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Globalization and infectious diseases: A review of the linkages

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Globalization and infectious diseases: A review of the linkages

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ABBREVIATIONS AND ACRONYMS

ACL	anthroponotic cutaneous leishmaniasis
AVL	anthroponotic visceral leishmaniasis
CME	WHO Commission on Macroeconomics and Health
DALY	disability adjusted life year
DNA	deoxyribonucleic acid
ENSO	El Niño Southern Oscillation
EWE	extreme weather events
FAO	Food and Agriculture Organization
FDI	foreign direct investment
GATS	General Agreement on Trade in Services
GATT	General Agreement on Tariffs and Trade
GBDS	Global Burden of Disease Study
GDP	gross domestic product
GIS	geographical information system
HIV/AIDS	human immunodeficiency virus/acquired immunity deficiency syndrome
ICT	information and communication technologies
ID	infectious diseases
IHA	International Health Regulations
ILO	International Labour Organization
IPCC	Intergovernmental Panel on Climate Change
JBE	Japanese B encephalitis
MDR-TB	multidrug resistant tuberculosis
MTA	multilateral trade agreement
NCD	non-communicable disease
RVF	Rift Valley fever
SAP	structural adjustment programme
STD	sexually transmitted disease
TB	tuberculosis
TBT	Agreement on Technical Barriers to Trade
TDR	UNICEF/UNDP/World Bank/WHO Special Programme for Research and Training in Tropical Diseases
TNC	transnational corporation
TRIPS	Agreement on Trade Related Intellectual Property Rights
UNAIDS	United Nations Joint Programme on HIV/AIDS
UNDP	United Nations Development Programme
UNITeS	United Nations Information Technology Service
WHO	World Health Organization
WTO	World Trade Organization
WTO	World Tourism Organization
ZVL	zoonotic visceral leishmaniasis

EXECUTIVE SUMMARY

Globalization is a complex and multi-faceted set of processes having diverse and widespread impacts on human societies worldwide. It can be defined as "*changing the nature of human interaction across a wide range of spheres including the economic, political, social, technological and environmental...... the process of change can be described as globalizing in the sense that boundaries of various kinds are becoming eroded. This erosion can be seen to be occurring along three dimensions: spatial, temporal and cognitive*" (Lee, 2003).

Globalization is driven and constrained by a number of forces: Economic processes, technological developments, political influences, cultural and value systems, and social and natural environmental factors. These varied forces, as part of the processes of globalization, impact directly and indirectly on health at a number of different levels.

As globalization spreads across the world, there is much to be understood about how the wide-ranging changes are impacting on infectious diseases. This paper reviews the existing evidence about the links between globalization and infectious diseases in terms of changes in disease distribution, transmission rate and, in some cases, management of disease. The aims of the paper are to:

- improve understanding of how globalization influences infectious diseases, particularly in the developing world;
- explore how the processes of globalization impact on the epidemiology of, risk factors for, and capacity to control, infectious diseases;
- examine how efforts to control infectious diseases need to take account of globalization processes.

Reviewing the evidence for the four spheres of change - economic, environmental, demographic, technological – this paper explores the complex causal relationships that may be arising. It shows both positive and negative consequences for the infectious disease burden potentially arise from globalization:

- Globalization appears to be causing profound, sometimes unpredictable, changes in the ecological, biological and social conditions that shape the burden of infectious diseases in certain populations. There is accumulating evidence that changes in these conditions have led to alterations in the prevalence, spread, geographical range, and control of many infections, particularly those transmitted by vectors.
- Individuals and population groups show varying degrees of gains and losses from economic globalization, and thus differential vulnerability to infectious diseases. Studies of globalization processes show increasingly that the processes of change impact on the lives of individuals and populations in many different ways. Crude assessments of globalization as "good" or "bad" are neither accurate nor useful to effective management of global change.
- Epidemiology in general, and disease surveillance in particular, offer useful analytical tools and methods for identifying and measuring transborder patterns of infectious disease arising as a consequence of globalization. Such approaches are needed in studying how globalization may be changing the distribution of health and disease within and across countries and regions of the world.
- Attention to the linkages between globalization and infectious diseases so far shows a disproportionate focus on selected acute and epidemic infections. While there are clearly real risks from such diseases, which pose obvious challenges to an effective response from public health systems both nationally and internationally, it is important to consider the wide range of infections potentially affected by globalization processes.
- Due to inequalities in capacity and access to disease surveillance and monitoring systems between the industrialized and developing world, there is a danger of underestimating the infectious disease

burden faced by poorer countries. There is a particular need to develop surveillance systems that can be used effectively in low-tech, developing world contexts in order that true impact can be accurately identified. It is also imperative to ensure that, when changes in disease patterns are detected, the information is transmitted to those able to implement appropriate action.

- The impacts of globalization on infectious diseases described in this report support the need for appropriate forms of global governance on key issues to improve systems of prevention, control and treatment.
- There is need for enhanced training on the global dimensions of infectious diseases. Medical practitioners would benefit from a greater understanding of the potentially changing profile of infectious diseases as a result of increased population mobility, intensified trade in goods and services, climate change, and other factors linked to globalization.
- The findings of this report support the need to pay greater attention to the impacts on the infectious disease burden of policy decisions taken in other sectors e.g. trade and investment, large infrastructure projects (e.g. dam building), migration, agriculture, transportation, communications.
- It is clear that improving action regarding the impact of globalization on infectious diseases on an a priori basis is a highly cost-effective policy intervention. It is increasingly recognized that the long-term sustainability of globalization requires greater attention to the social (including health) costs of current forms of globalization. What needs to be understood more fully is that resources committed to infectious diseases prevention, treatment and control in a globalizing world is a worthwhile investment.

