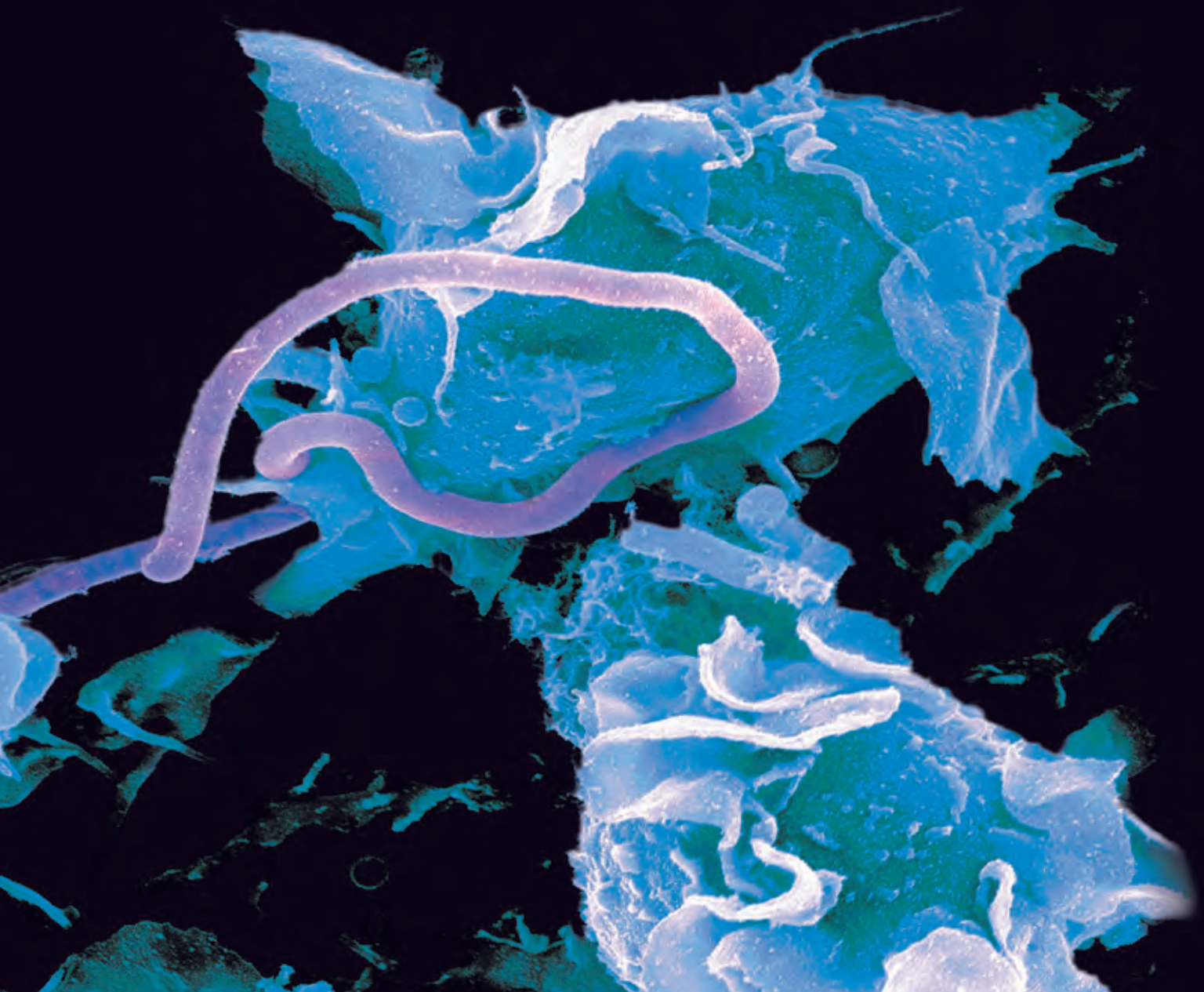


1 Introduction

This chapter introduces the work that the project has undertaken in order to analyse the future threat of infectious diseases.

It describes how the work fits into the wider project and discusses the technical approach adopted. It also outlines the many sources of expertise and information that have been drawn on.

1 Introduction

The Foresight project: Infectious Diseases: preparing for the future, looks 10–25 years into the future to consider infectious diseases[2] in humans, animals and plants. Its primary aim is to produce a vision of new systems for disease detection, identification and monitoring (DIM), and to assess how they might transform our capabilities in managing the future threat. It follows that a starting point is necessarily an appreciation of the evolving threat, and the factors driving changes in risk.[3] Both of these are the subject of this report.

This chapter discusses the technical approach adopted in the risk work, and shows how it fits into the wider project. Chapter 2 then briefly reviews the present-day situation. This provides a baseline of the size and nature of the threat of infectious diseases today. Chapter 3 discusses disease risks that are likely to be important in the future, particularly in sub-Saharan Africa and the UK. Eight exemplars have been chosen to allow the situation in developed and developing countries to be compared.

The work on future risks has drawn on a diversity of studies, workshops and reviews. Three of these studies are worthy of particular note and are reported here:

- Appendix A looks ahead 75 years to review the long-term effects of climate change on infectious diseases of humans, animals and plants.
- Appendix B considers future human and zoonotic disease in China, and assesses the drivers of change. Zoonotic diseases emerging from Asia are currently of global interest in view of the steady progression of avian influenza (AI), and the emergence of other zoonotic diseases from the region. This Appendix therefore provides the key findings of a study performed in China involving around 40 Chinese experts.
- Appendix C considers the effects of infectious diseases on ecosystems.

Further information on the risk analysis that has been performed may be found in a companion document, *Risk Analysis* (report T2 – see Appendix F for a list of all project reports). This compares the many factors affecting the future threat to human, animal and plant systems. It also contrasts the situation in the UK and sub-Saharan Africa, taking into account regional factors such as local systems of governance and local beliefs and culture. It has also considered important global factors, such as the growth of international travel and international regulations.

[2] In this report, 'infectious diseases' is taken to include diseases resulting from infections by transmissible agents such as viruses, bacteria, fungi and parasites.

[3] 'Risk' is defined here as the product of the probability of an event occurring, and its impact (measured in deaths, DALYS, costs etc). This value may be further modified by social factors, including the different ways the public may perceive risk, independent of any risk calculation. A public sense of outrage or dread may also influence risk values and the level of risk deemed acceptable by the public.

1a How the risk analysis informed the other parts of the project

The risk analysis informed several strands of work in the project (see Appendix E for an outline of the main parts of the project):

- The work on future threats was used primarily to define the future challenges against which new systems for DIM were tested (see reports D1, D2 and D2.1–D2.4).
- Early results from the risk work provided a preliminary view of important future diseases – these helped to inform the choice of ten state-of-science reviews that were commissioned by the project (S1, S3–S12). These reviews define the scientific and technological building blocks from which the DIM systems of the future could be constructed.
- For example, the future emergence of genetic variants of pathogens (e.g. drug-resistant strains) suggested the need to review diagnostic technologies based on genomics. Also, the need to spot the emergence of entirely new and unknown diseases suggested the need for a review of advanced data mining and data fusion techniques.
- The work on future risks helped to inform the selection of so-called 'user challenges' for analysis. These are four convenient classes of future DIM systems that the project analysed in detail. In brief, these user challenges are: advanced data processing to detect new or re-emerging diseases; genomics and post-genomics for characterising new or mutated pathogens; hand-held diagnostic devices; and high-throughput screening devices.

1b The technical approach to the work

The technical approach to the risk work was conditioned on what the resulting information would be used for – which was primarily to test future DIM systems that other parts of the project would postulate. For this, we needed a broad selection of disease categories that we could be confident were of future importance and which, between them, would comprehensively and variously exercise those DIM systems.

Eight broad categories of diseases were therefore selected by project experts, drawing on a series of international workshops, modelling studies, newly commissioned research on the emergence of pathogens, and comprehensive surveys of data from the UK, Africa and China. This approach was deemed sufficient for the task, without the need to postulate multiple future scenarios.

It was considered neither necessary nor desirable to attempt to accurately rank the various categories of future threats. Not only would that be very difficult (some of the categories overlapped, and comparing the threat of plant diseases with human diseases would be meaningless), but the extreme future uncertainty in the drivers of change would mean that any pretence of precise ranking would lack credibility.

1c Who was involved in the work

The risk work in the project was led by the Innogen Centre in Edinburgh. Overall, the project involved over 300 stakeholders and leading experts from diverse disciplines. These were drawn from nearly 30 countries across the world. It also included individuals from leading international organisations, such as the African Union, the New Partnership for Africa's Development (NEPAD), the World Health Organization (WHO), the Food and Agriculture Organization (FAO), the World Organisation for Animal Health (OIE (Office Internationale des Épizooties)), and also leading donor organisations.

A full list of all those who participated in the project may be found in the project Executive Summary, and a list of those specifically involve in the risk work is provided in Appendix D of this report.

Box 1a How the Foresight project differs from other studies

The technical approach in the project involved a unique combination of factors. It considered:

- diseases in humans, animals and plants
- the situation in both developed and developing countries
- a long-term perspective – 10–25 years[4]
- social as well as natural sciences.

Addressing diseases in humans, animals and plants. This important aspect of the project responds to several factors:

- Diseases in animal and plants are linked with human health and human infectious diseases. For example, animal infections can jump species to humans – the majority of new infectious human diseases that have become evident in the past 25 years are caused by pathogens arising from domesticated or wild animals (zoonoses). Also, in the developing world, diseases in plants and animals impact on human diseases through factors such as starvation, prejudicing economic development, and displacing populations.
- Diseases of humans, animals and plants are all affected by shared, global drivers such as travel, climate change and trade. Trade and commerce particularly link animal and plant diseases and their future impact (for example, see Box 1b).

More generally, there is a convergence of science and technologies that can be used in new DIM systems to manage infectious diseases across these three systems. These include genomics, information technology, and electronics.

Geographical focus. It was outside the scope of the project to consider every region of the world in detail. Therefore two were chosen for comparison – sub-Saharan Africa as an example of a developing region, and the UK as a developed country. Nevertheless, it is expected that the results will have broad applicability to other parts of the world.

Time horizons. Ten years (from 2005) was chosen as the near horizon, with the aim of looking beyond today's problems, taking a strategic and longer-term view. Twenty-five years was selected as a far horizon, since any visions of future science and DIM systems become very speculative beyond that. (Note: the project found a large overlap between the problems of tomorrow and those of today, so some aspects of the application of the DIM systems are nevertheless relevant to today's challenges.) The overall project findings focus on the steps we need to start to take today, in order to be in the best possible position in the future.

[4] In the consideration of climate change (Appendix A), a 75-year horizon was taken in view of the long-term nature of this driver of change.

Box 1b New roads, new diseases: Route 9 in Lao PDR

Source: Peter Kenmore, FAO

The convergence of infectious disease risks across human, animal and plant systems is well illustrated in the recent development of road systems in Indochina. Lao People's Democratic Republic (PDR) is a landlocked country seeking economic development, and has attracted development assistance to improve a road system, Route 9. This links the country's major central province, Savannakhet, with Vietnam on the east and Thailand on the west – both key potential markets and sources of goods within the booming Greater Mekong River sub-region. But highways also concentrate crop planting materials, domestic animals, and people engaged in traffic and trade, and therefore become conduits for disease.

Figure 1.1: Map of Route 9 in Lao PDR

An improvement programme for Route 9 was completed in late 2003. During the first five months of 2004, a new plant-pest problem, the coconut leaf beetle, spread from the Vietnamese border halfway across Savannakhet Province towards the Thai border. Coconut is a poor families' crop, significant for household food security as food and ready cash from local markets. While the leaf beetle is an insect, and not a disease, its spread and impact is very similar. Like diseases, it spreads along roads on plant material, infecting trees and causing severe yield loss in this valuable crop.

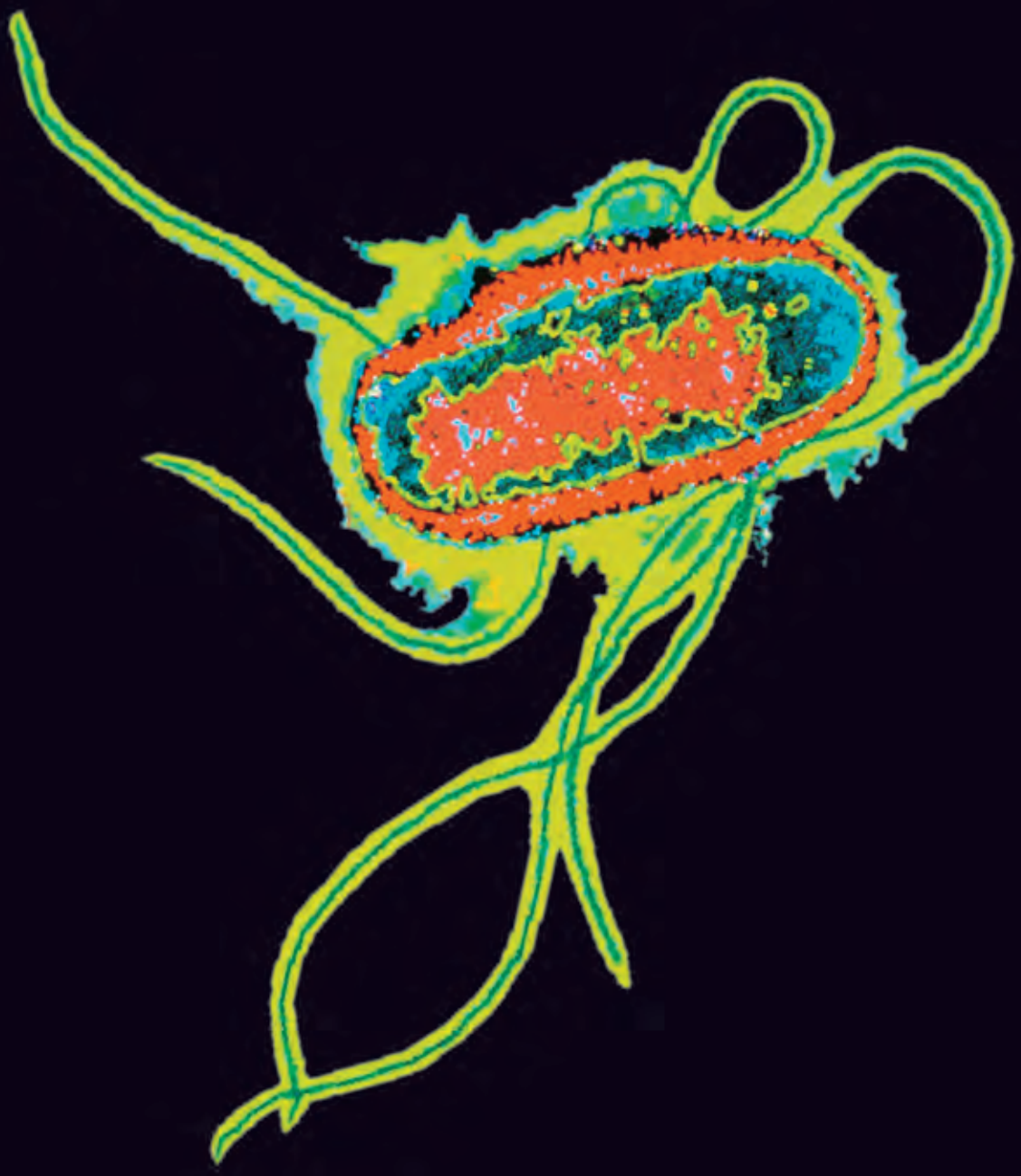
Between February and April 2004, highly pathogenic (H5N1) AI outbreaks were recorded in Savannakhet Province for the first time. Rather than spreading southwards from the capital city, which remained the only other focus in the country, AI spread from surrounding Thailand and Vietnam. Its appearance in Savannakhet Province through which Route 9 passes, was not surprising.

HIV/AIDS has been a growing problem in Indochina, but only recently in Lao PDR. Studies show that its incidence is particularly high at border crossings. By June 2004, about half of the national caseload of HIV/AIDS was in Savannakhet, where Route 9 connects Lao PDR with Thailand and Vietnam, two older foci of HIV/AIDS infection. This was nearly twice the caseload of the capital city, Vientiane, which has a population two–three times larger.

2 Infectious diseases today

2a The burden of infectious disease

2b The Millennium Development Goals



2 Infectious diseases today

This chapter briefly reviews the current threat of infectious diseases. As such, it provides a present-day baseline for their importance, both for the developed and the developing world.

The chapter also considers progress in meeting the Millennium Development Goals, particularly those relating to infectious diseases. These goals represent a vision for change, which world leaders would like to deliver by 2015.

2 Infectious diseases today

By the late 1960s, many infectious diseases were thought to be under control and some on the verge of global eradication. However, this optimism was misplaced. New threats such as human immunodeficiency virus (HIV) infection and severe acute respiratory syndrome (SARS) appeared; long-standing diseases such as tuberculosis and malaria re-emerged; and resistance to antimicrobials escalated into a major problem. Previously unknown animal diseases, such as bovine spongiform encephalopathy (BSE), have emerged, and new outbreaks of animal and plant diseases continue to be frequent events around the world.

The emergence of these new pathogens threatens developing and developed countries in different ways. The former often lack the basic resources to manage existing diseases, so new diseases can sometimes propagate unchecked – perhaps interacting with other diseases and becoming widespread. HIV is an example of this in Africa. Similarly, when diseases affect livestock or crops in developing countries, the inability to eradicate the disease can severely prejudice economic development and trade.

The situation in developed countries can be quite different. Firstly, there is a public expectancy for governments to provide protection and treatment – and even compensation in the case of diseases in livestock. Also, the drive for ever greater efficiency and productivity in many of these countries has resulted in social, business and transport systems that are finely tuned to maximise performance, but may be less resilient to disease-related shocks. So there is a danger that a major epidemic in a developed country could compromise essential services.

Finally, when we think of infectious disease threats, it is important that we recognise the different nature of chronic disease burden and the 'shock' of a new disease outbreak. Humans, plants and animals already suffer from costly chronic or endemic disease infections. The emergence of entirely new diseases will raise this disease burden to a new level, as will the re-emergence of diseases due, for instance, to a breakdown in disease control or resistance. However, infectious diseases, such as influenza viruses, may also exhibit sudden epidemics, or even pandemics. Governments have a particular concern about these infectious disease outbreaks because they are 'shocks' that can severely disrupt the functioning of our society and our economies. Both the burden of chronic disease and the shock effects of disease outbreaks on society are important dimensions of today's and tomorrow's infectious disease threat.

This chapter briefly reviews the present-day burden of infectious diseases, drawing on trends in recent decades. The aim is not to present a detailed and complete picture, but rather to provide a broad indication of the importance of infectious diseases to both developed and developing countries, and across humans, animals and plants. It also serves as a starting point against which the future threat of diseases is evaluated in Chapter 3.

2a The burden of infectious disease

Human diseases

The extent of the problem of human infections is not in doubt: infectious diseases are estimated to account for about a quarter of deaths worldwide, more than 13 million deaths each year (WHO 2004). The top five causes of death from infectious disease are lower respiratory tract infections, HIV, diarrhoeal diseases, tuberculosis and malaria (Table 2.1). Infectious diseases also account for over a quarter of the world's morbidity, as measured by disability-adjusted life years (DALYs).

Table 2.1: Burden of infectious disease
Source: Derived from WHO (2004) Statistical Annex.

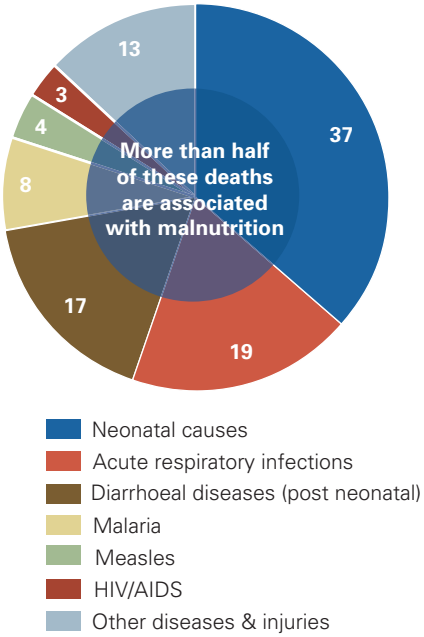
Disease	Worldwide mortality 2002 (% of total deaths, total number)	Worldwide morbidity 2002 (% of total DALY, total number of DALYs)
Lower respiratory tract infections	6.8%, 4.0 million	6.3%, 95 million
HIV/AIDS	4.9%, 2.8 million	5.7%, 85 million
Diarrhoeal disease	3.2%, 1.8 million	4.2%, 62 million
Tuberculosis	2.7%, 1.6 million	2.3%, 35 million
Malaria	2.2%, 1.3 million	3.1%, 47 million
Childhood infections[5]	2.0%, 1.1 million	2.8%, 42 million
Other infections	1.0%, 0.6 million	2.1%, 32 million

However, the situation is continually evolving, with entirely new diseases emerging such as SARS in 2003. Indeed, 40 years ago, HIV would not have appeared in the above table, but is now second on the list.

The emergence of new pathogens threatens developing and developed countries in different ways. The burden of infectious diseases is generally much greater in poorer countries than in wealthier countries, and children are affected particularly badly. Reducing child mortality depends on effective measures to combat infections. Of the 11 million deaths in children under five who die each year, half are lost to pneumonia, diarrhoea, malaria, HIV/AIDS and measles (Figure 2.1). In many cases, infection is compounded by malnutrition and deaths could be prevented by low-cost prevention and treatment measures such as vaccination or insecticide-impregnated nets to prevent malaria. Poverty, poor education and gender inequality increase vulnerability to infections.

[5] Pertussis, poliomyelitis, diphtheria, measles, tetanus.

Fig 2.1 Causes of death among children under five: 2000–2003 (percentage)
Source: UN (2005a)

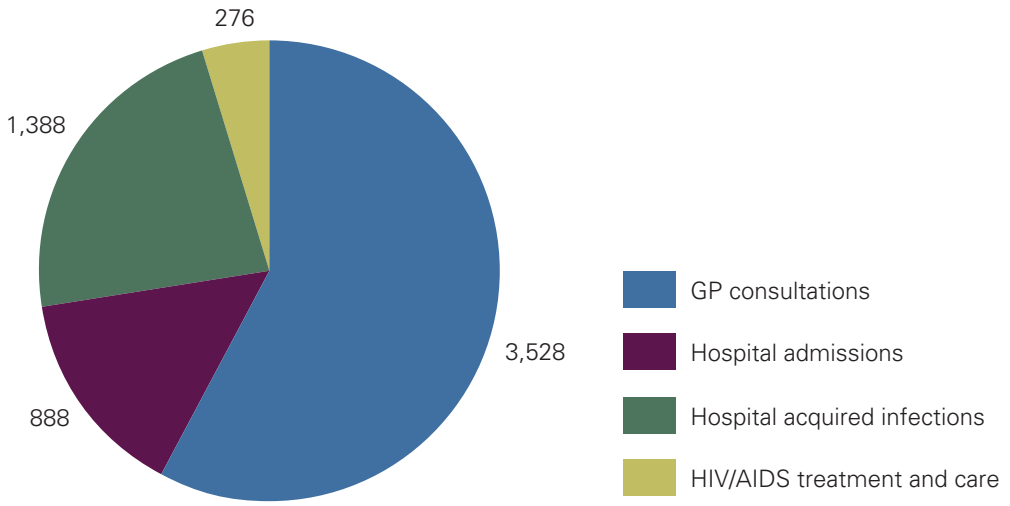


Causes of deaths among children under age five, 2000-2003 (Percentage)

In developed countries, infectious diseases cause less mortality but nevertheless generate enormous social costs. Human infectious diseases in the UK are implicated in about 10% of human deaths and constitute the top four reasons for primary care consultations: of 256 million annual consultations, 35% and 50% of consultations for adults and children, respectively, relate to infectious disease. The cost of treating human infectious diseases in England is around £6 billion per year (10% of the budget of the UK National Health Service), with £900 million spent on hospital admissions (HPA 2005a).

Fig 2.2 Estimated annual cost (£ million) of treating infectious diseases in England

Source: HPA (2005a)



Besides the measurable chronic burden of infectious disease, there is the potential cost to developed and developing countries of sudden outbreaks of new disease. Less than 1,000 humans died during the 2003 SARS outbreak, but its potential impact caused serious international concern and disruption. At the time of writing, less that 200 people have died from AI since 2003. International concern is fuelled by the potential for this disease to evolve into a human pandemic form, the economic impact of which has been estimated by the World Bank to be up to US$800 billion over a year.

Animal diseases

Animal diseases not only place a substantial economic burden on the agriculture industry, but have wider repercussions on rural communities and trade. For instance, as a result of outbreaks of BSE, foot-and-mouth disease (FMD) and AI in 2004, annual world meat trade fell for the first time in a decade.

Table 2.2 details the economic costs of disease outbreaks around the world. This shows that the size of the costs can be considerable – for example, the 2001 FMD epidemic cost the UK about £7 billion: this includes losses in tourism and other indirect effects on the rural economy, but takes no account of the trauma.

suffered by rural communities during the cull of livestock. Thus, the cost of this single animal disease outbreak was more than the £6 billion per year currently spent by the National Health Service in managing all human infectious diseases.

Table 2.2: Economic cost of some recent animal disease outbreaks (US$ million) Source: FAO (2002,2004); EU (2005).

Disease	Total costs (£ billion)	Impact on GDP
BSE, UK 1996/1997	2.3	–0.4%
FMD, Chinese Province of Taiwan 1997	4	–0.64%
CSF, Netherlands 1997/1998	1.4	–0.75%
FMD, UK 2001	7	–0.2%
AI, Vietnam 2003/2004	0.32	–0.3 to –1.8%
AI, Netherlands 2003	0.4	Not available

In Africa, the situation is worse. Livestock agriculture is the most important industry across sub-Saharan Africa, and disease is its biggest constraint. Overall, the industry represents 25% of the gross domestic product (GDP) of the region and in certain countries provides enough stock for export. However, compared with other parts of the world, sub-Saharan Africa has the heaviest burden of infectious diseases of animals – of the 15 'most contagious' diseases on the former OIE List A, 12 are found in Africa. By contrast, all 15 are exotic (i.e. foreign) to the UK.

Furthermore, the spread of livestock diseases in Africa has worsened in recent years. For example, contagious bovine pleuropneumonia (CBPP), which was reasonably well controlled in the 1970s and 1980s, has again become widespread, affecting 27 countries across the continent, and costing an estimated US$2 billion per year (FAO 2002). Serious animal diseases are also the most important impediment to international market access for African livestock commodities.

Plant diseases

Currently, it is estimated that more than 800 million people do not have adequate food – a figure largely unchanged since 1990. Indeed, in sub-Saharan Africa and southern Asia, the number has increased by tens of millions over the same period. In the case of children, malnutrition contributes to over half of child deaths.

Improved agricultural production is therefore crucial to meeting the dietary demands of the global population – both directly, and through feed for livestock. However, potential yields are rarely obtained due to the effects of weeds, pests and diseases. Worldwide, plant diseases reduce attainable yield of rice, maize, wheat and potato, the four crops that comprise over 50% of our food supply by 11–16% annually. In the USA, it has been estimated that plant diseases that have

been introduced from other countries cost the economy annually about US$21 billion in losses and control costs. In addition to this chronic disease burden, devastating plant disease outbreaks can threaten local food security or export economies.

Fig 2.3 Soybean rust damage
Source: Reid Frederick, USDA Agricultural Research Service

Table 2.3 illustrates some recent or recurrent disease outbreaks around the world and their impact on production. Note that yield losses are usually only a fraction of total crop losses from disease outbreaks; other costs include control and economic impacts on dependent farming communities.

Table 2.3: Impact of some recent plant disease outbreaks on crop production
Source: Strange and Scott (2005); Yorinori (2005), D3.1

Plant disease	Losses to production
Southern corn leaf blight, USA 1970	£0.6 billion losses in a single year on widely planted susceptible maize varieties
Soybean rust, Brazil 2001–2004	£3.0 billion accumulated losses since introduction to Brazil in 2001
Groundnut rosette virus, sub-Saharan Africa 1900 to present	15 epidemics in Sub-Saharan Africa with losses of up to £200 million per epidemic
African cassava mosaic disease, Uganda 1990–2000	60,000 ha of cassava worth £40 million lost annually from this new virus variant

The burden of crop losses due to plant diseases falls most heavily on developing countries. Estimated shortfalls on attainable yield are 16% in Africa but only 10% in Europe. As in the case of livestock diseases, outbreaks of disease can threaten national food security, displace populations, and damage economies that are highly dependent on agricultural export income.

2b The Millennium Development Goals

The Millennium Development Goals (MDGs) are drawn from the United Nations (UN) Millennium Development Declaration. Their adoption constituted an unprecedented promise by world leaders to address a range of issues, including human development, peace, security and human rights. The goals represent a vision of the world that our leaders would like to see in 2015.

There are eight MDGs, and infectious diseases are closely linked to four:

- eradicating extreme poverty and hunger
- reducing child mortality
- improving maternal health
- combating HIV, malaria and other diseases.

Human infectious diseases clearly play a key role in the last three. And diseases in humans, livestock and crops play a crucial role in the first. This is because they underpin economic development in many of the poorest countries, and because they impact on the food chain through diverse mechanisms, as previously mentioned.

There is another MDG worth mentioning in the context of infectious diseases – ensuring environmental sustainability. Here, freedom from plant and animal diseases can promote a more sustainable environment for food production.

In 2005, the UN reviewed progress in the MDGs since 1990 (UN 2005a). Table 2.4 reproduces a subset of the results. It details the current situation against targets set for the four MDGs of interest, listed above – three geographical regions have been selected for comparison. The colour coding provides an indication of progress, and the likelihood of achieving the targets by 2015 (only the green cells indicate where the goals are on course to be met).

Table 2.4: Progress in Millennium Development Goals relating to infectious diseases Source: UN (2005b).

Millennium Development Goal	Specific target	Sub-Saharan Africa	Southern Asiaz	Europe
Goal 1: Eradicate extreme poverty and hunger	Reduce extreme poverty by half			
	Reduce extreme hunger by half			
Goal 4: Reduce child mortality	Reduce mortality of under 5s by two-thirds			
Goal 5: Improve maternal health[6]	Reduce maternal mortality by three-quarters			
Goal 6: Combat HIV, malaria and other diseases	Halt and reverse spread of HIV/AIDS			
	Halt and reverse spread of malaria			
	Halt and reverse spread of tuberculosis			

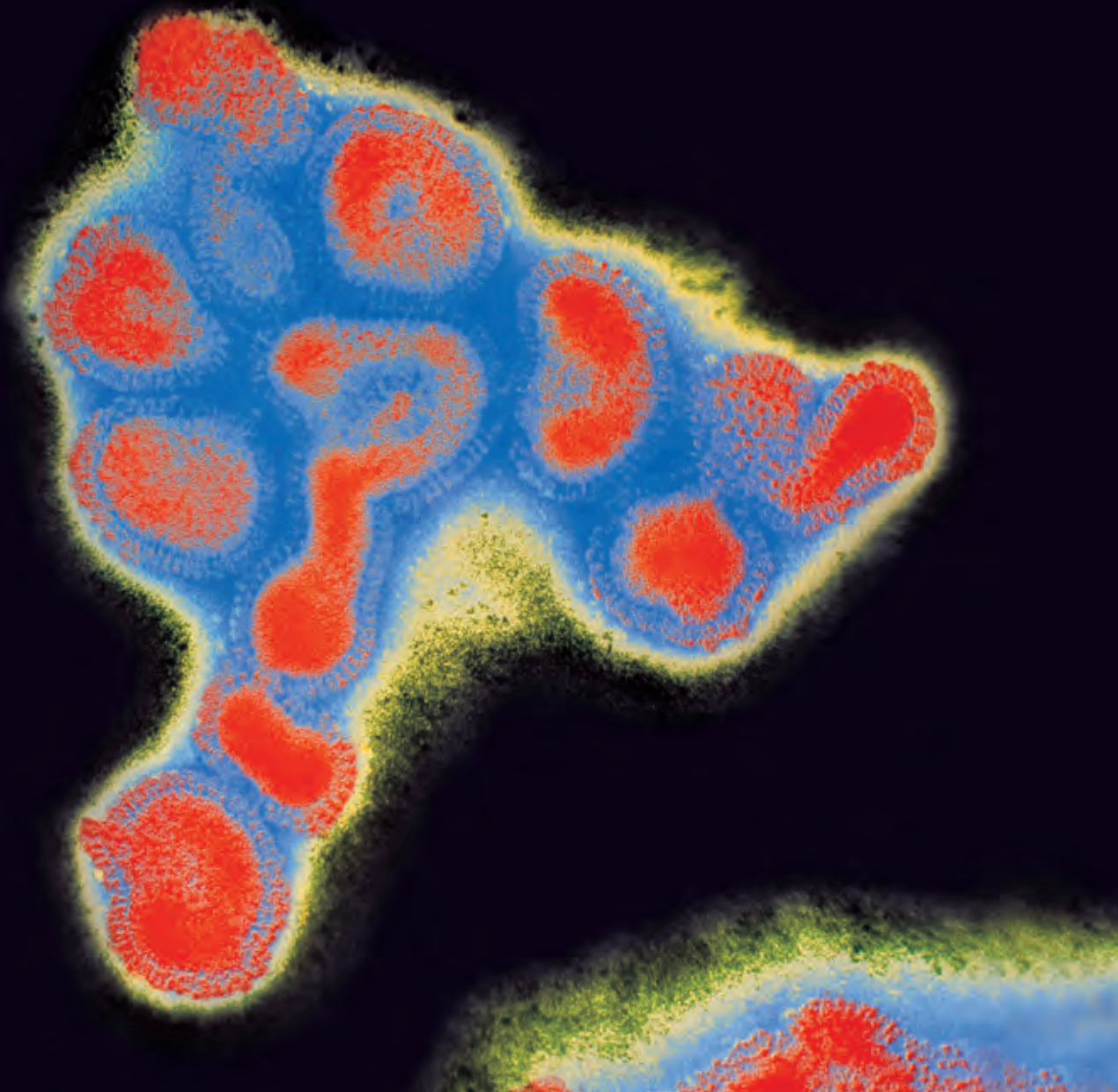
No progress, or a deterioration or reversal	Target not expected to be met by 2015 if existing trends persist	Target expected to be met by 2015 if prevailing trends persists; or not considered important in the region

Table 2.4 exposes the poor progress that has been achieved in relation to MDGs for which infectious diseases have a strong impact. In all of the geographical regions (including Europe), many of the targets are not projected to be met (red/yellow shading).

It is beyond the scope of this report to provide a detailed review of the MDGs. However, it is striking how many of the MDGs are influenced by infectious diseases, and how many currently seem set to fail. This argues strongly for the need to consider afresh how better disease management could contribute to redressing the situation.

[6] The available data for maternal mortality does not allow trend analysis. Progress represented in this chart has been assessed by responsible agencies using proxy indicators.

3 Future disease threats



3 Future disease threats

This chapter looks ahead 10–25 years to review the future threat of infectious diseases. It summarises the results of a risk analysis and then illustrates the threat by exploring eight important categories of diseases affecting people, animals and plants.

The potential importance of each of these categories is discussed and the key factors affecting the level of risk are considered. The impact on sub-Saharan Africa and the UK are also compared.

The importance of disease DIM systems are briefly discussed for each disease category and then together at the end.

3 Future disease threats

Today, we are accustomed to hearing regularly about some new disease outbreak, and we anticipate that the near future will bring new problems. But what will the situation be in 10 or 25 years? What will be the most important diseases, and will disease outbreaks become more or less frequent – and why? This chapter addresses these questions. However, it is useful to start by recalling why the project needed to perform this analysis of future threats and how the resulting information was used.

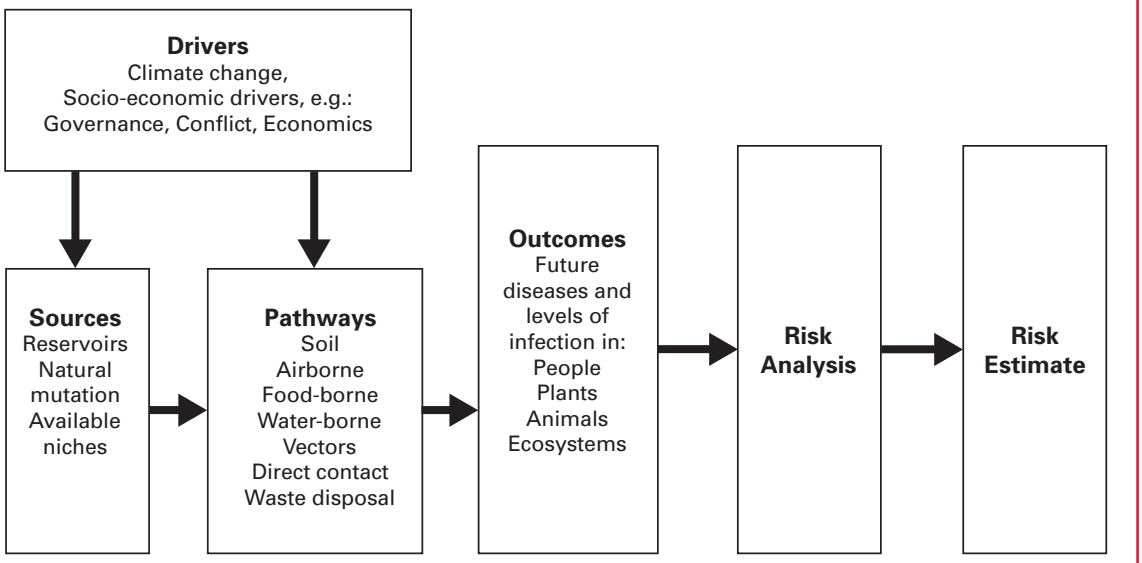
The prime purpose of the project is to determine how science could create new DIM systems that could transform our ability to manage infectious diseases in the future. However, these systems must be appropriate to tomorrow's threats, which may be the same or different from today's. The analysis of future threats therefore creates a basis for designing and evaluating future DIM systems. So, during the project, we brought experts on science and disease risk together to fit future technology to future disease threats. The result of this was the identification of four broad classes of DIM system for analysis – termed 'user challenges' (see reports D1, D2 and D2.1–D2.4).

3a Outputs of a risk analysis

A multi-faceted risk analysis was conducted to identify the key threats of infectious disease in the future. This included information derived from a structured consultation with experts in the UK and Africa, selected reviews and case studies. This study is presented in Risk Analysis (T2), and here we illustrate some of its conclusions.