1 INTRODUCTION

Although there is a flourishing literature on globalization and health,[1] much remains to be understood about how the processes of globalization affect health outcomes, and consequently about what local and global public health responses are appropriate. One major focus of this literature has been the links between globalization and infectious disease. There are particular concerns that globalization is impacting on the epidemiology of infectious disease, and on the capacity to effectively prevent, control and treat these diseases. It may, for example, influence the risk factors for specific diseases, and at the same time enhance the opportunities for improving surveillance, monitoring and reporting capacity through global information and communications technologies.

This paper reviews the current evidence for links between globalization and infectious disease. In particular, it identifies changes in disease distribution, transmission rate, and in some cases, management of disease. The aims of the paper are to:

- improve understanding of how globalization influences infectious diseases, particularly in the developing world;
- explore how the processes of globalization impact on the epidemiology of, risk factors for, and capacity to control, infectious diseases;
- examine how efforts to control infectious diseases need to take account of globalization processes.

The paper extensively reviews the relevant published English language literature and, where possible, literature in other languages. It also reviews a substantial amount of "grey" literature. The focus is on the priority diseases of the UNICEF/UNDP/World Bank/WHO Special Programme for Research and Training in Tropical Diseases (TDR).

[1] For a review of the literature see: Lee K. Globalization and health policy: a review of the literature and proposed research and policy agenda. In: Bambas A et al., eds. *Health and human development in the new global economy*. Washington DC, Pan American Health Organization, 2000:15-41. Also see: Lee K. *Globalization and health, an introduction*. London, Palgrave Macmillan, 2003.

2 BACKGROUND

2.1 What is globalization?

Despite widespread interest in its emergence and impact, there is limited agreement in the literature on precisely what globalization is. Frequently it is understood and defined according to selected aspects. Thus, for economists, globalization concerns the increasingly globalized nature of the emerging world economy. For lawyers, it concerns the threatened changes in legal status of states and their citizens. For environmentalists, it is the changes in the world's climate and other biosystems. And for information technology experts, it is the global spread and integration of information systems (Lee, 2003). However, such disciplinary-based perspectives can neglect the multiplicity of change processes, and hence fail to appreciate their complex direct and indirect impacts.

The numerous definitions of globalization in the literature also reflect a renaming of existing phenomena. In understanding the links between globalization and infectious disease, it is important to be aware of how the term 'globalization' is used interchangeably with terms such as 'internationalization', 'liberalization', 'universalization' and 'westernization'.[2] A strict definition of globalization distinguishes between cross-border and transborder flows. 'Cross-border' concerns the interactions across two or more countries through, for example, the documented movement of people, official trade of goods and services, or capital flows such as foreign direct investment (FDI) across national borders. Cross-border flows have increased quantitatively since the end of the Second World War but can be more accurately described as internationalization. 'Transborder' or transnational, in contrast, concerns flows of people, goods and services, capital, values and ideas, and other entities in a way that does not recognize national borders. Such flows are 'supraterritorial' in the sense that they are disconnected from territorial geography. While intensified cross-border flows can overwhelm the capacity of the state to regulate them, transborder flows are seen as potentially eroding or even redefining existing territorial boundaries separating human societies from one another (Scholte, 2000). Examples include global environmental change, undocumented population mobility (e.g. trafficking of people), and money laundering.

Along with changes to spatial boundaries, Lee (2003) argues that globalization is leading to changes in how we experience and perceive time. Globalization is shaping the timeframe in which natural and human-induced phenomena take place, as well as the time available and necessary for responding to these phenomena. For example, the time taken for some infectious diseases to spread across territorial space has become much quicker as a result of the increased amount, frequency, and speed of population mobility. Similarly, the potential capacity to detect and report disease outbreaks has quickened due to the advent of global information and communication systems.

Finally, in a variety of ways, globalization is influencing how we think about ourselves and the world around us. This cognitive dimension of global change arises from the proliferation of a range of individuals and institutions with global reach, which are concerned with the production and exchange of knowledge, values and beliefs. They include the mass media, think tanks, research institutions, consultancy firms, advertising agencies, religious groups, educational institutions and policy-making organizations. While some argue that this is leading to the emergence of a 'global culture' dominated by western values and beliefs, others believe the spread of ideas and principles on human rights, labour standards, and other social values across national or regional boundaries is a progressive force. Some writers point to the flourishing of competing ideologies and value systems, resulting at times in a 'clash of civilizations' in the form of religious or political conflict (Huntingdon, 2002).

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[2] For a useful discussion of the distinct meanings of these terms, see: Scholte JA. *Globalization, a critical introduction*. London, Palgrave Macmillan, 2000.

In summary, globalization is a complex and multi-faceted set of processes that are having diverse and widespread impacts on human societies worldwide. Globalization can be defined as a set of processes that are:

Changing the nature of human interaction across a wide range of spheres including the economic, political, social, technological and environmental. …the process of change can be described as globalising in the sense that boundaries of various kinds are becoming eroded. This erosion can be seen to be occurring along three dimensions: spatial, temporal and cognitive (Lee, 2003).

Overall, it is clear that globalization is driven and constrained by a number of forces: economic processes, technological developments, political influences, cultural and value systems, and social and natural environmental factors. These varied forces, as part of the processes of globalization, impact directly and indirectly on health at a number of different levels. For example, globalization can alter health status through changes in basic living conditions and household incomes. It can affect the availability of health workers and other resources in health care systems through changes in patterns of population mobility, impact on government health expenditure through changes in macroeconomic policy, and encourage the adoption and spread of health standards and principles through international and global agreements (Woodward et al., 2001). At different levels, therefore, global change can bring either health benefits or costs, depending on who you are and where you live. For poorer populations, there is substantial evidence to suggest that, so far, globalization has posed more negative than positive impacts on health, including risks from infectious disease.