A risk model was developed to provide a framework for the risk analysis. The model is presented in Figure 3.1 and the terminology explained below (this terminology is used throughout the rest of this chapter).

Fig 3.1 Risk model used in this study



Disease risks have **sources**, operate through **pathways** and have specific **outcomes**. Over time, these sources and pathways may change and so future risks are different from the risks we face today. These changes are often associated with particular **drivers** that will change the environment in which disease threats emerge.

A consultation with 80 experts in UK and Africa examined the sources, pathways and drivers of disease risks that our society may be facing in 2015 and in 2030. Risk estimates were calculated for a range of different kinds of threats. Significantly, this study identified the same three **sources** of greatest future disease threats for all six categories (i.e. corresponding to human, animal and plant diseases in UK and in Africa):

- new pathogens, or new strains of existing pathogens, arising through natural genetic change
- geographical extension of pathogens from within or outside the UK and Africa
- increased pathogen resistance (e.g. to microbicides).

In five of the six categories examined, diseases introduced from other species reservoirs, including wild species of animals and plants, were also considered to be major future sources of disease risk.

Changes in **pathways** of disease in the future were seen as less important generators of new risk than changes in sources and drivers, and more variation was found between systems and continents. In Africa, increasing direct host-to-host transmission facilitated by growing population size and density was seen as a key pathway for disease in future, with airborne transmission seen as particularly important for plants and humans, and water-borne transmission important for humans. Vector-borne plant disease was seen as a greater future risk in Africa as well. In the UK, host population growth was not an issue, but vector-borne diseases were seen to pose future threats for animals and plants.

Finally, with respect to **drivers**, two key trends were seen as important drivers of future disease threats in five of the six categories:

- emergence of resistance to current disease control, that is, the use of drugs in animal and human disease and pesticides for plant diseases
- a change in global temperature by 0.5–2°C, affecting conditions for disease emergence and or spread.

It was significant that many more drivers of future disease risk were identified in Africa than in the UK. Some of the drivers of particular significance in Africa included poverty, lack of technological innovation, lack of effective regulatory and governance structures, conflict and war. Experts postulated that drivers associated with legislation, governance, conflict and war might generate lower risks in 2030 than 2015 as these problems in Africa diminish.

In the UK, besides the two general drivers mentioned above which apply to human, animal and plant disease, additional drivers of future disease risk for animals and plants include changes in trade and transport, and for animals include poor systems for international disease surveillance and control, illegal imports and the manipulation of animal diseases for bioterrorism.

The consultation also examined current strengths and weaknesses, and future opportunities and threats relating to disease DIM systems. Expert views stressed the need for effective systems of surveillance, investigating or reporting infectious disease incidence, and the availability of expertise and trained personnel.

3b Eight global disease threats

The analysis of future disease threats to humans, animals and plants in the UK and Africa generates a complex matrix of diseases, sources, pathways and drivers that is difficult to distil into simple messages. However, there is also surprising convergence of key factors across these different systems and regions. In order to capture the key messages of this study and to underline their relevance to different stakeholders, we have distilled our analysis of future disease risk into eight broad categories of disease:

- new pathogens or novel variants of existing pathogens
- pathogens acquiring resistance, e.g. to microbicides
- zoonoses
- HIV/AIDS, tuberculosis and malaria
- epidemic plant disease
- acute respiratory infections
- sexually transmitted infections including HIV
- transboundary animal diseases.

These eight categories are intended to be illustrative of the future global infectious disease threat. They are not intended as an exhaustive or prioritised list. Some of these categories describe non-specific threats, e.g. new, unknown diseases, while others relate to specific categories of human, animal and plant diseases that have emerged from the analysis. Each of the threats is described in turn and the key factors influencing them discussed (these factors are considered more fully in the next chapter). The potential importance of the disease category to the UK and to sub-Saharan Africa is then compared. Finally, each of the threats is used to identify specific challenges for the development of new DIM technologies – and so to inform other parts of the project.

We have not attempted to rank these categories in terms of their importance. Some disease categories are intentionally overlapped, and comparing the threat of plant diseases with human diseases would be meaningless. Also, given the great future uncertainty in the change drivers of disease, any pretence of precise ranking would lack credibility.

The selection of the eight categories has drawn on the consultation with experts described earlier, as well as the following additional sources:

- international workshops in the UK and Africa (A4)
- modelling reviews (T8.1–T8.11)
- case example reviews of specific diseases (T5.1–T5.12)
- newly commissioned research on the emergence of pathogens (T15, T16).

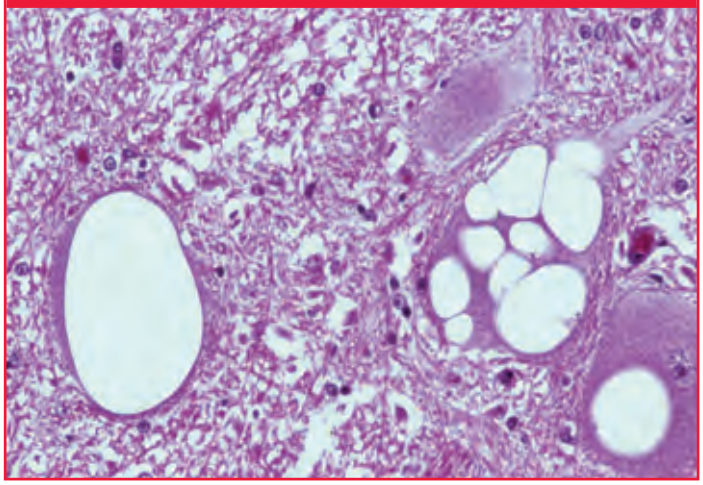
Overall, more than 200 experts and stakeholders have been involved in the above work.

3c Novel pathogens: new species and new variants

Introduction

There is a well-founded concern that, over the next 25 years, humans, animals and plants will be threatened by completely new infections as well as continuing to suffer from those that are already known. This view was reinforced in a major survey of experts in the UK and Africa (T3), who ranked it in the top three future risks for humans, animals and plants, and for both the UK and Africa. These concerns reflect two aspects of novel pathogens. First, they have the potential to cause disease problems on a global scale, as illustrated by the advent of HIV/AIDS in which HIV-1 became one of the world's major killers within 20 years of its first reported appearance. Second, novel pathogens may cause an entirely new set of problems, as illustrated by BSE and variant Creutzfeldt-Jakob disease (vCJD). These belong to a highly unusual category of infectious diseases caused by poorly understood aetiological agents which are difficult to diagnose and for which there is as yet no treatment.

Fig 3.2 Spongiform encephalopathy: vacuolations in the brain



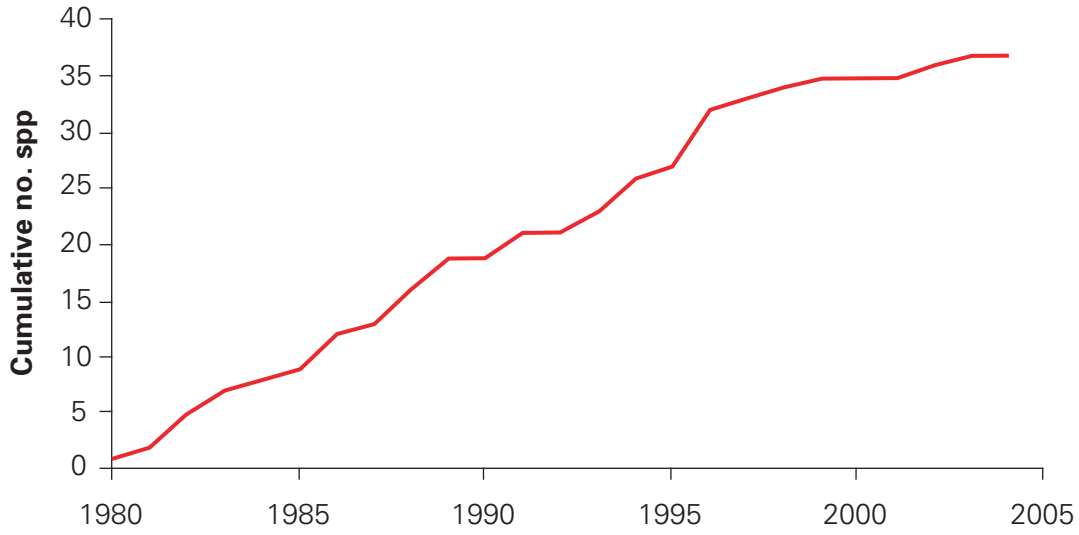
For the purpose of this project, 'novel pathogens' are classified as:

- entirely novel pathogens that have not previously been encountered, for example, HIV 1, vCJD, canine parvovirus and *Phytophthora ramorum* – a new fungal disease threatening American and British forests
- new variants of existing pathogens associated with increased levels of virulence and/or transmissibility, for example, the O157 serotype of *Escherichia coli* and the H5N1 strain of influenza A in birds and humans.

These categories exclude newly discovered aetiological agents of existing diseases (e.g. *Helicobacter pylori* as a cause of peptic ulcers, or *Bartonella henselae* as the cause of cat scratch disease). They also exclude a third, and extremely important, type of 'novel' pathogen – drug-resistant variants, considered in Section 3d.

Thirty-eight apparently new species of human pathogen have been recognised in the last 25 years (T16, Figure 3.3). There are fewer reported occurrences of novel pathogens of animals, but examples include BSE in cattle, canine parvovirus in dogs, circovirus in pigs and phocine distemper in seals. Most of the novel pathogens identified in humans and animals in the last 25 years are RNA viruses, though there are also examples of novel diseases caused by prions, bacteria, rickettsia, fungi, protozoa and helminths (T16). The over-representation of RNA viruses may reflect a genuinely greater risk that these pathogens will invade new populations, but it could also reflect improvements in the detection and identification of viruses in recent years.

Fig 3.3 Accumulation of newly recognised emerging human pathogen species since 1980. This does not include newly recognised aetiological agents of endemic diseases, nor pathogenic sub-species variants.



The recent pattern of emergence of new plant diseases suggests a particular capacity for rapid evolution through the hybridisation and mixing of genes conferring pathogenicity. This is implicated in devastating outbreaks in crops such as cassava mosaic disease in Africa (T5.10), and outbreaks in natural ecosystems such as Dutch elm disease, *Ophistoma novo-ulmi*, and *Phytophthora alni* on alder.

Impact

The threat posed by new pathogens is highly variable, ranging from the global AIDS pandemic to highly localised outbreaks of mild illness in Australian farm workers due to Menangle virus. However, even relatively small-scale outbreaks of novel pathogens, such as vCJD in the UK, *E. coli* O157 in the UK and the USA, or H5N1 influenza A in south-east Asia, can have profound social, economic and political impacts. The 2003 SARS outbreak, which caused less than 1,000 deaths, cost the global economy an estimated US$10–30 billion.

Risks and drivers

Most new human pathogens have their origins in animals. There is a wide variety of 'reservoir' hosts, including ungulates, carnivores, primates, rodents, marine mammals, bats, birds and other vertebrates (T16). Several novel pathogens are associated with livestock and/or food production, for example, BSE/vCJD, *E. coli* O157 and H5N1 avian influenza, and this has had major repercussions for the livestock industry and for responsible government departments. Of concern is the increase in activities involving 'exotic' species for food or as farm animals, pets, crops or garden plants. This may provide fresh opportunities for the transmission of novel pathogens, examples being diseases associated with trade in exotic 'bushmeat' (see Box 3a and project report T12) or the introduction of sudden oak death with horticultural stock (T5.11).

Bioterrorism is a further potential source of novel pathogens[7]. While the likelihood of such an event may be low, heightened concern makes this an important driver for the development of systems and technologies that may also be appropriate for responding to conventional threats.

New plant diseases often represent adaptation of pathogens from native to introduced crops. In Africa, major food crops – like maize, rice, cassava, groundnuts and export crops like cacao – host viruses that have probably switched from indigenous plant species to these introduced crop species (T5.10).

Novel pathogens may infect humans, animal or plants through many different routes. For novel human pathogens, contact with animals, faecal–oral transmission and contamination of food and water supplies are particularly important, as is transmission associated with medical procedures and hospitalisation. Novel pathogens may also be associated with transmission by aerosol, vectors (mainly mosquitoes and ticks) or through sexual activity (T16).

[7] The project has not considered the size and nature of the bioterrorist threat in detail, as that is already addressed by Governmental bodies with access to threat data. However, the project has considered the applicability of future DIM systems to counterterrorism – see report D1.

A wide variety of drivers has been linked to the emergence of novel pathogens. These include changes in land use and agriculture, societal and demographic change, urbanisation, poor population health (due to malnutrition, AIDS or other factors), hospitals and medical procedures, food production and water supplies, international travel and trade, especially in exotic species or their products, and intensification of agriculture and livestock-keeping. Against this background, the pathogens themselves are constantly evolving.

The emergence of novel pathogens appears to be associated with changes in human, animal or plant ecology that provide new or increased opportunities for the transmission of infection, especially to humans from animals, both domestic and wild. Since ecological changes seem set to continue or even intensify in the foreseeable future, it is likely that new pathogens will continue to emerge over the next 10–25 years and systems need to be in place that can rapidly detect and respond to previously unencountered threats.

UK and African perspectives

New pathogens and pathogen variants have emerged in many different regions of the world. However, globalisation allows rapid spread from the point of origin, for example, SARS, and new pathogens may first be reported far from their original location. Thus, HIV was first reported in the USA, despite having emerged in sub-Saharan Africa. The UK has first reported many of the new species or variants of human pathogens that have emerged in the last 25 years (T16). Although the majority of these remain exotic imports, some (e.g. HIV and *E. coli* O157) have become established and now impose a significant burden.

In sub-Saharan Africa, where the existing disease burden is already high, novel pathogens may not be seen as an immediate priority for national governments or regional agencies (A4). Nevertheless, the potential for rapid globalisation of new infectious disease problems means that disease events in sub-Saharan Africa, as elsewhere in the world, are of wider concern.

Despite the challenging nature of the threat of new pathogens, the experience of the SARS epidemic in 2003 strongly underlines the potential effectiveness of rapid, co-ordinated, multinational responses to combat emerging pathogens (www.who.int/csr/outbreaknetwork/en/).

Detection, identification and monitoring

New pathogens must be identified, characterised and monitored, often requiring a large-scale scientific effort. It took 2–3 years to identify HIV but, 20 years later, only 2–3 months to identify SARS coronavirus. This improvement was achieved through a concerted, global effort, involving new methods of information-gathering and analysis, and disease characterisation. The need to identify and characterise a new disease places a very substantial delay on effective and timely

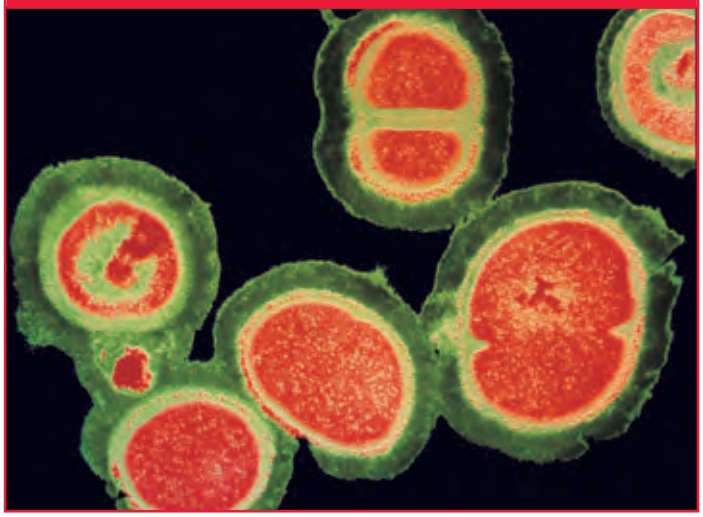
response to a new outbreak. Future DIM systems will need to accelerate both the discovery and the characterisation of new diseases so that methods to reduce their movement and to control them can be implemented before they are too widely spread.

3d Pathogens acquiring resistance

Introduction

The acquisition of antimicrobial resistance, which occurs across the spectrum of human, animal and plant pathogens, is a growing and serious threat to the treatment and control of infectious diseases. This view was reinforced in a major survey of experts in the UK and Africa (T3), who ranked it in the top three future risks for humans, animals and plants, and for both the UK and Africa. The umbrella term 'pathogens acquiring resistance' is used to denote resistance in bacterial, viral, fungal and parasitic diseases such as malaria. Theoretically, it could also apply to other infectious agents in the future – such as prions. The potential spectrum is wide, including resistance to antibiotics and other antimicrobial treatments, herbicides, insecticides and vaccines.

Fig 3.4 Methicillin resistant Staphylococcus bacteria



Resistance to hitherto efficacious therapies may result from natural selection by rapidly evolving micro-organisms, by genetic mutations or by incorporating genes acquired from other micro-organisms. Resistance can emerge extremely rapidly, with increasing disparity between disease problems and effective treatment. New product development and the closure of this gap is clearly a priority.

Human examples where antimicrobial resistance is a problem include enteric pathogens, streptococcal pneumonia, tuberculosis, gonorrhoea, malaria, HIV and hospital-acquired infections such as methicillin-resistant *Staphylococcus aureus* (MRSA). A growing number of antibiotic-resistant bacteria are also found in veterinary species. Examples include companion animals, where there is evidence of human–animal transfer, and livestock, where it is often associated with the incorporation of antibiotics into feedstuffs. Furthermore, drug resistance in veterinary helminths and nematodes affects a growing number of livestock on

a global level – the multi-drug resistance seen in Australasia, South Africa and Europe has forced farmers in some areas to abandon ruminant farming. For plant disease, the rapid recent development of resistance to strobilurins (a new class of cereal fungicides) illustrates the fragility of our chemical defence against new epidemics. Crop varieties which have been bred for resistance to plant diseases are also vulnerable to pathogen evolution and rapid breakdown of resistance.

Some forms of human bacterial infection are insensitive to multiple antibiotics. The increasing, and often sub-optimal, use of antimicrobials in both medicine and in agriculture is a potent cause of resistance. Moreover, the nature of the reservoirs of resistance that may be present in healthy human, animal and plant populations has only begun to be appreciated.

It is anticipated that the problem of antimicrobial resistance will increase substantially in the future unless resistant organisms are detected as they emerge and actions taken to contain them. Even diseases that are currently under control could become untreatable and could re-emerge, posing a serious public health threat.

Impact

Resistance in hospital-acquired infections and in infections in long-term care facilities is of current concern and likely to increase in the future. Seriously ill elderly patients, extremely premature infants, increased use of invasive interventions, high levels of antibiotic use and sub-optimal standards of cleanliness are among the contributory factors. MRSA, which is resistant to many other antibiotics as well as methicillin, is a serious cause of hospital-acquired infection and continues to spread (T5.1). Since it is readily carried as a commensal on skin and nasal sites, it is likely to extend into the community, thereby providing an expanded source of infection for susceptible contacts.

In the UK, hospital-acquired infections are estimated to cost the NHS about £1 billion a year. The proportion of serious infections with *S. aureus* where the organism is resistant to antibiotics has increased: an estimated 30–35% of hospital-acquired infections are attributable to MRSA. The increased cost of MRSA contributes 77% of the *per diem* costs for extra days spent in hospital, 21% of the use of antimicrobial agents in treatment and 2% to additional laboratory costs (T5.1).