2.2 Global burden of infectious disease

Historically, infectious diseases (IDs) have been the most important contributor to human morbidity and mortality until relatively recent times, when non-communicable diseases (NCDs) began to rival, and sometimes exceed, infections. Today, IDs still account for a large proportion of death and disability worldwide and in certain regions remain the most important cause of ill health. The Global Burden of Disease Study (GBDS) estimates that, in the year 2000, infectious diseases were responsible for 22% of all deaths and 27% of disability-adjusted life years (DALYs) worldwide (WHO, 2002). Although infectious diseases can affect people of all ages, they impose a particular burden on the young, notably on children under five. This is not only because younger age groups have a lower prevalence of NCDs, but because they are more susceptible than adults to new infections, lacking the protective mechanisms to reduce the impact of these illnesses. Consequently, in regions where a high proportion of the population is made up of young people – Africa, Latin America and many other developing regions – infectious diseases usually extract a relatively high toll on the population. For example, GBDS estimates for 2002 were that infectious diseases were responsible for 52% and 50% respectively of all deaths and DALYs in sub-Saharan Africa but only 11% and 5% in the established market economies (WHO, 2000).

The term ‘infectious disease’ does not refer to a homogeneous set of illnesses but rather to a broad group of widely varying conditions. The relative and absolute importance of particular infections or groups of infections varies dramatically across regions. In high-income countries, deaths from IDs are overwhelmingly due to respiratory infections and HIV/AIDS. In sub-Saharan Africa, respiratory infections, diarrhoeal diseases, HIV/AIDS, TB and malaria account for roughly similar proportions of total ID deaths (Murray and Lopez, 1997a). In addition, rates of specific infectious diseases are generally much higher in poor countries, regardless of the relative importance of these diseases. Therefore, in both relative and absolute terms, IDs are a considerably higher burden in low-income than high-income countries. An analysis of GBDS data concludes that the poorest 20% of the world’s population experiences a far higher burden of infectious disease compared to the remaining 80% of the world’s population (Gwatkin et al., 1999).

It should be noted that estimates of the burden of infectious disease at regional or global level can obscure the importance of specific infections in particular populations. For instance, tropical diseases impose a heavy burden on some of the poorest populations in the world but, since they occur almost exclusively in certain climates, can be recorded as making a proportionately small contribution to the overall infectious disease burden (Murray and Lopez, 1997a). Also, certain diseases such as dengue fever vary greatly with environmental and other determinants, and can rapidly assume epidemic proportions. This is often poorly represented in estimates of average annual disease incidence and prevalence. Finally, in most assessments, certain illnesses with a strong infectious component, such as liver cancer and several important neurological diseases, are not considered part of the infectious diseases burden (Satcher, 1995).

Estimates of the future burden of infections fall into two categories: predictions for individual diseases, and calculations of the overall impact of infectious diseases in the future. Examples of the former include those for HIV/AIDS and multidrug resistant tuberculosis, which often predict significant rises in prevalence and mortality (WHO, 1997; WHO, 2002). The most influential summation of the likely overall future burden of infectious diseases predicts a gradual decline in both the rates of infection and their proportionate contributions to overall disease burden in all regions of the world (Murray and Lopez, 1996). However, these estimates assume that disease patterns will evolve in much the same way as they have in high-income countries over the past 100 or so years, and that current efforts to contain their impacts will be sustained. One finding from this review is that the future impact of many infections is uncertain because globalization is impacting on human societies and the natural environment in ways hitherto not experienced. Also, cases of certain infectious diseases (particularly vector-borne infections) have either been rare or entirely absent in most high-income countries during the last 100 years (Murray and Lopez, 1996). Finally, shifts in political and economic values may lead to changes in current resources for infectious disease control, particularly in low and middle-income countries (Lee, 2003).

3 GLOBALIZATION AND THE CHANGING NATURE OF INFECTIOUS DISEASE

The processes of globalization potentially influence a broad range of biological, environmental and social factors that affect the burden of many important human infections. This report considers the nature of infections and how, in simple terms, globalization may increase or decrease the distribution, spread and impact of infectious diseases in a given population.

An infection occurs when a micro-organism survives and multiplies within another, usually larger, organism. The infected organism (e.g. human being) is called the host. In infectious diseases, unwanted signs and symptoms usually result from damage to the tissues and organs of the host, and the micro-organism is known as a pathogen. A huge variety of pathogens cause human infections, ranging from sub-cellular viruses that cause lung infections in children to complex protozoan (e.g. the malaria parasite) and multicellular (e.g. filarial worms) organisms.

To trigger infection, pathogens must first reach the host., where they may survive unnoticed unless an internal or external event (for example, the herpes virus) triggers the disease. In most cases, pathogens reach the human host from the external environment through a variety of transmission systems (see examples in Box 1). The transmission system in operation determines which factors are capable of enhancing or inhibiting the spread of a particular infectious disease.