Risks and drivers

The misuse of antimicrobials is a key driver of the evolution of resistance in humans, animals and plants. The treatment of common human conditions based on symptoms rather than on accurate diagnosis, self-medication and failure to complete treatment courses contribute to the problem. Diagnostic uncertainty engenders the misuse and overuse of antibiotics and this may lead to antimicrobial selection pressure and the emergence of resistance. The problem is compounded by the growing use of adulterated or fake medicines, particularly in developing countries, and their increasing availability over the internet. The inclusion of antibiotics as a growth promoter in animal feed may also drive antimicrobial resistance in livestock.

Antiviral drugs offer promise for the treatment of viral infections, but resistance is already a problem and increasing – for example, resistance to antiretroviral drugs for HIV. Vaccines are still the major form of control for viral diseases in humans and animals but where pathogens are highly adaptable (e.g. influenza, HIV, malaria), vaccine resistance may pose a future risk. There is insufficient research on which to base an assessment of future risks from vaccine 'escape.' However, the potential for this to occur may be considerable, as suggested by the difficulty encountered in the development of effective vaccines against highly mutable infections.

Resistance to antimicrobials, such as fungicides for controlling plant disease, would pose particular problems for developed countries where they are used extensively. While all farming systems benefit from disease-resistant crops, breakdown of this protection due to pathogen evolution would have particular impact on developing countries. The promise of biotechnology to accelerate the development of resistant varieties may be constrained by concern about GM crops.

UK and African perspectives

African countries, in common with many other developing countries suffer from: a heavy burden of infectious disease, a limited capacity to correctly diagnose infections, the misuse of antibiotics and the widespread availability of poorly regulated drugs that may be adulterated or sub-standard. Resistance poses the greatest problem in Africa in diseases that are major causes of mortality and morbidity and where second-line treatment is often not available. Particular examples are resistance to drugs used in tuberculosis, HIV infection, malaria and gonorrhoea. In the UK, the threat of antimicrobial resistance has focused predominantly on hospital-acquired infections such as MRSA and on selected treatment groups such as HIV, tuberculosis and gonorrhoea.

Detection, identification and monitoring

Advances in the detection and identification of pathogens are essential to combat the problem of resistance. In particular, improved diagnostic precision would reduce uncertainty and permit the more precise prescribing of antimicrobials. This would reduce microbial selection pressure by promoting the initiation or withdrawal of treatment soon after the onset of symptoms. For example, in humans, new methods to distinguish rapidly between viral and bacterial infections in the community would provide a basis for the more appropriate use of antimicrobials for common problems such as respiratory infections, tonsillitis, middle-ear infection and diarrhoeal diseases.

3e Zoonoses

Introduction

Zoonoses are human diseases resulting from the transmission of infection from an animal reservoir – which may act either as a continual or point source. The animal host is the undisputed primary source of continuing infections in humans, such as rabies, West Nile virus (T5.12), brucellosis and transmissable spongiform encephalopathies (TSEs). In other cases, animals have been the point source of a 'species jump', with the onward transmission facilitated by human-to-human infection, for example, Ebola/Marburg viruses and yellow fever.

Nearly 40 'new' human pathogens were first reported in the last 25 years, and the majority of these had zoonotic origins (T16). The risk of zoonotic infection shows no sign of diminishing and may well increase in the future (T3). Indeed, in the survey of experts conducted in the UK and Africa (T3), diseases that cross species were deemed to be one of the top future risks. Both domestic and wildlife reservoirs of infection can lead to human zoonoses. In rank order, cloven-footed livestock (cattle, sheep and goats), carnivores and rodents pose the greatest risk, whereas birds, bats and marine mammals are of proven, but lesser, risk. Many infected animals show little or no clinical evidence of disease and remain potent 'silent' sources.

Fig 3.6 Large colonies of bats carry viruses with potential for transmission to humans

Impact

Once zoonotic infections become efficiently transmitted between humans, they may have a profound impact in terms of morbidity, mortality and cost – as exemplified by HIV (T5.2), vector borne diseases like Japanese Encephalitis viruses and West Nile virus (T5.12). Even where animals remain the primary source for human infection as in TSEs and food-borne diseases such as such as bacterial infections including E. coli 0157 and Salmonellosis (T5.5), their impact is considerable. The economic costs of infectious human diseases derived from animal populations cannot be overestimated. The annual cost of food-borne zoonotic diseases in the UK alone is of the order of £750 million (D4.3).

Risks and drivers

The major threat of zoonotic transmission in the UK are TSEs and food-borne disease due to the contamination of food by animal faeces (T5.5). Most food-borne infections are due to bacteria that have wildlife hosts and can survive in water or soil, such as campylobacteria.

Endemic infection in wildlife hosts may provide the key risk for zoonotic diseases. A current example is Mycobacterium bovis infection of the European badger (Meles meles) which constitutes a natural vehicle for persistent and geographical spread of tuberculosis infection into cattle (T8.4), with risks of transmission to humans. Without effective control strategies, this could become a major constraint to cattle farming in the UK by 2015.

The potential exists for zoonotic diseases elsewhere in the world to be introduced into the UK. A topical example is the risk of AI being introduced by migratory or deliberately imported birds. Drivers of future disease risk include the globalisation of trade and travel, lack of disease control, poor international disease surveillance, increase in trade in animal and animal products and illegal trade in animals and animal products (including captive birds, aquarium fish and companion animals). Bioterrorism could also exploit animals as vectors of human disease – anthrax, for example.

UK and African perspectives

In the UK, contact is more commonly with companion animals than with livestock or wildlife. The greater risks are from the food-borne diseases e.g. Salmonella, Coliforms, rota virus or campylobacteria. These infections are usually disabling and only very occasionally fatal.

However, there exists an intimacy and cultural importance of livestock in many African communities (D7). Traditional African rural communities were usually self-contained and self-sufficient, with zoonotic disease limited to occasional epidemics of vector-borne infections such as Rift Valley fever, Lassa fever and tick-borne haemorrhagic fevers. However, destabilisation of rural communities resulting from political mismanagement, armed conflict, urbanisation and continued drought in many regions has disturbed traditional ways of life.

The need for food in many urban and impoverished peri-urban areas of African cities has created backyard rearing and marketing of livestock, particularly of pigs and poultry. Moreover, the increasing demand for bushmeat enhances the risk of new infection ‘jumps’ between wildlife and humans (T12). This, together with the increasing vulnerability of immunosuppressed individuals with AIDS (T5.2), will increase the likelihood of zoonotic disease over the next 15–30 years.

Fig 3.7 A wide range of bushmeat for sale

In recent years, there has been a profound decline and fragmentation of veterinary infrastructure and services in Africa (A4). This has resulted in a loss of capacity for the early detection of animal diseases that may pose risks to human populations (D5). This contrasts with services in earlier years when major epidemics of animal disease were controlled (T5.9). In the absence of a co-ordinated veterinary and medical approach (D4.3), the risk of zoonotic infections remains high.

Detection, identification and monitoring

The particular challenge with zoonotic disease is to understand and anticipate its spread within and between both animal and human populations. This will require monitoring systems that can operate in very different contexts to detect the same disease, its 'jump' between animals and humans, and the genetic changes that might be associated with these. Zoonotic infections arising from wildlife create particular challenges for DIM, because wildlife species are less biddable to sampling or traceable for monitoring. Greater co-operation between veterinary and medical communities will be important to building better systems of detection, identification and monitoring.

3f HIV/AIDS, tuberculosis and malaria

Introduction

In 2004, HIV/AIDS, tuberculosis and malaria caused an estimated 6 million deaths. It is anticipated that they will pose an increasing problem and remain a priority for the next 15–25 years. African experts concurred with the prediction that HIV/AIDS, malaria and respiratory infections including tuberculosis will remain the most important infectious diseases in Africa in coming decades (A4). Models forecasting the future risks and burden of HIV and tuberculosis also concluded that these infections would continue to increase unless current control efforts were greatly stepped up (T.8.4, T8.7).The resurgence of tuberculosis is attributable to the rising prevalence of HIV.

It is appropriate to consider HIV/AIDS, tuberculosis and malaria in the same section since there are close interactions between them, they occur in the same populations and are associated with poverty. An integrated approach is essential for effective control and this will pose an increasing challenge as diagnosis and treatment become more complex. Vaccines against malaria, tuberculosis and HIV are in development but they are unlikely to be available in the next decade.

Impact

In the past 25 years, HIV/AIDS emerged from being an unrecognised disease to one that causes over 3 million deaths each year. In 2005, there were an estimated 40.3 million people in the world living with AIDS, 4.9 million newly diagnosed cases and 3.1 million deaths (WHO 2005). The epidemic is still at a relatively early stage and may not peak for decades to come (T5.2). Treatments are available and being rolled out but there is no cure and the long-term sustainability of treatment remains an issue.

Most HIV infections occur in sub-Saharan Africa where, in some countries, around a quarter of the population is living with HIV/AIDS. It is predicted that by 2010 as many as 25 million children are likely to become orphaned as a result of the disease. Globally, HIV accounts for 10% of deaths in children under five, but in the worst-affected African countries, it is as high as 80% (T8.7). Since HIV largely affects children and also, to a great extent, young adults who are parents and bread-winners, there are huge social and economic consequences.

Tuberculosis constitutes a serious and worsening international health problem. HIV infection and inadequate public health programmes have fuelled the resurgence of tuberculosis, while the growth of multi-drug-resistant strains threatens control. Tuberculosis is a leading cause of death in people with HIV infection and up to 80% of people with tuberculosis are HIV-infected in countries with high HIV prevalence. HIV accelerates the course of tuberculosis and tuberculosis hastens the progression of HIV to AIDS. The incidence of

tuberculosis is increasing in Africa, where the cost of controlling it depends on the background prevalence of HIV. In low-prevalence areas, the cost is estimated to be in the order of $2.8 billion, and in high-prevalence areas $12.8 billion over the period 2006–2015 (T8.4). About one-third of the world's population is infected with tuberculosis and 10% will develop active infection. In 2004, there were an estimated 9 million new cases and 2 million deaths, 98% of which were in the developing world. Only 15% of people with clinically manifest infection were receiving effective treatment.

There has been a resurgence of tuberculosis in the UK, with about 7,000 new cases each year. The highest rates are in London and over 50% of cases occur in individuals born abroad in countries where the disease is prevalent and the risk of infection high. Most infected individuals have arrived in the UK in the past ten years.

Malaria continues to be the most important tropical parasitic disease. The WHO estimates that 300 million episodes of acute illness occurred in 2002, accounting for an estimated 1.27 million deaths and a loss of over 46 million DALYs globally: most fatalities are in children. Despite the existence of effective interventions, annual deaths from malaria continue to rise and most of these deaths occur in the world's poorest countries, the vast majority in children under five. Pregnant women with HIV are at increased risk of malaria and malarial placental infection, with associated anaemia and low birth weight. Treatment and control have become more difficult with the spread of drug-resistant strains and insecticide-resistant parasites. In 2005, an estimated 343 million clinical attacks of malaria occurred in Africa; 209 million among children under five in sub-Saharan Africa, where the total economic burden of malaria is estimated by the WHO at US$12 billion annually.

Risks and drivers

Drivers common to HIV/AIDS, tuberculosis and malaria in Africa include resource-poor socio-economic conditions, deficient healthcare infrastructure, migration and urbanisation, war and social upheaval. Related to these background factors is a lack of or inappropriate use of drugs, lack or cost of effective interventions (such as insecticide-impregnated bed nets for malaria), and the emergence of resistant strains of pathogens. In addition, and particularly in the case of HIV/AIDS, denial, stigma and superstition play an important role (T5.2).

HIV infection is associated with sexual behaviour and the sexual exploitation of women. Without a political commitment and an appreciation of the lifestyle behaviours associated with HIV transmission the infection will be impossible to eradicate (T5.2). Most infection is acquired through sexual intercourse, mother-to-child transmission in the perinatal period, or breast-feeding (T8.7); or in the case of intravenous drug use and transfusion, from contaminated blood. Sexually transmitted infections, particularly with ulceration, increase the risk of transmission of HIV, whereas male circumcision reduces the risk. HIV infection and its associated immunodeficiency is a potent driver of tuberculosis.

Lack of investment in malaria control has resulted in an increase in the vector population. Anophelene vectors and their plasmodium parasites are sensitive to humidity, rainfall and temperature so that changes in climate and land use, including deforestation and irrigation, increase vector population. These are important environmental drivers and, together with insecticide resistance, will increase risk. Also, demographic changes such as population growth and urbanisation will influence future malaria disease burden estimates (T5.8, T8.2). Population growth increases the number at risk but this is slightly reduced with increased urbanisation (T8.2).

Immunodeficiency associated with HIV infection, nutritional status and poverty also impacts on the severity of malaria. Migration of people with low immunity from non-endemic to endemic areas increases risk of malaria. Climate change and international trade (T8.5) might allow new vector species of malaria to become established in the UK but standards of living are likely to alleviate this threat (T8.10). Malaria also poses a risk to travellers and immigrants, with imported cases increasing in non-endemic areas.

UK and African perspectives

In the UK, HIV and tuberculosis are growing health problems and, although the prevalence of HIV infection is low compared to Africa, it is increasing. In contrast to Africa, mortality from AIDS is low in the UK due to screening and early treatment, with about three-quarters of cases diagnosed. However, treatment costs are high – about £14,000 to treat a symptomatic patient per year. The recent re-emergence of tuberculosis in the UK poses a new challenge.

Fig 3.8 HIV prevalence in adults aged 15–49 in sub-Saharan Africa and all developing regions (percentage) and number of AIDS deaths in sub-Saharan Africa (millions), 1990–2004

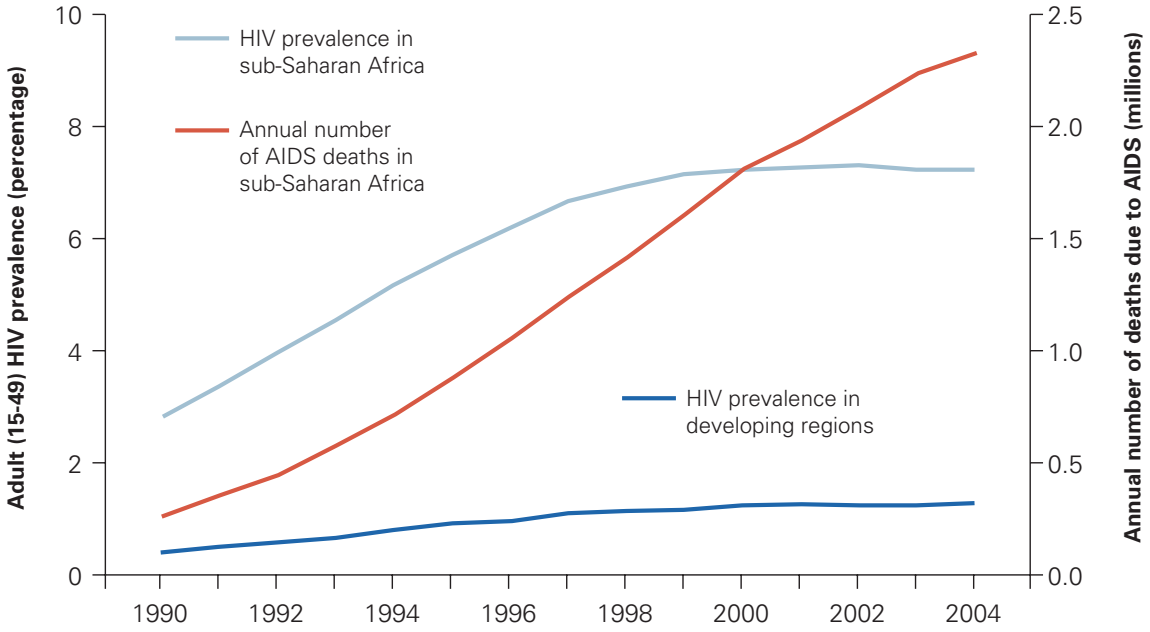


Fig 3.9 Trends in the prevalence of HIV infection in pregnant women, by area of residence. Based on the national unlinked anonymous newborn dried-bloodspot survey.
Source: HPA (2005b)

Detection, identification and monitoring

The current detection rate for active tuberculosis is low. Accurate, rapid, robust and affordable tools are needed that can distinguish between exposure, infection and disease so that timely and appropriate interventions can be implemented to treat, and prevent the spread of, infection. Diagnosis of dual infection with HIV using a single test would greatly facilitate the management of these inextricably linked diseases. Rapid, reliable tests are needed for the early diagnosis of malaria to enable prompt treatment, particularly in children under five and pregnant women, in whom infection is associated with low birthweight and adverse perinatal outcome. In regions where malaria prevalence is high, the diagnosis of disease in older children poses a particular diagnostic problem as many are carriers and, in those with parasitosis and fever, the diagnosis is not straightforward. In individuals infected with HIV, tests are needed to measure immunological function or viral load in order to determine whether treatment should be initiated and multiple tests carried out on a single sample for the early diagnosis of potentially treatable opportunistic infections.

3g Epidemic plant diseases

Introduction

More than 150 crop species are grown around the world and each hosts a range of specific, fungi, bacteria, viruses and other micro-organisms that can cause disease and reduce crop yield. This makes it difficult, in contrast to human and animal systems, to identify a handful of key global plant disease threats. Each country will have priority threats related to its particular food and industrial crops. However, four staple food crops – rice, maize, wheat and potatoes – make up half of the global supply. Epidemic diseases that affect these crops can pose global threats. The recent re-emergence and spread of wheat stem rust in east Africa, a fungal disease which had devastating impacts in the first half of the 20th century, exemplifies such a potential global threat.

Impacts

Plant diseases are estimated to account for 10–15% of losses to crop production worldwide, their impact being greater in developing countries. They constitute one of a range of important chronic threats to crop production, along with pests and weeds. However, in an epidemic state, they have a capacity for sudden and devastating outbreaks on particular crops in specific geographical areas. The severity and speed of such outbreaks may be such that national food and/or economic security is threatened. The outbreak of potato late blight fungus, *Phytophthora infestans*, in Ireland in the 19th century, eliminated the sole food crop of a large poor population unable to access other food resources, resulting in famine and massive population displacement (T5.7). Recent outbreaks of cassava mosaic disease (T5.10) and banana bacterial blight (D4.1) in east Africa

demonstrate that serious and sudden disease risks to food security continue. Similar crises of an economic nature have followed outbreaks of diseases on critical export crops, such as cocoa swollen shoot virus in west Africa in the early 1900s (T5.10) and coffee wilt disease (D4.1) in east Africa today.

Fig 3.10 Cassava severely damaged by the virulent form of mosaic disease in Uganda at the height of the epidemic in the mid-1990s

Plants in natural ecosystems are also affected by disease epidemics. Some epidemics are natural and benign, but others may affect 'keystone' species, such as a dominant forest tree, which are critical to the functioning of the natural ecosystem and hence to ecosystem services such as watershed management, soil stabilisation or provision of clean water. In the UK, a shift in priorities for land management from food production to maintaining environmental quality and services will make disease outbreaks in natural ecosystems more significant (T11, T5.11).

Risks and drivers

While the sheer diversity of crops and their pathogens confounds the selection of a specific future risk, diseases with severe effects and a capacity for rapid spread such as wind- and vector-borne diseases will be particularly significant. Seed-borne diseases will be important, but may be more easily contained by phytosanitary measures, as may soil- and water-borne diseases.