Box 1: Transmission of infectious diseases

Some pathogens live in the environment and are transmitted to humans directly, for instance, from the soil. Other pathogens can survive only in a host (an animal or human). If a pathogen survives in two (or more) animal species (e.g. humans and another type of animal) then the species within which the pathogen *preferentially* survives and multiplies is known as the *primary* host; the other is known as the *secondary* or *intermediate host*. An intermediary agent (usually a biting insect or arthropod) that spreads a pathogen to humans is known as a *vector*, and an infection so transmitted is a *vector-borne disease*. Most TDR diseases are vector-borne infections. When pathogens spread directly from host to host, it is *direct transmission*. If direct transmission occurs between humans (or animals) the infection is *contagious*. Infections spreading between humans, without another animal reservoir host being involved (whether or not an intermediate host or vector is involved), are termed *anthroponotic infections*. When spread of an infection to a human or animal involves an intermediate host, it is *indirect transmission*. An infection that can be maintained in vertebrate animal populations, and is transmissable between animals or from animals to humans, is known as a *zoonotic infection*. The mode of transmission influences which factors impact on the spread and overall impact of a specific infection. For instance, transmission of vector-borne diseases is influenced by factors which affect vector numbers (e.g. warmer temperature increases mosquito reproduction rates), contact between humans and vectors (e.g. tourism brings people to areas where malaria-carrying mosquitoes thrive), susceptibility of humans to vector-borne pathogens (e.g. migration of non-immune people to areas where malaria is prevalent), intermediate host numbers (e.g. dams provide breeding grounds for snails carrying schistosomiasis), or human or animal behaviour (e.g. warmer temperatures encourage people to bathe in pools, which may be contaminated by schistosome larvae).

A pathogen in a human host will only cause infectious disease if it is able to survive and multiply within the person. The success of this 'amplification process' is influenced by the presence or absence of many factors. For example, the person must be susceptible or non-immune to the infectious agent. People who are resistant to the pathogen are immune to the disease, typically as a result of a previous infection that has led to the production of protective antibodies or cells, or through immunization. There must also be sufficient numbers of pathogens present to overcome the body's natural resistance to a foreign organism, and certain pathogens require physiological circumstances favourable to their multiplication; for instance, *Clostridium perfringens* infection usually requires the presence of dead or dying tissue.

Thus, amplification processes and transmission systems depend on multiple factors that determine not only whether a specific pathogen can survive and spread in the environment, but also whether an individual will become infected after the agent has reached this host, and whether the infection will cause disease (Jacob, 1998). These links can be appreciated through consideration of the 'basic reproductive rate' (or Ro) of an infectious agent, which refers to the average number of infections produced by a single case of the infectious disease in question. Where Ro is >1, the prevalence of the infection will increase, and where Ro is <1, it will decrease (Anderson and May,1991). Therefore, the effect of an ecological or other type of change on an infection can be considered by asking how this change will affect the Ro of the infectious agent.

Box 2: Infectious diseases and the natural environment

Pathogens are highly sensitive to their environments. There are two main reasons for this: first, their ability to survive and multiply depends on the availability of the right climatic and nutritional conditions; second, to cause new infections, local conditions must facilitate a pathogen's spread to a susceptible host. With human disease, this means that the environment must support the survival of humans and, where necessary, the secondary host or vector, or contain an appropriate natural niche within which the free-living pathogen can flourish. There must be adequate means for humans to come into contact with the pathogen, either from other people or animals or the natural environment. Diverse environmental factors, such as ambient climate and the presence or absence of overcrowding, clean water or particular types of flora and fauna, influence a pathogen's chances of flourishing and causing disease. Some pathogens thrive in warm and wet climates while others only survive in colder, drier conditions. Still others can survive almost anywhere. Thus some pathogens cause disease worldwide while others are only found in well-defined areas where the local environment is favourable to their propagation. The latter is particularly true for vector-borne diseases since here the local environment needs to support the survival and multiplication of not only the offending pathogen but also the relevant vector and often a third host as well.

Since, in general, the rate at which a single case of human infection produces new infections depends on a mixture of biological and social factors, transmission is affected not only by the population of infectious agents but also by the living conditions of the human population. Ro is affected by changes in, for example, the environment, and social and cultural practices, as well as by population size, age-distribution and density (May, 1994). Changes in the environment (Box 2) are particularly important to vector-borne infections since the proliferation and behaviour of vectors and (where appropriate) intermediate hosts are especially dependent on availability of the right conditions. Changes in all variables (economic, environmental, demographic), either individually or combined, may carry Ro from below to above unity (Ro = 1) or vice versa, thereby influencing the emergence, re-emergence or disappearance of specific infectious diseases. An understanding of the interactions between ecological factors and infectious diseases is therefore vital to predicting the future impact of infectious diseases and developing appropriate measures for their control.

Appreciation of transmission systems and amplification processes also helps in understanding how infections can be prevented, controlled and treated. Interrupting the transmission of pathogens to susceptible people will prevent infections, while eliminating or controlling a pathogen's ability to survive and multiply in an established case will curtail the infection. Where treatment of an infectious case also renders that case non-infectious, it will also prevent further transmission. Box 3 lists some of the methods available for preventing or treating infections.

Box 3: Preventing and treating human infections

To prevent human infection, *interrupt transmission of an infectious agent to humans by*:

- eliminating sites where pathogens, vectors, or intermediate hosts proliferate
- reducing human exposure to pathogens or vectors through:
  - regulating the natural and built environment and/or trade
  - using protective equipment (e.g. bednets to prevent malaria)
  - using chemoprophylaxis (e.g. antimalarial drugs to prevent malaria)
  - modifying behaviour (e.g. not engaging in unprotected sex to prevent HIV/AIDS)
  - isolating and treating infected cases (human or animal) to prevent them from spreading the infection to others (e.g. identifying and treating TB cases as soon as possible to prevent transmission to others)
- increasing human immunity to pathogens through vaccination programmes.

To treat established infections, *control multiplication of a pathogen in an infected person* by:

- administering chemotherapy to kill pathogens
- using surgery or medical treatment to remove any continued source of infection, such as an abscess
- providing supportive treatment to enhance a person's ability to destroy the pathogen using his/her natural immunity to infectious agents.