A key driver of future risk will be the reduced resilience of agricultural and natural plant systems to infectious disease outbreaks. Intensification and extensification of fewer, more genetically uniform crop varieties create ideal conditions for disease epidemics. In 1970, for instance, the appearance of a new variety of southern corn blight, *Cochliobolus heterostrophus*, coincided with the planting of 80% of the US maize crop to a new variety that was particularly susceptible. This led to enormous yield losses, costing about US$1 billion. Habitat degradation, and particularly a reduction in soil fertility and in biodiversity, will also increase the likelihood, duration and impact of disease outbreaks. Many natural ecosystems are also increasingly degraded and 'simplified' and this will increase their susceptibility to damaging disease epidemics (T11).

Fig 3.11 Rhododendron dieback – Phytophthora kernoviae

A second driver of future risk is the increasing movement of plant material, largely through agricultural and horticultural trade. It is important to note that international trade in food is not the major pathway here: most new plant disease introductions have been associated with the deliberate import of plants and seeds for planting, a pathway that can be controlled. In Europe, historical records of new diseases suggest that the rate of introduction of new plant diseases increased in the last century.

In recent years, several plant disease outbreaks have drawn attention to a further risk, the evolution of new, more virulent diseases. Diseases from native species may adapt to new crops, or organisms may hybridise, producing new and different diseases. Movement of pathogens and plants by human activity is a major source of opportunities for such hybridisation and evolution. The fungal genus *Phytophthora* is particularly prone to such evolutionary change (T5.7, T5.11).

Climate change will affect the pattern of crop production as crops are moved or adapted to suit new water and temperature conditions (T7.2). For instance, a drier Africa will encourage the substitution of maize with drought-tolerant millet and sorghum. Different pathogens have different climatic optima, making it difficult to generalise about the overall effects of climate change. However, given their particular sensitivity to temperature, insect vectors of disease may thrive in warming climates, making vectored diseases, e.g. many plant viruses, more of a risk in future.

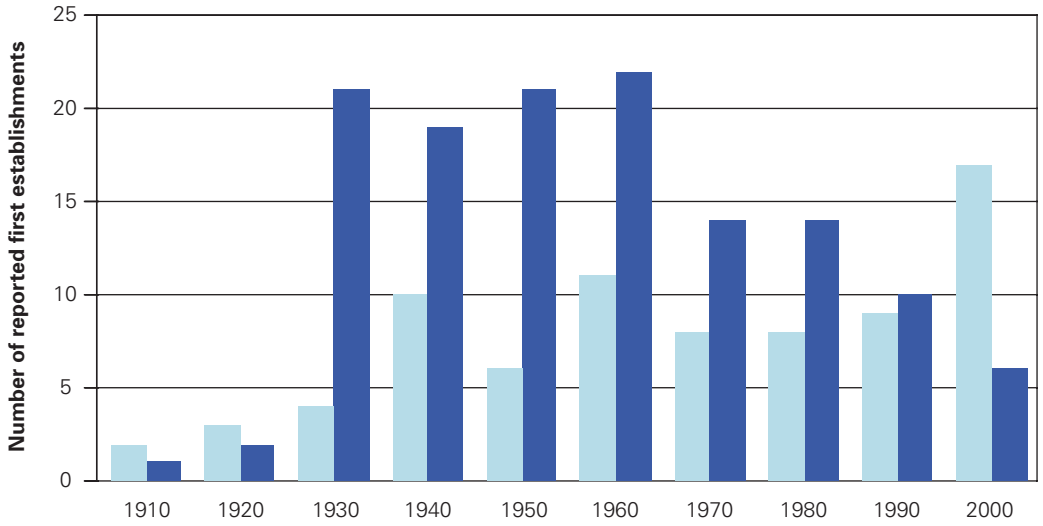
Advances in plant protection will help to mitigate risks in future (D3.1). Chemical control of plant diseases will continue to be important, particularly in wealthier countries. However, the decline in the development of new, effective products is seen as a major threat in the developed world. More progress is expected from improving plant resistance to disease through conventional breeding and the application of biotechnology, particularly for the developing world.

UK and African perspectives

In the UK, plant disease management is increasingly proactive, with regional (EU) collaboration in the early detection of new diseases and on risk assessment, backed up by contingency plans for disease eradication. Emerging economies, such as China, are rapidly improving their reactive capacity to detect and contain new diseases, and can draw on a growing global pool of information on plant disease and disease movement to become proactive (D4).

While the rate of establishment of new exotic plant diseases grew in Europe during the last century, African records of new disease establishments do not show this trend: recorded rates of establishment have fallen since the mid-20th century, when there was a burst of introduction of new crops and varieties. This may reflect a lower intensity of international trade than in Europe, which suggests that trade liberalisation and the intended growth of wealth-generating export agriculture in Africa poses particular, future disease threats.

Fig 3.12 Records of first establishments of new plant diseases in Europe (light blue) and sub-Saharan Africa (dark blue) per decade in the 20th century. While the rate of reported establishments in Europe have risen, possibly due to growing plant trade, those in Africa peaked mid-century. This African pattern might reflect a substantial colonial activity in both crop introduction and plant pathology, followed by a decline in crop introductions and/or national disease diagnostic capacity. See T15 for further details.



On the other hand, this pattern may reflect something quite different, namely a declining capacity in African institutions for detecting and monitoring new diseases (T15). The need to increase capacity in plant disease research and management is urgent in many African countries. This goes beyond the early detection of new problems. Many countries also lack the capacity to react to new diseases with effective eradication and management. This means that new diseases may quickly cause national-scale epidemics, even if they are detected early. Every new disease epidemic therefore makes the task of poverty reduction more difficult. Political unrest both increases the movement of people and disease, and creates large reservoirs of disease on abandoned or poorly managed crop land (D2).

A growing dependence on international assistance to combat disease outbreaks, while accessing valuable expertise, creates delays in response that make it harder to avert crises. As stressed earlier, the greatest opportunity to prevent disastrous new plant disease epidemics may lie in a concerted approach to protect crops on which large, poor populations depend for most of their nutrition and livelihood, such as a few tropical cereals and commodity crops like coffee and cocoa. Crop varieties resistant to disease will be an important approach for resource-poor African systems.

Detection, identification and monitoring

Moving towards proactive systems of plant disease prevention will require improved systems of detecting disease on shipped and imported plant material. Presently, only a small percentage of inbound shipments can be tested. New, cost-effective and rapid methods can help to expand this coverage, and hence interception. Portable devices may be particularly valuable in monitoring for disease in extensive crop lands, while remote monitoring systems may be needed for diseases in natural plant communities, e.g. sensors in rivers to detect disease spores draining from forested catchments.

3h Acute respiratory infections

Introduction

The threat to humans of acute respiratory infections (ARIs) has an exceptionally high profile at present due to fears of a possible global pandemic of influenza A virus, compounded by the recent experience of the SARS coronavirus epidemic. The ARIs of greatest concern are those causing diseases of the lower respiratory tract, pneumonia, bronchitis and bronchiolitis (WHOa). These diseases are associated with a range of endemic and epidemic viral and bacterial pathogens, such as influenza A virus, SARS coronavirus, *Streptococcus pneumoniae, Haemophilus influenzae*, respiratory syncytial virus, parainfluenza type 3, *Mycoplasma pneumoniae* and *Legionella pneumophila*. Significant burdens of respiratory disease are also associated with other agents such as measles virus.

Impact

Influenza pandemics occurred in 1918, 1957 and 1968, causing an estimated 40–50 million, 2 million and 1 million deaths respectively (WHOb). The SARS epidemic of 2003 was much smaller, causing fewer than 1,000 deaths, but still had serious consequences, especially for international travel. Even in the absence of a visible pandemic, the WHO estimate that ARIs are responsible globally for almost 4 million deaths annually, approximately half in children, and the loss of almost 100 million DALYs (WHO 2004).

In the UK, respiratory infections account for over 10,000 deaths per year (mostly in the elderly), over 100,000 hospital admissions per year, and over 5 million GP visits. This adds up to the single greatest burden to the NHS imposed by any single category of infection (HPA 2005a).

The likelihood of future epidemics or pandemics of influenza or other ARIs is regarded as high, although the consequences of such events is inherently uncertain, mainly because the virulence of new strains of ARI-causing viruses or bacteria cannot be known in advance. Even so, it is anticipated that new ARIs could spread around the world very rapidly (in weeks) and could cause millions of

deaths worldwide, and tens of thousands in the UK alone. The World Bank has suggested that an influenza pandemic could cost the global economy US$800 billion in a single year.

Epidemic ARIs are associated with zoonotic origins: SARS with live animal markets in south-east Asia; influenza A with birds, especially chickens. The current high-profile example is the H5N1 strain of influenza A, which is an avian virus that can affect people in close contact with poultry but in its present form is not capable of significant transmission from person to person.

The biology and epidemiology of ARIs have several features that increase their potential to cause serious public health problems (T5.3). First, the time course of an infection is typically rapid, with incubation periods of a few days and recovery from clinical disease over a similar time period. This makes them especially 'fast-moving' infections. Second, not all infected persons, perhaps only a minority, will develop symptoms that are sufficiently severe to be noticed by or reported to health protection agencies, potentially allowing extensive transmission in the general population to take place undetected. Third, the transmission potential of ARIs in the general population may be high: e.g. for both SARS and influenza A, it has been estimated that each case can generate more than two further cases on average, allowing an epidemic to develop in a few weeks. Fourth, effective protection or treatment through vaccines or drugs may not be immediately available once an outbreak is detected.

UK and African perspectives

ARIs are considered to pose a major threat to human health in the immediate future. Because of their global nature, this threat is common to the UK, Africa and other regions. However, its nature and scale will depend on local conditions such as differences in the degree of contact between humans and livestock.

At the global level, the ARI threat (in particular of influenza A) is associated with the following main drivers and pathways:

a poultry keeping and close contact between poultry and humans. Other non-human hosts, such as wildfowl and pigs, may also play important roles in the epidemiology and evolution of influenza viruses.

b urbanisation. High human population densities, may, in turn, be associated with small-scale poultry keeping, especially in developing countries.

c global travel. Air travel by asymptomatic or pre-symptomatically infected people was a major contributor to the rapid spread of SARS to more than 20 different countries from its point of origin in south-east Asia, and is likely to make a similar contribution to the spread of pandemic influenza.

d hospitals. Hospitals are potentially important contributors to the spread of SARS and influenza, and hospital staff may be at greatly increased risk of infection, which could have serious consequences for the wider delivery of healthcare.

e Ineffective surveillance. The early detection of outbreaks of novel ARIs has been shown by modelling studies to be vital for there to be any chance of containing outbreaks before they spread more rapidly (Ferguson 2005).

Fig 3.13 Ugandan market with trading of fowl in open conditions

Detection, identification and monitoring

ARIs are characterised by their capacity for rapid spread. This puts a premium on speed of detection and diagnosis. The detection of asymptomatic individuals may be critical: even intercontinental flight times are now much less than the incubation period of typical ARIs, so relying on the detection of clinical symptoms may be insufficient to prevent entry of disease. Screening in areas of high throughput, such as airports and public transport, may be particularly important to monitor and arrest spread, and this may require special technology.

3i Sexually transmitted infections

Introduction

Sexually transmitted infections (STIs) including HIV are increasing in prevalence throughout the world and constitute a major infectious disease problem in the UK. In 2004, more than 780,000 new episodes of chlamydia, gonorrhoea, syphilis, genital warts or genital herpes were diagnosed in England, Wales and Northern Ireland, an increase of about 20% compared with 1999 (HPA 2005b). In Africa, where the prevalence of STIs is high and most infections are undiagnosed, STIs were highlighted as an important future infectious disease threat (A4). The problem is exacerbated by the fact that STIs substantially increase the risk of HIV transmission, particularly when associated with ulcerative lesions (see 3f).

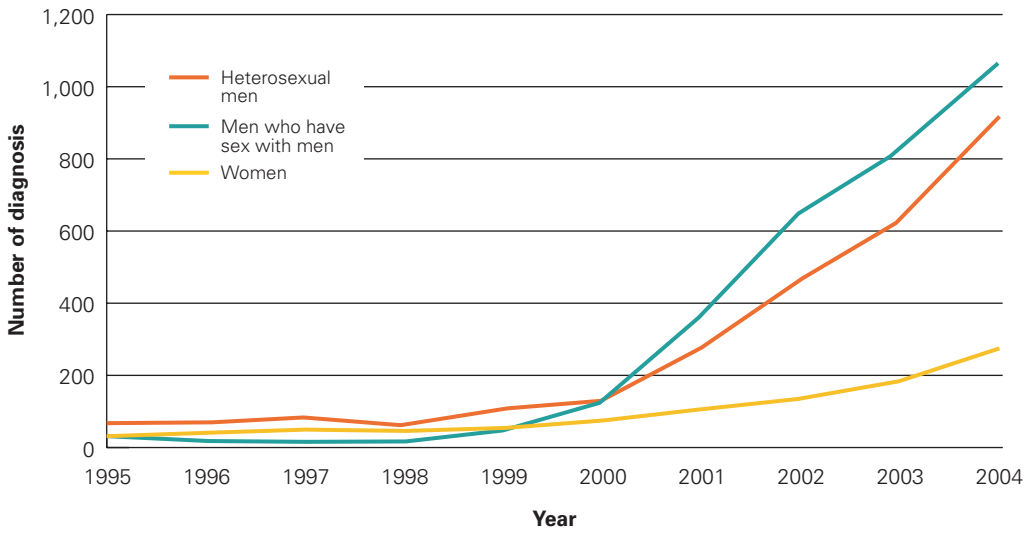
Impact

Based on initial appointments and follow-up visits, the cost to the NHS of STIs excluding HIV is approximately £165 million annually. HIV continues to be one of the most important communicable diseases in the UK and is associated with serious morbidity, high costs of treatment and care, significant mortality and a high number of potential years of life lost. In England, the approximate cost of the treatment and prevention of HIV is £400 million (HPA 2005b).

If undiagnosed and untreated, genital chlamydia and gonorrhoea can result in pelvic inflammatory disease, infertility and ectopic pregnancies. These infections can also be transmitted from a mother to her baby at the time of birth, causing eye infections which, particularly in the case of gonorrhoea may cause blindness. Genital infection with chlamydia trachomatis, the most commonly diagnosed STI in the UK, affects one in eleven sexually active women and the number of diagnosed cases continues to rise, particularly among young women. Although this is likely to reflect increased testing and screening practices, true rates will be higher as most infection is asymptomatic. Similarly, most infections with *Neisseria gonorrhoeae* are asymptomatic. Effective treatment has been complicated by the ability of *Neisseria gonorrhoeae* to develop resistance to antimicrobial agents with around 14% of isolates in the UK resistant to ciprofloxacin in 2004 compared to 9% in 2003 (HPA 2005b).

Syphilis is characterised by multiple clinical stages and long periods of latent asymptomatic infection. Primary infection is localised to the genital tract but the organism rapidly disseminates throughout the body. In the UK, there has been a dramatic recent increase in diagnosed cases. In 2004, there were 2,254 cases – an increase of more than 500% since 2000. Routine screening of women in pregnancy is recommended so that treatment can be given to prevent congenital infection and its adverse effects.

Fig 3.14 Increase of syphilis in the UK



Data sources: KC60 and STISS/ISD(D)5 returns from GUM clinics

Genital warts, caused by human papilloma virus (HPV), types 6 and 7, are the most common viral STI diagnosis. These types represent only a small proportion of the HPV infection pool and other types cause invasive cervical cancer and cancers of the anogenital tract. Genital herpes 1 and 2 are the most commonly diagnosed viral genital infections in young women. Herpes infection may facilitate HIV transmission and can cause severe systemic disease in neonates and in individuals with impaired immunity.

HIV is associated with serious morbidity, high costs of treatment and care, significant mortality and a high number of potential years of life lost (see 3f). The prevalence of HIV in the UK continues to rise (there was a 14% rise in individuals accessing treatment and care services in 2004 compared to 2003) and it is likely to remain a serious problem for the next 15–25 years. By the end of 2004, there were an estimated 58,000 people living with HIV in the UK, over a quarter of whom were not aware of their infection (HPA 2005b). Treatment with antiviral therapy has had a major impact on quality of life and life expectancy but diagnosis late in the course of the disease is associated with a much poorer prognosis than is the case with early diagnosis.

Risks and drivers

In the UK, chlamydia infection occurs in young people from all populations but the highest rates of gonorrhoea, syphilis and the other STIs are seen in urban deprived areas and disproportionately affect certain population sub-groups, including men who have sex with men, some black ethnic minorities and young men and women with high-risk sexual lifestyles. In recent years, there have been several syphilis outbreaks in the UK occurring within these risk groups and

associated with concurrent HIV infection. Urban deprivation, the growing pool of HIV-infected individuals, high rates of partner change, increasing levels of unsafe sex among men who have sex with men and changing sexual and social networks constitute drivers of a growing risk.

The main risk of new HIV infection in the UK has been in men who have sex with men and in heterosexual men and women from sub-Saharan Africa. The HIV prevalence among pregnant women in the UK who were born in sub-Saharan Africa is estimated to be 2.4%. Infection in intravenous drug users remains low. International travel, migration and population movement are likely to be the key drivers of infection acquired through heterosexual intercourse (T5.2).

UK and African perspectives

In the UK, STIs including HIV are a growing problem for healthcare as indicated above. In Africa, HIV constitutes a major cause of mortality and morbidity (see 3f) and, in contrast to the UK, is primarily a heterosexual problem. STIs contribute substantially to the spread and impact of HIV infection. Individuals who have STIs are more likely than uninfected individuals to acquire HIV if they are exposed to the virus through sexual contact. In addition, an HIV-infected individual with another STI is more likely to transmit HIV through sexual contact than other HIV-infected persons. Even though the control of STIs is an important component of HIV prevention in Africa, the late presentation of STIs, inadequate diagnosis and treatment, the growing problem of resistance and poor health infrastructure contribute to their increasing spread.

Pregnant women are a target group for testing for STIs including HIV. Undiagnosed and untreated maternal syphilis may result in foetal loss, stillbirth or prematurity and one-third of infants will be congenitally infected. Without prophylactic antiretroviral drugs for women with HIV, around 30% of their infants will acquire infection.

Detection, identification and monitoring

Most STIs are not associated with symptoms, remain undiagnosed and therefore continue to spread and pose a public health problem. Individuals, particularly the asymptomatic, are often reluctant to attend medical facilities to be tested for STIs. A test that could be carried out by the individual concerned would be likely to increase the number tested and result in early treatment. In Africa, a presumptive diagnosis of STIs other than HIV is usually based on defined symptoms (a syndromic approach), and tests for specific infections are rarely available. The development of a cheap, rapid and reliable test for specific STIs would result in important benefits for the diagnosis of symptomatic infections, particularly those with ulcerative lesions where the risk of HIV acquisition is high. Multiple infections diagnosed from a single sample would facilitate the institution of prompt effective treatment.

3j Transboundary animal diseases

Introduction

Transboundary animal diseases are epidemic diseases that move across national boundaries. Such epidemics may be severe in scale, for example, rinderpest (T5.9). More recent examples include FMD (type O pan-Asia) which moved from north India in 1990 to reach Taiwan in 2000 and the UK in 2001. Other examples of severe disease epidemics include CBPP, a mycoplasma infection of cattle and buffalo, and Gyrodactylus salaris (a parasitic infection of salmon) (T5.6).

The transboundary nature of these epidemic diseases means that effective control relies on rapid and accurate diagnosis coupled with the co-ordination of international response and control. In some instances, for example, rinderpest, control has been highly successful (T5.9). However, major epidemics continue to circulate across wide areas of the world. An important factor contributing to failure of control is the transboundary movement of people and trade (T10).

Fig 3.15 Transhumance crossing the Bani tributary of Niger River at Djénné Mali. During November and December, after the crop harvesting period, herdsmen and their cattle from Niger, Mali, Burkina Faso and Mauritania congregate at Djénné, Sofara or Diafarabé crossing points in migration from north Sahel to the flooded pastures of the Niger River and its tributaries.
Source: Dr Bouback Seck, Mali

The control of epidemics is complicated when a disease co-exists in more than one host, for example, bovine tuberculosis in cattle and badgers. Complications also occur where there is a reservoir of infection in insect vectors and/or wildlife species such as West Nile virus (T5.12) in wild birds or rabies in foxes and feral dogs. Furthermore, when entirely new diseases escalate rapidly, control measures are unlikely to be available.

Impact

The impact of transboundary epidemic diseases in animals was illustrated by the 2001 UK outbreak of FMD, when over 6 million animals were culled during a costly control programme. In 1997, an outbreak of classical swine fever (CSF) in Holland resulted in the culling of over 12 million pigs at a cost of over £4 billion.

Fig 3.16 Burning pyres of cattle in the 2001 outbreak of FMD in the UK

In addition to the direct economic consequences of these diseases, costs are amplified by the restriction of national and international trade, disruption of farming communities and even closure of the countryside for access and tourism.

Risks and drivers

Food security and supply, key priorities for governments, can be profoundly affected by transboundary animal diseases. An important driver of future risk includes the unregulated importation, possibly illegal, of infected animals or their products, such as the importation of FMD-infected food, importation of illegal bushmeat and the importation of caged wild birds incubating AI (T12). However, for some animals, such as the natural movement of birds (T5.12) and fishes (T5.6), control is not feasible.

As a result of climate change (T7.1, T7.3), insect vectors will migrate to new geographical regions, carrying with them the potential for extending insect-borne diseases such as bluetongue virus of sheep and cattle (T8.3) and Rift Valley fever (T8.5). Also, climate change may allow diseases to spread to regions where new vectors can act as carriers.

Rapid diagnoses with early control are crucial steps for the prevention of epidemics and obstacles to their implementation constitute a risk. Increased unregulated livestock ownership within growing urbanisation is one such risk. In the UK, the substantial number of 'smallholder' enterprises rearing a few cattle, sheep, or pigs posed a problem for disease security during the FMD outbreak in 2001. In the next 30 years, this trend is likely to increase, particularly concerning backyard chicken keeping, thereby creating potential reservoirs that are difficult to monitor.

Agricultural bioterrorism is a potential risk that could impact on international trade and, depending on the pathogen, threaten livestock communities. Rapid detection will be important if pathogens are introduced maliciously. However, it should be noted that this requirement is no less important for non-malicious introductions. Also, if newly evolved or genetically engineered organisms are delivered, an ability to rapidly diagnose and identify new and 'unknown' diseases will be crucial.

UK and African perspectives

In sub-Saharan Africa, 12 of the world's 15 major epidemic diseases of animals (in the former OIE List A) are endemic, whereas all are exotic to the UK (T8.5, D3.2).

Livestock farming in Africa contributes 25% to the gross national product of sub-Saharan Africa countries. The impact of epidemic animal diseases on rural African communities can be catastrophic: the cultural status and wealth of pastoralists are represented almost entirely through their cattle herds, whereas peri-urban communities place considerable reliance on pigs and poultry.
The risks from diseases are not diminishing (T3); the drivers for this include the impact of climate change on disease vector populations (T8.5, T8.8) and drought, the migration of people across national boundaries and the evolution of new livestock diseases.

Fig 3.17 Settlement of nomadic pastoralists in east Africa changes the pattern of both human and livestock diseases

Africa is facing a loss of the veterinary expertise and infrastructure which, in the past, permitted rapid diagnosis and identification of disease (A4). Diseases of particular importance include CBPP, peste des petits ruminants (PPR) and FMD – the latter being the most transmissible and greatest impediment to international market access by sub-Saharan African countries.

AIDS and other human diseases are having a serious impact on the sub-Saharan Africa manpower needed for productive livestock farming and are undermining the self-sufficiency of many communities and compounding the failure of food supplies.

Detection, identification and monitoring

For transboundary animal diseases, there is an international responsibility for worldwide surveillance (co-ordinated through the OIE). This identifies a need for effective monitoring systems and close linkages with and between national systems. The detection of new outbreaks is often delayed by the time taken to sample, transport and identify diseases – currently this may involve the international transportation of samples, which can be a major problem. A capacity to identify diseases locally, i.e. at 'pen side' will greatly speed the stamping out of new outbreaks. Variation and evolution of disease virulence (e.g. the recent emergence of the highly transmissible pan-Asia O serotype of FMD virus) makes it important that diagnostic tests are sensitive to the range of existing serotypes, particularly to facilitate vaccination, which will be an important response.

3k Advances in DIM technology that could reduce the future threat of infectious diseases

In 3c–3j above, the potential of individual DIM systems has been briefly discussed for each of the eight categories of disease. However, in order to perform a detailed analysis of DIM systems elsewhere in the project, it was considered desirable to group them into broad categories – we term these 'user challenges' (UCs). The following outlines the four categories chosen, and explains which of the UCs address each of the eight categories of future threat. It also details where further analysis of each user challenge may be found in the project reports. The four UCs are:

- UC1: novel information technology for the capture, analysis and modelling of data for the early detection of infectious disease events. Detailed analysis of this UC may be found in project report (D2.1).
- UC2: early detection and characterisation of new or newly resistant/virulent pathogens using genomics and post-genomics (D2.2).
- UC3: taking technology for the identification and characterisation of infectious diseases to individuals by designing smart swabs, hand-held or portable devices that analyse fluids (D2.3).
- UC4: high-throughput screening for infectious diseases of people, animals and plants using surrogate, non-invasive markers (e.g. electromagnetic radiation, volatiles), for example, in airports, containers and livestock markets (D2.4).

In addition to the detailed reports mentioned above, a summary of the analysis of all of the UCs may be found in report D1.

Table 3.1 shows the extent to which each of the four UC systems could contribute to the management of each of the eight disease threats. The following points are worth noting:

- Hand-held devices (UC3) have considerable potential across the entire spectrum of human, animal and plant diseases.
- Rapid identification of new and resistant diseases will depend on DIM systems that detect unusual patterns of disease (UC1), linked to systems that characterise new disease agents (UC2).
- Rapidly evolving diseases will also depend on rapid characterisation technology (UC2).
- Managing diseases that move rapidly around the world, through agricultural trade or as rapidly spreading acute respiratory infections of humans, will benefit particularly from DIM systems that analyse data on disease patterns (UC1) and movement and which detect diseases at ports of entry (UC4).

Table 3.1: Comparison of disease threats with DIM technologies. Potential contribution ranges from moderate (*) to high (***)

Categories of disease threat	Potential contribution to managing future risk			
	UC1	UC2	UC3	UC4
Novel pathogens	***	***	**	**
Pathogens acquiring resistance	***	**	***	*
Zoonoses	**	**	***	***
HIV/AIDS, tuberculosis, malaria	**	*	***	*
Epidemic plant diseases	***	*	***	***
Acute respiratory infections	***	**	***	***
Sexually transmitted infections	**	*	***	*
Transboundary animal diseases	***	**	***	***

Box 3a Novel sources and pathways: wildlife trade Abstracted from technical paper (T12)

The wildlife trade (domestic and international trade of animal or plant products), particularly the trade of wildlife for consumption, has been linked to the evolution and outbreak of diseases such as AI, severe acute respiratory syndrome (SARS), Ebola, and HIV.

Wild meat is a major source of protein for people in subsistence economies. Hunting has often been transformed into commercial trade, with meat sold to consumers through an extensive network of trappers, hunters and middlemen. 'Bushmeat' is an African term for the meat of wild animals, including duikers, rats, porcupines, a variety of monkeys, great apes, elephants, as well as snails, turtles, snakes and crocodiles. 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'. Animals sold in these markets include masked palm civets, ferret badgers, barking deer, wild boars, hedgehogs, foxes, squirrels, bamboo rats, various species of snakes, endangered leopard cats, and domestic animals.

Annually, it is estimated that 1–3.4 million tonnes of bushmeat are consumed in central Africa; 67,000–164,000 tonnes in the Amazon; and 23,500 tonnes of wild meat (2.6 million animals shot) in Sarawak, Malaysia. The market value of bushmeat is significant, estimated at US$117 million annually in the Côte d'Ivoire alone, where its share of GDP in 1999 was higher than domestic beef production, tropical wood exports, bananas and pineapples combined. Meat has even been transported internationally to cities such as London.

Fig 3.18 The bushmeat trade involves the transportation and sale of both live and dead animals

Box 3a Novel sources and pathways: wildlife trade Abstracted from technical paper (T12) (continued)

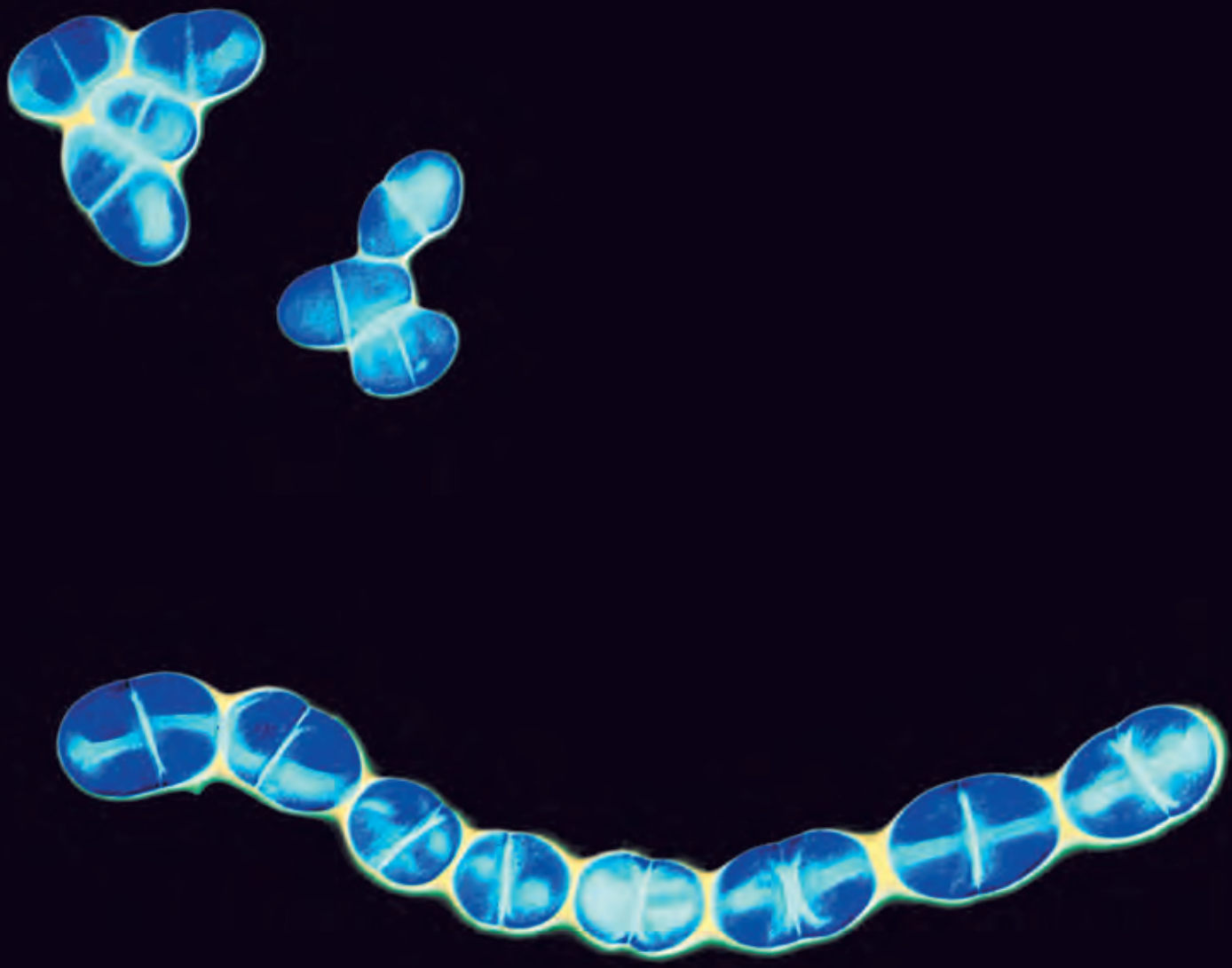
Sources, pathways and drivers

The hunting, preparation and consumption of wild meat and its sale at wet markets offer pathways for disease exchange from wild animals to humans, and can provide fertile ground as a source of new diseases. The high volume of commercial bushmeat hunting activity can increase opportunities for disease transmission and for virus exchange and evolution.

HIV is thought to have evolved from a family of primate viruses, possibly transferred to humans during hunting. Recently, 13 of 16 Ebola outbreaks in Gabon and the Republic of Congo have resulted from the handling of a gorilla or chimpanzee carcass. A recent study documents simian foamy virus (SFV) in individuals engaged in bushmeat hunting in rural Cameroon.

While butchering and dressing wild meat, humans with an increased likelihood of cutting themselves are exposed directly to animal pathogens. Wet markets also provide opportunities for disease evolution as a wide variety of wild mammals, birds and reptiles come in contact with dozens of other wild species, domestic animals, vermin and pests, as well as countless people. 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. The disease may have jumped to civets from bats in wet markets in southern China.

Population growth, globalisation, infrastructure development, rural poverty, urban demand and consumer preferences are drivers of the wild meat trade and are thus disease sources and pathways.



Appendix A

Climate change and its impact on infectious diseases

Change facilitates the emergence and spread of infectious disease. Altered landscapes bring hosts into contact with new pathogens; greater population densities help their rapid spread; faster, longer-distance travel and trade carry diseases to new populations; and natural disaster or war disrupts our ability to keep diseases in check, at least temporarily. Climate change, of natural or anthropogenic origin, is also a driver of disease.

This report provides a brief overview of key conclusions from studies of the anticipated effects of climate change on infectious diseases of humans, animals and plants in the UK and sub-Saharan Africa during the 21st century. It draws on a number of technical papers that were commissioned by the project, and which considered, or touched on, this subject:

- UK and Africa survey (T2, T3)
- disease case studies: malaria (T5.8), West Nile virus (T5.12)
- State-of-science reviews: the effects of climate change on infectious diseases of plants (T7.2), animals (T7.3) and humans (T7.4)
- Modelling studies: malaria in sub-Saharan Africa (T8.2), bluetongue in Europe (T8.3), tsetse in sub-Saharan Africa (T8.8), and malaria in the UK (T8.10).

A1 The future climate of the UK and Africa

The United Kingdom Climate Impacts Programme (UKCIP 2002) predicts that the UK will warm by 0.5–1.5 °C by the 2020s and by 2–4 °C by the 2080s. Warming patterns in Africa are more spatially diverse, given its size and the greater number of forces acting on its climate, but are of broadly similar magnitude to those predicted for the UK. Rainfall predictions are more varied and less precise. UKCIP (2002) predicts that the UK will experience drier summers and wetter winters, with little or no net change overall. The UK's climate, then, will become increasingly Mediterranean as we move through the 21st century. Much of Africa is expected to become significantly drier at the same time as it gets warmer. Some regions, however, such as parts of east, central and west Africa, will experience greater rainfall.

A2 Climate and disease

The state-of-science reviews (T7.2, T7.3, T7.4) argue that we must understand how climate affects infectious diseases today before we can predict climate change's impacts of the future.

Climate affects certain pathogens directly. In order to move from one host to another many pathogens spend a period of time in the environment, exposed to

the weather. The time period can be as long as months/years (spores of many fungal plant diseases; spores causing anthrax in animals and humans) or as short as seconds/minutes (human cold and influenza viruses, rinderpest virus in animals). In most cases, climate and weather determine when the pathogen can successfully reach and enter a new host and, thereby, the seasonality of the disease.

Climate is known to affect hosts, particularly plants, directly. For example, some plants lose their resistance to certain pathogens above threshold temperatures.

Many pathogens employ the use of intermediate hosts (vectors) to facilitate transmission between primary hosts. The huge abundances attainable by such vectors and their finely tuned delivery mechanisms (preferential feeding on specific host types combined with insertion of mouthparts directly into blood/phloem) makes the use of vectors a highly successful transmission route for pathogens. However, vector-borne pathogens are then limited to the spatial and seasonal distributions of the intermediate host. In the case of arthropod vectors, climate often plays a dominant role in determining where and when they occur and, accordingly, vector-borne diseases are often climatically restricted in both time and space.

A3 Climate change and disease

Although climate change is still in its relatively early stages, expert opinion indicates that climate change is widely expected to be among the most important drivers of infectious disease in the future (T3). The key driver in the UK is expected to be rising ambient temperature. In Africa, where people, animals and crops live in conditions of much greater moisture stress, experts believe rising temperature is still important but less so than changes to rainfall patterns and the frequency of droughts.

Climate change's impact is expected to be greatest on vector-borne diseases. The changing spatiotemporal map of temperature and moisture will lead to latitudinal and altitudinal shifts in the distribution of certain vectors, potentially exposing naive populations to new diseases. Warmer winters may allow more vectors to survive from one season to the next, leading to faster and earlier disease development.

Key impacts on the UK

In general, warmer temperatures in the UK, with no net change in rainfall, will be favourable to arthropod vectors and we may face greater challenge from vector-borne diseases. New human vector-borne infections do not appear imminent. This includes malaria, despite it having been endemic to parts of the UK until the mid-20th century and the presence, still, of large populations of the *Anopheles* vectors in the south and east. Malaria disappeared because of land-use changes,

better housing and more affordable anti-malarials. Climate change is unlikely to lead to malaria's permanent reappearance in the UK but, nevertheless, our climate will become more favourable for the disease transmission, and the risk of small, localised epidemics will increase (T8.10).

UK ruminant livestock, however, are at growing risk of bluetongue, a vector-borne viral disease of cattle and sheep, which has spread through southern Europe because of recent climate warming in the region (Box A1).

Box A1 The increasing risk of bluetongue

The biting midge *Culicoides imicola* was, until the late 1990s, restricted to the warmest corners of Europe: southern Spain and Portugal to the west, and the Greek islands to the east. In recent years, the insect has spread across much of southern Europe, including France and Italy, together with a significant move northwards. A devastating epidemic of bluetongue in southern Europe, a midge-borne viral disease of ruminants, has followed in its wake. The spread of bluetongue and its vectors presents some of the strongest evidence to date that climate change is driving vector-borne diseases into new regions, as warming and disease spread have occurred at the same times in the same places. Further climate change is predicted to drive bluetongue risk even further north, putting the UK in 2030 at measurable risk of a disease that, in the previous century, was never within 1.000km of our borders. For full details see T8.3.

Fig A1: A blood-engorged *Culicoides* biting midge
Source: Image courtesy of Steven Archibald and Eric Denison

Plants will also be at greater risk of vector-borne disease, as mild winters and warm springs favour the survival and early development of aphid vectors of numerous pathogens. In some instances, however, very hot and dry summers may impact negatively on certain vectors: excessive water stress in summer may reduce threats to animals in the UK from the liver fluke (fascioliasis) which is vectored by water-sensitive lymneid snails, and may cause enhanced mortality of the aphid vectors of plant diseases.