In any situation, the appropriate preventive and treatment strategy depends on the particular pathogen or clinical disease to be controlled. Vector control is, for example, crucial to the prevention of vector-borne infections; the environment can be modified to deprive vectors of favourable breeding sites, or people may be advised to avoid areas where vectors flourish. Sometimes such modifications may enhance proliferation of one disease's vector while inhibiting that of another's, and therefore strategies must be appropriate not just in terms of their effect on a particular infection but also in terms of their effect on the whole infectious disease burden in a given area or population. In addition, for some diseases a quantitative or qualitative distinction is drawn between the measures required to control epidemic versus endemic infections.[3]

[3] For example, controlling epidemics of arthropod borne viral encephalitides might require intensification of measures that already play a part in controlling endemic disease. Thus vector control might be enhanced through fogging or spraying of suitable insecticides from airplanes and, in the case of Japanese B encephalitis, immunization of pigs might be considered. For typhoid fever or cholera, qualitatively different measures might be required to control an outbreak, e.g. chlorination of water supplies (Beneson AS, ed. *Control of communicable diseases manual*, 16th edition. Washington DC, American Public Health Association, 1995).

Globalization may profoundly influence many of the biological, social and environmental factors that impact on a pathogen's potential to survive, spread and cause human disease. In addition, at both global and local levels, the processes of globalization can influence the chances of successfully implementing measures to prevent, control and treat infections. Although good quality disease surveillance systems can help detect changes in disease patterns, it is difficult to conclusively prove that globalization is itself responsible for changes in the spread or distribution of particular infections, or of infectious diseases in general. To prove that globalization is responsible for the increasing prevalence of a specific infection would require standardized monitoring of the exposure (the process of globalization being studied), the outcome (incidence of a particular infectious disease), and other determinants of disease (e.g. immunity, treatment, socioeconomic factors) over many years. The necessary studies would be extremely difficult to construct, and highly vulnerable to confounding due to new and unforeseen factors developing out of the enormous transformations occurring in most aspects of contemporary political, economic and cultural life. In addition, surveillance systems describing the incidence and prevalence of infectious diseases over time are very rare, particularly for populations in developing countries, who are often the most likely to experience the adverse health effects of global transformations. Even if a causal association were detected, there would likely be considerable dispute over whether the relevant process, for instance global warming, was in fact caused by globalization.

Thus, the assessment of health risks associated with globalization must accommodate much unavoidable uncertainty. This does not mean that no conclusions should be drawn on the influence of global processes on past, present and future disease levels. Indeed, poor or absent supportive evidence for the benefits of globalization has not dissuaded proponents of unregulated economic globalization from arguing forcefully for its introduction. The need to respond in situations where we do not have full and incontrovertible evidence for our actions is well expressed by the precautionary principle: 'Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used for postponing cost-effective measures.'[4]

Given the broad approach to globalization adopted by this paper (as described in Section 2.1), this review discusses four major aspects of globalization – economic, environmental, political and demographic, and technological change. After a general discussion of each sphere of global change, consideration is given to how it may be influencing the distribution and spread of specific infectious diseases, and the severity of disease within certain population groups, in different parts of the world. This review focuses, in particular, on how the global change may impact on the distribution, spread, treatment and control of the TDR priority diseases. Admittedly, this subdivision is a simplification of a complex set of interrelated processes. For example, the links between global environmental change and infectious disease cannot be seen independently from global economic change. Similarly, global economic change affecting the availability of resources for infectious disease control cannot be separated from shifts in political ideology shaping policy change at the national and global levels. These linkages are illustrated by the complex inter-relationships between the various aspects of globalization and malaria and dengue fever (see Boxes 10 and 12). For example the geographical reach and prevalence of malaria have been influenced by the economic, environmental, political and demographic aspects of globalization through economic adversity, increase in trade, spread of drug resistance, global warming, conflict, urbanization, and tourism, while technological advances have improved our understanding of the disease and should ultimately help improve its control. There have been various efforts to develop a conceptual framework to explain the linkages among these various spheres of change.[5] Nonetheless, systematic assessment of each sphere provides a heuristic framework. It is a useful starting point to consider each sphere of globalization in terms of risk factors, epidemiology and transmission (including vectors), and control (including treatment and surveillance) of infectious disease. This also enables an examination of the positive and negative consequences of global change, and is a first step towards identifying key gaps in current knowledge.

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4 *UN Conference on the Environment and Development*, Rio de Janeiro, 1992

5 For example see Woodward D et al. Globalization and health: a framework for analysis and action. *Bulletin of the World Health Organization*, 2001, 79:875-81; and Labonte R. *Brief to the World Trade Organization: World Trade and Population Health.* IUHPE Board of Trustees, 1999.

4 ECONOMIC GLOBALIZATION AND INFECTIOUS DISEASE

Economic globalization describes the restructuring of the world economy, from one centred on production and exchange relations between economic entities located in different countries (international economy), towards "a highly complex, kaleidoscope structure involving the fragmentation of many production processes and their geographical relocation on a global scale in ways which slice through national boundaries" (Dicken, 1998). While this transition from an international to global economy has been a gradual one spanning many centuries, the processes of change have accelerated since the end of the Second World War and particularly since the early 1970s with major events such as the collapse of the gold standard, oil crises, and increased debt burden.[6] These fundamental changes to economies worldwide are believed to be having a range of impacts on infectious diseases.

4.1 World Trade Organization and multilateral trade agreements

The emergence of the global economy has been facilitated, since 1945, by the significant growth of international trade, as well as of regional and international organizations that govern trade relations. Since the creation of the General Agreement on Tariffs and Trade (GATT) in 1944, member states have undertaken successive rounds of negotiations to reduce barriers to trade. In 1995, GATT was replaced by the World Trade Organization (WTO), a permanent body responsible for administering and enforcing a number of binding multilateral trade agreements (MTAs). These include the Agreement on Trade Related Intellectual Property Rights (TRIPS), General Agreement on Trade in Services (GATS), and Agreement on Technical Barriers to Trade (TBT).[7]

The economic impact of this proliferation in bilateral, regional and international trade agreements has been enormous. Since 1950, gross world production has increased five-fold while world trade has increased fourteen-fold (Lang, 2001). Marked changes were seen during the 1990s, when many countries embarked on rapid economic reforms encompassing market liberalization, deregulation and privatization. Within a decade, populations living within market economies, or in countries engaged in market-oriented reforms, rose from one billion to roughly five and a half billion (Lehmann, 2001). A substantial increase in all forms of international economic activity – FDI, capital markets, trade of goods and services, information and technology transfer – followed. As well as this internationalization of the world economy, there has been growing economic globalization in the form of restructuring of key sectors such as telecommunications, pharmaceuticals and food production.

There remains substantial debate about the precise impacts of trade on social welfare and, in particular, on health. Proponents argue that trade is the "motor force" of the global economy and "human progress", and that "more trade leads to more wealth, which in turn improves health" (Feachem, 2001). Others point to a more complex relationship, highlighting the need to ensure targeted protection of "human needs, social welfare, quality of life, indigenous understanding of knowledge and property" as well as to regulate goods and services that are harmful to health (Baris and McLeod, 2000; Lee, 2003). Although there is a strong relationship between increasing national wealth and overall health status, as income reaches US$ 5000 per capita, gains in health status and other economic factors, such as

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6 For a detailed discussion see: Held D et al., *Global transformations, politics, economics and culture*. Stanford, Stanford University Press, 1999.

7 For a discussion of the public health implications of specific multilateral trade agreements see: WHO. *WTO agreements and public health*. Geneva, WHO/WTO, 2002.

degree of income equality, become more important (Wilkinson, 1996). Furthermore, there is growing evidence that trade is leading to growing socioeconomic inequalities within and between countries (UNDP, 1999). While some writers continue to dispute the methodology behind such analyses (Ravallion, 1997), it is widely acknowledged that economic growth per se must be considered separately from the distribution of those benefits (Dikhanov and Ward, 2001). For many poor people, increased trade can lead to greater inequalities (Lunderg and Squire, 1999, as cited in Carpenter, 2000) that, in turn, have detrimental consequences for human health (Cornea, 2001; Goesling, 2001). The precise impact of MTAs on health, therefore, must be considered in relation to specific terms of trade and the resultant balance of winners and losers arising from them.

At a macroeconomic level, such changes can influence the overall level of resources available to governments for health expenditure. Rapid economic transition in central and eastern Europe during the 1990s, for example, was found to have undermined government capacity to provide for health care, and marked increases in the rates of several infections were reported (Maclehose et al., 2002). The Asian financial crisis in the late 1990s had a similar impact on public health spending. There is evidence to suggest that this, in turn, had detrimental effects on the rates of certain infections such as HIV/AIDS, tuberculosis and sexually transmitted diseases (STDs) (Sivaraman S, 1998). Reduced spending on vector-borne disease control programmes in Africa during periods of structural adjustment has led to failures to control diseases such as malaria, as well as to resurgence of some parasitic infections such as African trypanosomiasis (Sanders and Chopra, 2002). Furthermore, outbreaks of infectious diseases are themselves associated with significant costs in terms of lost trade and tourism revenue, and there is some evidence that fear of economic penalties has sometimes led authorities to under-report epidemics, risking serious public health consequences. More comparative empirical analysis of the effects of trade liberalization on the epidemiology of infectious diseases is much needed.

Trade in specific products may have a more direct impact on infectious diseases. The most obvious examples are trade in food products and pharmaceuticals, and these are explored in more detail below. More esoteric examples also exist. For instance, the trade in used car tyres has led to the spread of dengue fever to cities, as examined below (section 6.4.2i). Economic change also leads to migration, and to alterations in land use and water requirements, which in turn have impacts on infectious diseases. This is also considered below.

4.2 The global trade in food

Consequences for infectious diseases arise from intensified trade in particular goods and services; this can be observed in the trends towards globalization of the food industry. Over recent decades, huge increases in international trade have transformed the availability of food products, particularly for inhabitants of high-income countries. This, in turn, has led to changes in dietary habits, and there is now a demand for year round availability of fresh fruit and vegetables, and for so-called "ethnic" foods. The convergence of tastes in many countries has meant greater demand for generic rather than local produce; cheaper transport systems of global reach now allow companies to manufacture many food products in less expensive labour markets, using ingredients from different parts of the world, and then to transport them worldwide.

The largest ten transnational corporations (TNCs) in the food industry are North American or European in ownership (Lang, 2001). Four companies control 90% of the world's exports of coffee, tea, corn, wheat, pineapples and tobacco (Lee and Patel, 2002). In addition, large agrochemical TNCs are involved in the increasingly globalized food industry and account for 85% of the world market (Lang, 2001). Hence, a small number of large concerns now wield powerful control over the entire food chain, including agricultural production, processing and packaging, transporting and marketing (Lang, 1999). In 1994, the value of food trade was more than 300% greater than twenty years earlier (Kaferstein et al., 1997).

Although poor statistics make it difficult to estimate the global incidence of foodborne diseases, and there is substantial under-reporting, data from industrialized countries indicate that up to 10% of populations are affected annually by foodborne diseases (Kaferstein et al., 1997). Mass production, handling procedures, environmental factors, new and emerging pathogens, and poor regulation are believed to be contributing to a marked increase in worldwide incidence (Lang, 2001; Kaferstein et al., 1997; Swerdlow and Altekruse, 1998). Several factors may be responsible. First, the increasing reliance on producers abroad means that food may be contaminated during harvesting, storage, processing and transport, long before it reaches overseas markets. For example, outbreaks of *Salmonella* poona infection in the US associated with eating imported melons from Mexico have been linked to unhygienic irrigation and packaging practices at source farms. Low-income countries may also cultivate non-indigenous crops to meet the needs of the export market, and these may be more susceptible to indigenous pathogens. This happened when Guatemalan raspberries became contaminated with the protozoan Cyclospora, causing outbreaks of gastroenteritis in the US and Canada.