Key impacts on Africa

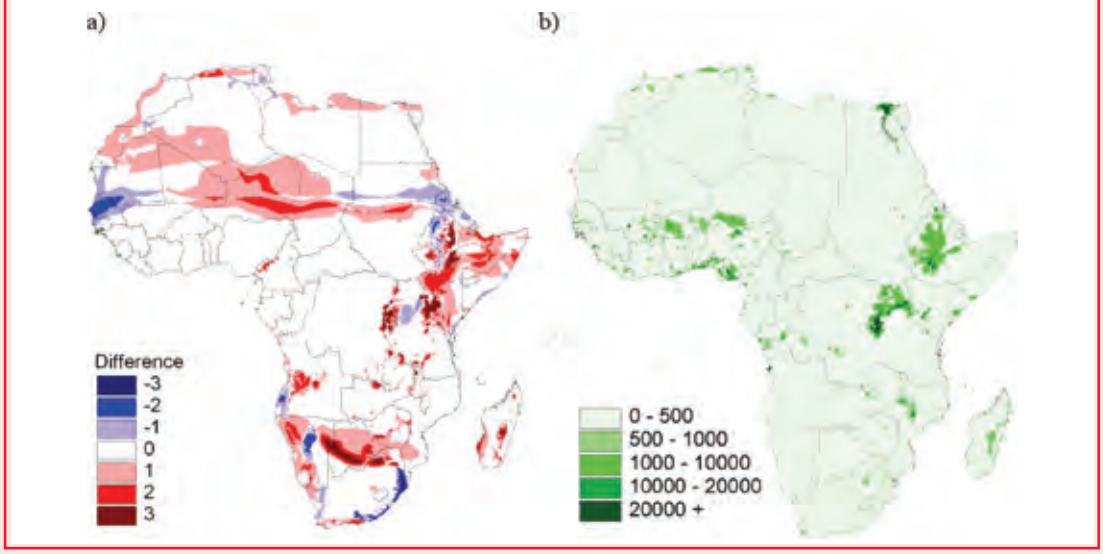
The impacts of climate change on vector-borne diseases will be greater in Africa than in the UK, if only because they are already more significant causes of suffering. For example, vector-borne diseases are a negligible cause of human mortality in the UK, but five – malaria, sleeping sickness, leishmaniasis, schistosomiasis and filariasis – are major causes of human suffering in Africa. Climate change is expected to alter the distributions of some or all of these diseases. In the case of malaria, the impact of climate change on human disease is important, but small compared to other drivers of change (Box A2).

Animal trypanosomiasis is one of the major constraints to livestock in Africa and a significant contributor to poverty. The tsetse fly vectors are predicted to alter their distributions in response to climate change by 2030 (T8.8). Many tsetse species are predicted to lose their footholds at the southern and northern extremes of their ranges, probably in response to increased moisture stress, but some species are predicted to expand into parts of east and west Africa.

Box A2 Malaria in sub-Saharan Africa

Predicted climate change alone is estimated to increase the human population at risk (PAR) of malaria in Africa by 13% by 2015 and 14.5% by 2030. Human population growth, however, is predicted to increase the PAR by a much greater amount (22% by 2015 and 61% by 2030), indicating that climate change is just one of several drivers of change in the risk of infectious disease.

Fig A2: Change in fuzzy climate suitability class (red = more suitable: blue = less suitable) across Africa between 2005 and 2030: (2a) as a result of climate change; and (2b) projected population growth over the same period. The combination of maps allows visualisation of the population at risk of malaria and how it may change in the next 25 years. See T8.2 for full details and T5.8 for further discussion.



West Nile virus was discovered in New York in 1999 and it has subsequently spread across the continent, causing deaths of humans, horses and birds. Epidemics of West Nile are often associated with heavy rainfall succeeding a period of drought, the very conditions that preceded the first US cases (T5.12). Climate change is predicted to increase the frequency of such extreme events, in part because of effects on the El Niño Southern Oscillation (ENSO) which is often a harbinger of drought and rain. There may, accordingly, be an increased risk of ENSO- or extreme-weather-linked vector-borne diseases, in Africa and beyond, such as malaria, dengue, West Nile virus and Rift Valley fever.

Conclusions

The Foresight reports concur that predicting our disease future with precision is not possible. This is due to the considerable uncertainties arising from the many, often conflicting, forces that climate imposes on infectious diseases. Furthermore, climate change will interact with other drivers of change in complex, often unpredictable ways. Finally, there is continued uncertainty in the extent of climate change itself. However, despite these reservations, there is consensus that many infectious diseases of animals, humans and plants will be affected by climate change.

There is agreement that vector-borne diseases are the most susceptible to the effects of climate change, although certain diseases spread by other means will be affected too. Climate-change mediated spread of infectious diseases will cause direct human suffering, especially in Africa. It will increasingly challenge current production systems of livestock and crops in the UK and Africa. While climate change is by no means the sole driver of our infectious future, its relative importance is increasing and its effects are already being felt.

Appendix B

China – future trends in human and animal infectious diseases

Within the Foresight project, the majority of the work to evaluate future disease threats focused on sub-Saharan Africa and the UK as exemplars. However, it was decided to look also at China, specifically for human and animal diseases. This recognised the importance of Asia as a source of zoonotic diseases, and China as an important country in the region. This appendix outlines the work that was undertaken, and presents the key findings (see T13 for a detailed account). The work was almost entirely conducted in China.

The objectives of the work were to:

- develop priority lists of human and animal infections in China for the next 10–25 years
- identify and analyse the factors driving change in risk.

The aim was to determine the future diseases threats in China that were likely to be most important (singly or in groups) for surveillance and control.

B1 Methodology

The work devised a simple but novel methodology for identifying likely future trends in families of infectious diseases. This uses the risk model described in Chapter 3. However, while this methodology has only been applied to China, it is a useful tool that could be applied to any country.

The project team first identified priority classes of human and animal infectious diseases in China (Table B1), and also important societal drivers of current and future trends for those diseases (Table B2). The relationships between the diseases and the drivers were then determined and used to populate relationship matrices. For example, known drivers that would tend to increase sexually transmitted infections (including HIV) include adverse changes in sexual behaviours, increasing migrant labour, declines in educational level, and declines in the earning capacity of women. The opposite trends would tend to be protective and lead to decreases in sexually transmitted infections, including HIV.

Next, the likely trends in drivers of infections were identified. Of particular interest were those that would have a strong effect on levels of priority animal and human diseases, today and in the future. Following approval from the Ethics Committee of the Chinese Academy of Medical Sciences, Peking Union Medical College, this was achieved by undertaking a review of the views of 36 Chinese experts who were specialists in the various drivers. These specialists were recruited by the project team in China and were not necessarily specialists in infectious diseases.

The views and opinions of the specialists were derived by face-to-face interviews undertaken by a small team of postgraduate students trained by the project manager in China (Dr Zhaohui Xie). Analysis was then undertaken in China in November 2005 to collate the views and identify the key trends in the drivers. These were then applied to the matrices to identify priority groups in human and animal diseases that would be likely to increase or decrease. This prioritisation took into account public health principles and the current policy priorities of the Government of China – in particular, the expected impact in China on:

- human health and disease
- economics and development
- social stability.

Fig B1: China – a changing country

By the above analysis, future gaps and trends in vulnerabilities in China for human and animal infectious diseases were identified. These suggest areas where countermeasures could usefully be developed or mitigations put in place.[8] In particular, the findings demonstrated a number of areas where the Chinese authorities are likely to experience difficulties in the future, such as rising numbers of hospital-acquired infections, zoonoses and sexually transmitted infections, including HIV.

Finally, it is suggested that the above method could also be used in the future to determine priorities for surveillance and countermeasures, including measures to reverse some of the underlying drivers where that is possible.

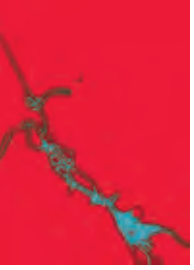
B2 Results

The most important drivers

The relationship matrices indicated the most important drivers for each family or single animal or human infectious disease(s). Areas of strong consensus on projected trends by the experts were:

- There would be greater movements of animals around the country and internationally (into and out of the country).
- There would be more and greater internal migrations of people in China.

[8] The work paid particular attention to emerging and re-emerging animal and zoonotic human infections which it is anticipated will contribute the bulk of emerging infections.



- Tourism within, from and to China will all increase.
- The production of waste, including from animals, would increase substantially and, with it, problems of waste disposal.
- Internal movements of animals, people, foods and other animal products would increase and with it rates of movements in micro-organisms.
- Genetic uniformity would increase in crops and animals.
- High-technology medicine, transplants and use of antimicrobials in secondary care would increase substantially, because of technological change, an ageing population and increasing expectations of healthcare in the populations.
- Use of hospitals and eventually overcrowding In hospitals would increase with the consequence of increasing risks from healthcare-associated infections and antimicrobially resistant organisms.
- There would be many more opportunities for sophisticated surveillance through technological developments.
- Overall wealth and levels of education would rise, though the views on income disparity were inconsistent and need further analysis.
- Sexual lifestyles will change in ways that increase the risk of acquiring and transmitting sexually transmitted infections, including HIV.
- Popular acceptance of risks from infection would decline significantly and there would be greater public expectations and demands for safety.

Priority infections

A preliminary application of these changes in the drivers would suggest that if these trends materialise, *and no countermeasures are applied*, adverse changes (rises) in the rates of the following groups of infections can be expected:

- infections acquired as a result of receiving healthcare (nosocomial infections)
- antimicrobially resistant organisms
- sexually transmitted infections, including HIV/AIDS.
- blood-borne viruses associated with high-technology care (hepatitis B and C)
- some food-borne infections and zoonoses in general
- imported and exotic infections.

Table B1: Infection groupings: classes of human and animal infectious diseases identified at the start of the China study for further consideration

Human	Antimicrobial resistance
	Blood-borne infections e.g. hepatitis B and C
	Gastrointestinal disease (food poisoning)
	Healthcare-associated infections
	HIV/AIDS
	Other sexually transmitted infections
	Malaria
	Nosocomial infections
	Respiratory infections – acute influenza (seasonal and pandemic)/SARS
	Parasitic diseases (schistosomiasis etc)
	Tuberculosis
	Vaccine-preventable diseases (childhood)
	Other novel infections (excluding zoonoses)
Animal/human (zoonosis)	Highly pathogenic AI (poultry and multi-species)
	SARS (as a model for a novel infectious zoonosis)
	BSE
Animal only	FMD
	CSF

Table B2: Nine families of drivers considered by the China study

Note: the right-hand column provides only examples of the drivers considered. See T13 for a full list.

1 Governance and social cohesion	• Governance of technology (drugs and pesticides) • Social cohesion as an enabler or constraint on identification and control of infectious diseases • Illegal practices • International/national/regional interactions affecting governance • Lack of interaction between policy and regulatory agencies leading to delays in detection and identification • Problems across international agencies, particularly barriers to the sharing of data
2 Demography and population change	• Immigration and urbanisation • Ageing population and gender imbalance • Dietary and occupation changes (affecting exposure and susceptibility to disease)
3 Technology and innovation and their governance	• Impact of genomics-related innovation on disease identification and treatments • Ability to control infections; control strategies • Improved diagnostics, leading to more accurate, less costly and more rapid detection of diseases • Information dissemination (web-based information for disease diagnosis) for alerting to existence of new diseases
4 Conflict	• Loss of effective identification and surveillance systems • Movement of refugees spreading diseases • Bioterrorism
5 Agriculture and land-use change	• Changes in animal husbandry methods; greater genetic uniformity in animal and plant populations • More intensive farming systems • New developments in production economics involving greater movement of animals
6 Economic factors (income, prosperity, employment)	• Education levels in the general population • Quality of sanitation and water supplies • Poverty and malnutrition • Waste disposal as a source of disease spread
7 Trade and market-related factors	• Future diets and demands for exotic products • Illegal trade (e.g. bushmeat) • Food preservation technology
8 Transport and tourism	• Future levels of tourism • Changes in the rate of movement of diseases; compressed timescales
9 Human activity and social pressures	• Changes in sexual practices • Public perceptions of risk and willingness to change behaviours • Media reporting as a driver of how governments react to disease

Appendix C

The future effects of infectious diseases on ecosystems

Abstracted from the report of a workshop (T11)

Introduction

Infectious diseases are natural components of ecosystems, with microbial pathogens part of their biodiversity. Thus, outbreaks of disease, even dramatic epidemics, can be part of the normal functioning of ecosystems, contributing to biodiversity and to the ecosystems' dynamic stability over time. However, when natural ecosystems are stressed, disease outbreaks may have longer-term, negative impacts on ecosystems and potentially on society, as most natural ecosystems provide value in terms of ecosystem services such as the provision of clean water and air, recreation, tourism, and 'existence value'.

Fig C1: Rainforest deforestation

Future risks

The greatest potential human hazard arises where human interference renders ecosystems so degraded, simplified and non-resilient that it becomes easier for a disease outbreak to have a disruptive domino effect on them. Examples include: over-fished marine ecosystems; eutrophied freshwater ecosystems; over-grazed grasslands; plantation forests; and a wide range of ecosystems affected by

invasive animal and plant species. All of these may have reduced biodiversity, fewer and more vulnerable keystone species and less capacity to return to their pre-disease structure and function. Degradational processes – pollution, over-production, habitat fragmentation and bio-invasions – are all likely to increase in developing countries. In developed countries, changes in natural resource and land-use policy are likely to reduce pollution and over-production in the next 20 years, and perhaps bio-invasions over a longer period.

The greatest potential impact on ecosystem services as a result of disease outbreaks would be to undermine water and geochemical cycles, ultimately contributing to climate change. However, the probability of this is regarded as very low. Impacts on natural production systems and on other useful biodiversity, while of lower impact, have a greater probability. The risk of both events will increase as human activities simplify and degrade ecosystems.

Drivers of future risk

The introduction of new diseases to ecosystems is a major source of future risk, and a growth in trade (including horticultural plants, produce, pets) and travel will be a major driver, with ballast water exchange and other aspects of shipping practice being key pathways for marine systems. Factors that lead to the simplification and degradation of ecosystems will increase the probability of disease outbreaks and their impact.

Changing attitudes to the environment will drive concern and even political prioritisation about disease effects on biodiversity. But, while urbanisation of wildlife and the extension of human habitation into natural habitats will drive an increase in awareness of diseases in ecosystems, the risk of zoonotic disease may also increase.

Actions to address risk and its drivers

Maintaining ecosystem health and resilience would reduce the frequency and impact of future disease outbreaks. This will involve biodiversity conservation to minimise the degradation and fragmentation of natural ecosystems.

The complexity of natural ecosystems makes detection of new disease outbreaks, monitoring of their spread and prediction of their impacts difficult. There is therefore a need to build and maintain broad expertise and capacity in the biology and taxonomy of pathogens and pathogen–host relations. Scientists involved in the study of natural ecosystems are in the best position to discover and characterise new disease outbreaks. An informed public, including amateur naturalists, can be a valuable resource in detection and monitoring. Improvements in communications technology and data mining and fusion will enhance the early detection of new problems through experts networking across disciplines, methodologies and countries.

Appendix D

Experts involved in the work

The authors and the UK Office of Science and Innovation would like to thank the many experts and stakeholder organisations who have contributed to the project's risk work. These people are listed below (the authors of this report are shown in bold).

Experts who were involved in the work		
Dr Richard Adegobola	Director	Medical Research Council Laboratories
Dr William Amanfu	Animal Health Officer	Food and Agricultural Organization
Dr Richard Baker	Principal Scientific Officer	Central Science Laboratory
Professor Matthew Baylis	**Chair in TSE Epidemiology**	**University of Liverpool**
Professor Christopher Bartlett	Visiting Professor of Infectious Disease Epidemiology	Centre for Infectious Disease Epidemiology, University College London and London School of Hygiene and Tropical Medicine
Dr Louise Bennett	Director	Vivas Limited
Professor Malcolm Bennett	Head of Department of Veterinary Pathology	University of Liverpool
Mr Paul Bessell	Epidemiology Group	University of Edinburgh
Dr Martin Bidartondo	Lecturer	Imperial College London and Kew Gardens
Professor Stephen Bishop	Senior Principal Investigator – Division of Genetics and Genomics	Roslin Institute
Dr Robert F. Breiman	International Emerging Infections Programme	Centers for Disease Control and Prevention, Kenya
Professor Joe Brownlie	**Professor of Veterinary Pathology and Director of ECTP**	**Royal Veterinary College**
Dr Lee Calvert	Plant Virologist	Centro Internacional de Agricultura Tropical, Colombia
Dr Diarmid Campbell-Lendrum	Scientist	World Health Organization
Dr Annette Carey	Technical Manager	Horticultural Development Council
Dr Tim Chancellor	Group Leader: Plant, Animal and Human Health Group	Natural Resources Institute, University of Greenwich
Professor Chifumbe Chintu	Professor of Paediatrics and Child Health	University of Zambia
Professor Hoosen Coovadia	Doris Duke Medical Research Institute	Univeristy of KwaZulu-Natal
Dr Andrew Cottam	Head, Biological Agents Unit	Health and Safety Executive
Dr Adama Diallo	Head of the Animal Production and Health Unit	International Atomic Energy Agency, Austria
Dr Diadier Diallo	Epidemiology and Data Management Unit	Centre National de Recherche et de Formation sur le Paludisme

Experts who were involved in the work *(continued)*		
Dr Christopher Dye	Tuberculosis, HIV/AIDS and Malaria	World Health Organization
Dr John Edmunds	Head, Modelling and Economics Unit	Health Protection Agency
Dr Denis Fargette	Plant Virologist	International Relief and Development, France
Professor Neil Ferguson	Department of Infectious Diseases and Epidemiology	Imperial College, London
Professor C G Gemmell	Director of Scottish MRSA Reference Laboratory and Professor of Bacterial Infection and Epidemiology	University of Glasgow
Professor George Gettinby	Co-Director	Veterinary Informatics and Epidemiology, University of Strathclyde
Dr Jeffrey Gilbert	Western Pacific Region	World Health Organization
Professor Christopher A Gilligan	Professor of Mathematical Biology	University of Cambridge
Dr Simon Gowen	Principal Research Fellow	Department of Agriculture, University of Reading
Dr Simon Eden-Green	Consultant	EG Consulting
Professor Jim Hall	Professor of Earth Systems Engineering	University of Newcastle-upon-Tyne
Dr Simon Hay	Department of Zoology	University of Oxford
Dr Nigel Hardwick	Fellow	Central Science Laboratory
Professor Stephen Hill	Head of Plant Health Group	Central Science Laboratory
Dr Abraham Hodgson	Director	Navrongo Health Research Centre
Ms Elizabeth Hoile	Project Officer for China and Hong Kong activities	Health Protection Agency Centre for Infections
Professor Jianshi Huang	Professor of Epidemiology and Assistant President	Chinese Academy of Medical Sciences and Peking Union Medical College, Beijing China
Dr Stephen Hunter	Head of Plant Health	Defra
Dr Geoff Jenkins	Hadley Centre	Met Office
Professor Anne Johnson	Department of Primary Care and Population Science	University College London
Dr Peter Jones	Project Coordinator	Centro Internacional de Agricultura Tropical, Colombia
Dr Phil Jones	Plant Pathogen Interaction Division	Rothamsted Research
Professor Dominic M. Kambarage	Dean, Faculty of Veterinary Medicine	Sokoine University of Agriculture
Professor Salim Abdool Karim	Deputy Vice-Chair Chancellor	University of KwaZulu-Natal
Dr Matthew J Keeling	Department of Biological Sciences	University of Warwick
Mr Peter Kenmore	Global Integrated Pest Management Facility	Food and Agriculture Organization
Dr Lawrence Kenyon	Plant Pathologist/Virologist	Natural Resources Institute, University of Greenwich
Dr Francis Kimmins	Crop Protection Programme Manager	NR International