Second, centralized processing and mass distribution may lead to widespread dissemination of contaminated foods. This risk has been augmented by changes in methods of food production such as the rearing of huge poultry flocks in communal housing, which practice generates large numbers of birds with common risk profiles. Similarly, outbreaks of *E. coli* O157:H7 have been traced to hamburgers from multiple outlets of a fastfood chain in the US, and clusters of gastroenteritis to flocks of *Salmonella typhimurium* infected poultry throughout Europe (Altekruse et al, 1997). Contaminated animal feeds may also be widely disseminated throughout the world, as exemplified by the bovine spongiform encephalopathy variant Creutzfeldt-Jakob disease (BSE/vCJD) crisis in the UK.

"New" pathogens not previously associated with human illness, such as *Cyclospora* and *E. coli* O157:H7, were first identified through epidemics of foodborne disease. Emerging zoonotic pathogens are becoming increasingly resistant to antimicrobial agents, largely because of widespread use of antibiotics in the animal reservoir. For example, *Campylobacter* isolated from human patients in Europe is now increasingly resistant to fluoroquinolone drugs, after these were introduced for use in animals (Endtz, 1991). Overall, there is a need to understand better how the global trade in food has spread hitherto local risks more widely, and has created new risks from increased economies of scale and changing methods of production.

4.3 The global trade in pharmaceuticals

In low and middle-income countries, pharmaceuticals account for about 30% of total health expenditure. The potential health benefits and risks posed by trade liberalization to access to pharmaceuticals are varied. Baris and McLeod (2000) argue that, as freer trade reduces tariffs on imported pharmaceuticals, drug imports will increase. In theory, countries will benefit from enhancing the range of drugs available, particularly where there is little or no domestic capacity to produce such products, and foreign competition should exert pressure on prices overall. In practice, however, the effects on production and consumption are more complex given the changing structure of the pharmaceutical industry. Like the food industry, pharmaceuticals are increasingly dominated by a small number of large TNCs. In 1992, the top ten pharmaceutical companies were based in the US and Europe, accounting for about one-third of total combined sales worldwide (Baris and McLeod, 2000).

No low-income country appears in this super league (with the exception of China, which produces all of its essential drugs), but such countries do have the advantage of cheap labour and indigenous medicinal plants. Hence, there is a thriving generics industry in the developing world, and rapidly growing international trade. However, increased access by large TNCs to markets in the developing world could undermine these local producers. Under the TRIPS agreement, domestic subsidies on drugs could be deemed an unfair trade advantage, and there may be a tightening of regulations around the production and trade of generic drugs.

In relation to drug development, an emerging global market for pharmaceuticals raises concerns about a greater focus on conditions and markets deemed most profitable, regardless of the global burden of disease. How drugs will be developed for infectious diseases afflicting the poorest population groups within such a context remains unclear. For example, only 13 of the 1223 new chemical entities commercialized between 1975 and 1997 were for tropical diseases (Pecoul et al, 1999), and no new drugs for tuberculosis have been developed for over 30 years because, despite its enormous toll, only 5% of the 16 million infected can afford medication.[8] These inequities contribute to the 10/90 gap in which 90 per cent of research funds address the health needs of 10 per cent of the world's population (Global Forum for Health Research, 1999).

Finally, unregulated access to, and inappropriate consumption of, pharmaceuticals in a global marketplace raises the issue of drug resistance. These factors have, for example, contributed to the spread of multidrug resistant tuberculosis (MDR-TB) worldwide, and will lead to further spread of resistance to antiretrovirals for HIV, particularly given the important role that the unregulated private sector plays in providing care for stigmatizing conditions (Brugha, 2003).[9] Control of such diseases could therefore be jeopardized, and the misuse of pharmaceutical products facilitated, if sufficient regulatory mechanisms (including proscribed standards of use with adequate monitoring and enforcement) are not implemented alongside globalization of the pharmaceutical industry.

8 Global Alliance for TB Drug Development, www.tballiance.org/2_3_C_NoRandDin30years.asp (accessed 27 August 2003).

9 As cited at www.tballiance.org/2_3_C_NoRandDin30years.asp.

5 GLOBAL ENVIRONMENTAL CHANGE AND INFECTIOUS DISEASE

The environment consists of not only the natural world but also the built and social environments, and it plays an important role in shaping human health. The natural environment is modified by local influences, such as local weather conditions, physical disasters or building developments, as well as global forces, such as changes in the great biophysical systems of the world that alter the global environment. Both local and global environmental change may be either natural or human-induced. Anthropogenic (human-induced) changes are increasingly linked to the processes of globalization (McMichael and Haines, 1997). Over the past 50 years, huge increases in economic and industrial activity have led to unprecedented effects on air, land and water environments, and the resulting changes have important and wide-ranging implications for human health, with different populations facing varying degrees of vulnerability to positive and negative impacts. This section explores the known and expected impacts on infectious diseases.

Box 4: Projections of the health impacts of global environmental change

Current knowledge can be used to make 'best guesses' of whether climate change is likely to have broadly positive or negative effects. Experts on the Intergovernmental Panel on Climate Change (IPCC) concluded that climate change is likely to expand the geographical distribution of several vector-borne diseases, including malaria, dengue and leishmaniasis, to higher altitudes (high confidence) and higher latitudes, assuming limited public health defences (medium/low confidence), and to extend transmission seasons in some locations (medium/high confidence). Climate change may decrease transmission of vector-borne diseases in some locations by reducing rainfall or raising temperatures to levels too high for transmission (medium/low confidence) (McMichael, 2001).