Experts who were involved in the work *(continued)*		
Mr Sari Kovats	Lecturer – Epidemiology	London School of Hygiene and Tropical Medicine
Dr Jerome Kubiriba	Banana Programme	National Agricultural Research Organisation, Uganda
Dr Patti Kristjanson	Operating Project Leader	International Livestock Research Institute, Nairobi, Kenya
Mr Russ Kruska	Scientist	International Livestock Research Institute, Nairobi, Kenya
Professor Steve Leach	Scientific Leader	Health Protection Agency
Mr Joseph Litamoi	Pan-African Veterinary Vaccine Centre	African Union
Professor Steven Lindsay	Institute of Ecosystem Science, School of Biological and Biomedical Sciences	University of Durham
Dr Oumou Sangare Loko		Laboratoire Central Veterinaire, Mali
Professor John Lucas	Head of Plant Pathogen Interactions Division	Rothamsted Research
Dr Catherine Lyall	**Research Fellow**	**Economic and Social Research Council, Innogen Centre**
Professor Kevin Marsh	Centre for Geographic Medicine	Kenya Medical Research Institute/ Wellcome Trust Collaborative Programme
Benjamin J J McCormick	TALA Research Group, Department of Zoology	Oxford University
Professor John McDermott	Deputy Director General	International Livestock Research Institute, Nairobi, Kenya
Dr Martin McPherson	Director – Plant Pathology	Stockbridge Technology Centre
Dr Christopher Marooney	Centre for Epidemiology and Risk Analysis	Veterinary Laboratories Association
Laura Meagher, PhD	**Senior Partner**	**Technology Development Group/ Innogen**
Dr Dilys Morgan	Head of the Emerging Infections and Zoonoses Department	Health Protection Agency
Professor Ivan Morrison	Head of Research	Royal (Dick) School of Veterinary Studies, University of Edinburgh
Dr Bonaventure Mtei	Senior Livestock Officer, SADC Secretariat	South African Development Community, Botswana
Dr Charles Mwansambo	Director	Lilongwe Central Hospital, Malawi
Professor Marie-Louise Newell	Centre for Paediatric Epidemiology and Biostatistics	Institute of Child Health, University College London
Professor Angus Nicoll	**Seconded National Expert**	**European Centre for Disease Prevention and Control and Health Protection Agency UK**
Dr Rose W Njeru		University of Nairobi, Kenya
Professor Timothy U Obi	Professor, Veterinary Medicine and Public Health	Ibadan University, Nigeria

Experts who were involved in the work *(continued)*		
Professor Kwame Offei	Dean, Department of Crop Science	University of Ghana
Dr William Olaho-Mukani	Director of Animal Resources	Director of Animal Resources Ministry of Agriculture, Uganda
Dr Fina Opio	Director of Research	Namulonge Agricultural and Animal Production Research Institute
Dr William Otim-Nape	Consultant and Former Acting Director General	National Agricultural Research Organisation, Uganda
Professor John Oxford	Retroscreen Virology Ltd	Bart's and the London Queen Mary's School of Medicine and Dentistry
Professor Stephen Palmer	Department of Epidemiology, Statistics and Public Health	Cardiff University
Dr Roger Paskin	Vet Manager	Trade, Meat Board of Namibia
Professor Catherine Peckham	**Professor of Paediatric Epidemiology**	**Institute of Child Health, University College London**
Dr Ed Peeler	Veterinary Epidemiologist	Centre for Environment, Fisheries and Aqua Culture Science
Professor Hugh Pennington	Institute of Medical Sciences	University of Aberdeen
Professor John Pickett	Head, Biological Chemistry Division	Rothamsted Research
Dr Yvonne Pinto	Head of Agriculture	The Gatsby Charitable Foundation
Dr Bethan V Purse	TALA Research Group, Department of Zoology	Oxford University
Mr Dennis Rangi	Director	CABI, Africa Regional Centre, Kenya
Dr Robin Reid	Ecologist	International Livestock Research Institute, Nairobi, Kenya
Dr Tim Robinson	Pro-Poor Livestock Policy Initiative	Food and Agriculture Organization
Dr Peter Roeder	Animal Health Service, Animal Production and Health Division	Food and Agriculture Organization
Professor David J Rogers	TALA Research Group, Department of Zoology	Oxford University
Dr Gabriel Rugalema	Policy Adviser	The International Institute for Educational Planning, UNESCO, France
Dr Mark Rweyemamu	Consultant	Tanzania
Dr Victoria Sanderson	TALA Research Group, Department of Zoology	Oxford University
Dr Abraham Sangula	FMD Laboratory, Embakasi	Nairobi, Kenya
Dr Claire Sansford	Principal Risk Analyst	Central Science Laboratory
Dr David Serwadda	Consultant	Makerere University Institute of Public Health, Uganda
Dr Mike Shaw	Faculty of Life Sciences	University of Reading
Dr Jan Slingenbergh	Senior Officer, Animal Health Service	Food and Agriculture Organization
Dr Alan Smith	Specialist Registrar in Public Health Medicine	Health Protection Agency
Professor David G E Smith	Head of Functional Genomics and Proteomics	Moredun Research Institute

Experts who were involved in the work *(continued)*		
Professor Geoffrey Smith	Head of Department of Virology	Imperial College London
Professor Bob Snow	Centre for Geographic Medicine	Kenya Medical Research Institute/Wellcome Trust Collaborative Programme
Mr Jonathan Suk	Research Fellow	Economic and Social Research Council, Innogen Centre
Professor Joyce Tait	**Risk Analysis Team Leader, and Director**	**Economic and Social Research Council, Innogen Centre**
Dr Andrew J Tatem	TALA Research Group, Department of Zoology	Oxford University
Dr Yaya Thiongane	Director	Laboratoire de Virologie au Laboratoire National de l'Elevage, Dakar, Senegal
Dr Philip Thornton	Senior Scientist/systems Analyst	International Livestock Research Institute, Nairobi, Kenya
Professor J M Thresh	Professor of Plant Virus Ecology	Natural Resources Institute, University of Greenwich
Dr Michael J Tildesley	Department of Biological Sciences	University of Warwick
Dr Wilna Vosloo	Exotic Diseases Division	Agricultural Research Council, South Africa
Professor Jeff Waage	**Director, Centre for Environmental Policy**	**Imperial College London**
Dr Stuart Wale	Head of Crop Services	Scottish Agricultural College
Dr Andrew Ward	CPP Deputy Programme Manager	NR International
Professor Robin Weiss	Professor of Viral Oncology	University College London
Mr Richard Wheeler		University of Edinburgh
Dr Jimmy Whitworth	Head of International Activities	The Wellcome Trust
Dr Stephan Winter	Head, Plant Virology	DSMZ Plant Virus Department, University of Ghent, Germany
Dr James Wood	Director	Cambridge Infectious Diseases Consortium
Dr James Woodhall	Plant Health Group	Department for the Environment, Food and Rural Affairs
Dr Marion Wooldridge	Head, Centre for Epidemiology and Risk Analysis	Veterinary Laboratories Agency
Professor Mark Woolhouse	**Director, Centre for Infectious Diseases**	**University of Edinburgh**
Dr Paul Wilkinson	Public and Environmental Health Research Unit,	London School of Hygiene and Tropical Medicine
Dr S G Willis	Institute of Ecosystem Science, School of Biological and Biomedical Sciences,	University of Durham
Dr Alison J Wright	Plant Health Group	Department for the Environment, Food and Rural Affairs

Experts who were involved in the work *(continued)*		
Professor Gonghuan Yang	Deputy Director	China Centres for Disease Control, Chinese Academy of Medical Sciences and Peking Union Medical College, Beijing, China
Professor Zhaohui Xie		Chinese Academy of Medical Sciences, Peking Union Medical College, Beijing, China

Contributors to the China consultation exercise	
Director – Public Health	Department of International Co-operation, Ministry of Health
Deputy President – Public Health	Department of International Co-operation, Ministry of Health
Deputy President – Health Management	Department of International Co-operation, Ministry of Health
Director – Health Management	Department of Disease Prevention and Control, Ministry of Health
Chief Scientist Professor	National Centre for Public Health Surveillance and Information Services CDC
Director Professor	Beijing University
Associate Professor	National CDC
Director Professor	Department Epidemiology, Peking Union Medical College
Professor	Department Epidemiology, Peking Union Medical College
Director Professor	Department of Infectious Diseases, Peking Union Medical College
Professor	Beijing Centre for Disease Prevention and Control
Associate Professor	Dean's Office, Peking Union Medical College
Deputy President	Beijing You'an Hospital
Professor, Senior Doctor	Beijing You'an Hospital
Professor	Beijing Centre for Disease Prevention and Control
Associate Professor	Dean's Office, Peking Union Medical College
Professor	Department of Epidemiology, Peking Union Medical College
Associate Professor	Department of Biochemistry, Peking Union Medical College
Associate Professor	Beijing Capital Medical University
Professor	Research Institute, China Agricultural Academy
Associate Professor	Ministry of Agriculture Fed Industry Center
Professor	Institute of Zoology Chinese Academy of Sciences
Professor	Institute of Agriculture Economics and Development Chinese Academy of Agricultural Sciences
Manager	Welltech Health Management Co. Ltd
Director	Sinochem Corporation
Professor	State-owned Assets Research Centre of the State Council
Associate Professor	Department of Epidemiology, Peking Union Medical College
Vice-President	Beijing Dianji Technology Ltd
Visiting Professor	School of Management Beijing University of Posts and Telecommunications

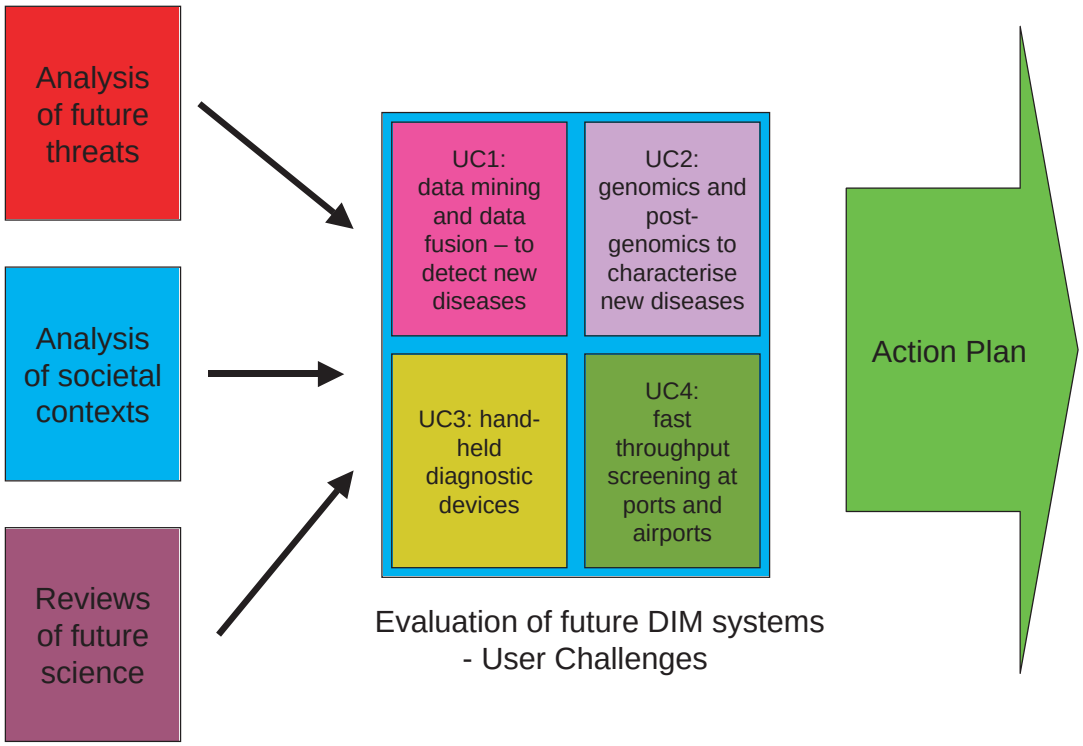
Contributors to the China consultation exercise *(continued)*	
Vice-President	China Ocean Shipping (Group) Company
Director, Senior Doctor	Emergency Office, Beijing Municipal Health Bureau
Professor	Beijing University
Associate Director	The Center for Tourism Research, Chinese Academy of Social Sciences
Associate Professor	Development Research Centre of State Council
Professor	School of Management Beijing International Studies University
Professor	School of Tourism, Beijing Union University
Associate Senior Doctor	Emergency Department, Peking Union Medial College
Professor	Department of Social Sciences, Peking Union Medical College
Professor	School of Public Health, Peking University Health Science Centre
Associate Professor	School of Public Health, Peking University Health Science Centre

Appendix E

Overview of the work of the project

The key parts of the project are set out in Figure E1 and are described below. Relevant project reports and technical papers are indicated in brackets (these are also listed in a chart in Appendix F):

Figure E1: The principal parts of the project



Analysis of future threats. A starting point was to generate a vision for the future threats of infectious diseases, and the factors driving them. This defines the challenge for future DIM systems. This report (T1) provides a synthesis of the risk work and report T2 provides a description of the analysis performed. All of this drew on the following:

- new research on the nature of emerging diseases (T15, T16), reviews of the impact of climate change (T7.1–T7.4), and the effect on ecosystems (T11)
- reviews of illustrative disease threats (T5.1–T5.12)
- workshops and reviews of important drivers of risk – including travel and migration (T10), and the bushmeat trade (T12)
- reviews of disease modelling work (T8.1–T8.11)
- surveys, one-to-one interviews and international workshops held in the UK; Entebbe, Uganda; and China (T3, A4, T13).

Analysis of societal contexts. The effectiveness of future DIM systems will depend greatly on their sensitive development and deployment in different systems of culture and governance. These issues were explored through:

- studies comparing the effect of culture and governance on the deployment of DIM systems in Africa, the UK and China (D4.1–D4.3)
- analysis of the control strategies for future diseases (D3.1–D3.3) – this was performed so that future DIM systems could be viewed within this wider context
- a study of historical perspectives (D5)
- a comparison of public perceptions of risk in Africa and the UK (D7)

Reviews of future science. Reviews of the state of the art of ten areas of science were commissioned (S3–S12). An overview of each is provided in S1. These reviews were used to inform the capabilities of future DIM systems. The topics for review were:

Table E1: Topics of the state-of-science reviews

Intelligent sensor networks	Data mining and data fusion
Non-invasive screening and scanning	Genomics and bioinformatics
Biosensors and biomarkers	Interrogation of natural signals and biomarkers
Predictive and real-time epidemiology	Earth observation
Host genetics and engineering	Immunological techniques

Evaluation of future DIM systems – User Challenges. Four classes of future DIM systems were identified for analysis by four teams of experts. The analysis (D1, D2) drew on all of the above work and informed the action plan which has been produced in consultation with key stakeholders (P1).

Action plan. All of the above has led to the development of a detailed action plan by key stakeholders around the world (P1).

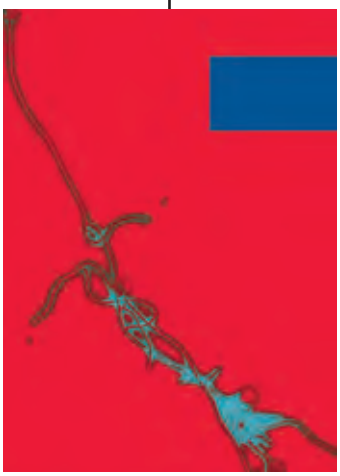
Finally, a substantial part of the project concerned the future threat of diseases in Africa and the possible contribution of future DIM systems to managing the threat. All of the Africa-related strands of the project are drawn together in report A1.

Appendix F

Structure of the project reports and supporting papers

E1: Executive Summary

S1: Science Review Summaries



T1: Future Threats

Detailed reviews of science:

S3: Intelligent sensor networks
S4: Data mining and data fusion
S5: Non-invasive screening and scanning
S6: Genomics and bioinformatics
S7: Biosensors and biomarkers
S8: Interrogation of natural signals
S9: Predictive and real-time epidemiology
S10: Earth observation
S11: Host genetics and engineering
S12: Immunological techniques

Risk analysis:

T2: Risk analysis
T3: Expert survey of the UK and Africa

Disease case studies:

T5.1: MRSA
T5.2: HIV/AIDS
T5.3: Influenza in humans
T5.5: Food-borne pathogens
T5.6: Fish diseases
T5.7: Potato late blight
T5.8: Malaria
T5.9: Rinderpest
T5.10: Plant viruses in sub-Saharan Africa (SSA)
T5.11: Sudden oak death
T5.12: West Nile virus

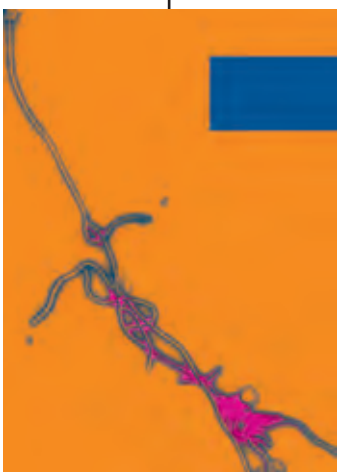
Climate change:

T7.1: Overview
T7.2: Plant diseases
T7.3: Animal diseases
T7.4: Human diseases

Modelling reviews:

T8.1 Overview
T8.2: Malaria in SSA
T8.3: Bluetongue in Europe
T8.4: TB control in SSA
T8.5: Global traffic
T8.6: Foot-and-mouth disease (FMD)
T8.7: Paediatric HIV/AIDS
T8.8: Tsetse in SSA
T8.10: Malaria UK
T8.11: Eco-costs of potato ring rot

NOTE: Report numbers are not sequential.
Some report numbers were originally reserved for reports which were subsequently not commissioned.



A1: Africa

D1: Vision of Future Detection, Identification and Monitoring Systems

P1: Action Plan

Further reviews and research:

T9: Review of initiatives
T10: Travel and migration and their impacts on diseases
T11: Effects of diseases on ecosystems
T12: Wildlife trade
T13: China – human and zoonotic diseases
T15: Plant pathogen database analysis
T16: Human pathogen database analysis

Africa papers:

A3.1 Paper for the Commission for Africa (CfA)
A3.2 CfA paper appendices
A4: Report of a pan-African workshop
A5: Report of a pan-African workshop (French)

User Challenge work:

D2: Introduction to the User Challenge work
D2.1: UC1 – Data mining and data fusion
D2.2: UC2 – Genomics and post-genomics for characterising new pathogens
D2.3: UC3 – Hand-held diagnostic devices
D2.4: UC4 – Fast-throughput screening devices

Future control of diseases:

D3.1: Plant diseases
D3.2: Animal diseases
D3.3: Human diseases

Culture and governance:

D4.1: Plants
D4.2: Animals
D4.3: Humans

D5: Historical perspectives
D7: Public perceptions of risk

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Details of all the reports and papers produced by the project can be obtained from the Foresight website (www.foresight.gov.uk). Any queries may also be directed through this website. The reports and outputs of the project should not be taken to represent the policies of any governments or organisations involved in the work.

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