Quantitative statements about the impact of climate change on the burden of infectious diseases can be arrived at by coupling data from existing studies with estimates of expected global climate change. For instance, data from the Peru diarrhoea study cited above can be applied to IPCC projections to make approximate estimates of how much the worldwide incidence of diarrhoea might increase with global warming (McMichael et al., 2003). More complex models have been used to investigate the possible effects of climate change on geographic distribution of, and vectorial capacity in, vector-borne diseases. These either integrate climate effects on various components of the transmission cycle (e.g. Jetten and Focks, 1997; Martens et al., 1999), or simply make a statistical correlation between the current distribution of diseases and the most important climate variables (e.g. Hales et al., 2002; Rogers and Randolph, 2000).

Although these models should improve in the future, particularly as better quality health monitoring data become available, they will remain subject to major uncertainties, partly around the likely extent of future climate change but also around the relationships between climate and health outcomes, as other factors change. Socioeconomic factors, in particular, are often more important determinants of infectious disease burden, therefore global models based on climate alone are unlikely to give accurate predictions, particularly at the local level. Climate change will tend to increase risk over what would have been expected if no change had occurred, but socioeconomic development and control interventions could reduce both the existing (i.e. climate change independent) risk, and the vulnerability of populations to climate change. This is well illustrated in the context of diarrhoea. The provision of clean water and sanitation, combined with increased handwashing with soap, should not only cause very large reductions in diarrhoea rates, but by reducing the relative importance of water-borne and food-borne bacterial infections (which tend to respond positively to higher temperatures), compared to viral infections (which do not), the effects of climate change should become less important.

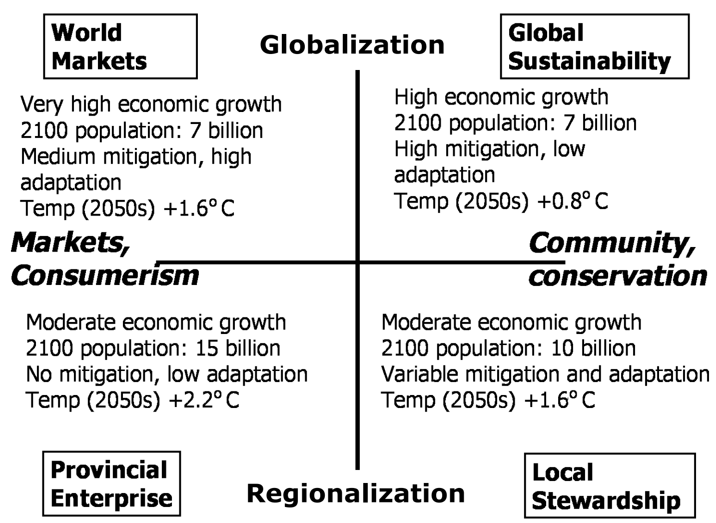
5.1 Global climate change

Current concerns about global climate change can be divided into two main subjects: rising global average land and sea surface temperatures ("global warming"), and increasing frequency of extreme weather conditions in many parts of the world. These are aetiologically linked, but since each is associated with different patterns of infectious disease, they will be discussed separately. In general, climate constrains the range of infectious diseases, while weather affects the timing and intensity of outbreaks (Dobson and Carper, 1993).

5.1.1 Global warming

There is now substantial evidence that global average land and sea surface temperatures have increased by 0.6°C since the mid-nineteenth century. Most of this change has taken place since 1976, and 14 of the warmest years on record have occurred since 1980. In 1999, the UN Intergovernmental Panel on Climate Change (IPCC) predicted that average global temperatures would increase by 1.4-5.8°C by 2100.

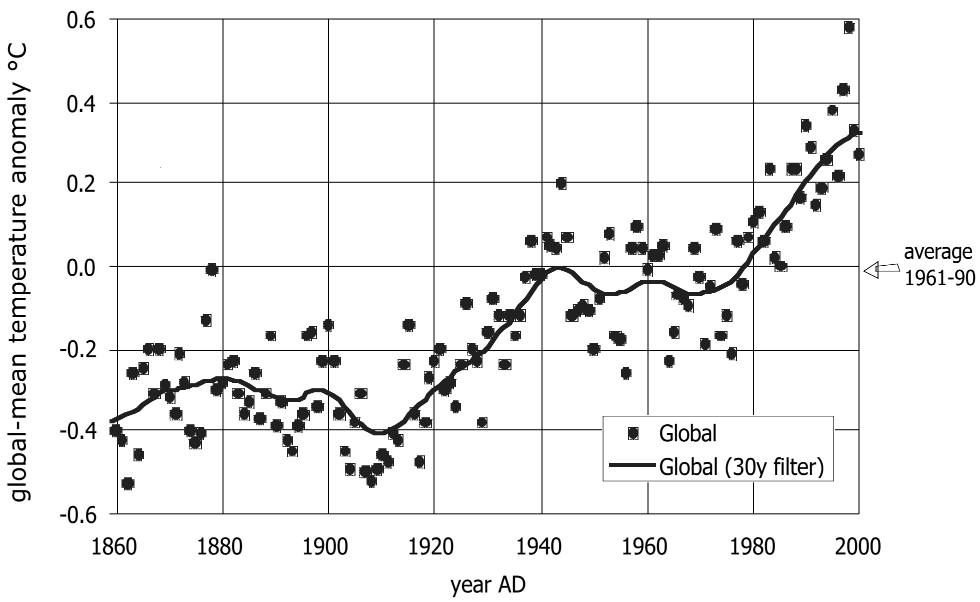
Fig. 1: Alternative scenarios of future development and associated climate change developed by the IPCC



Source: United Kingdom Climate Impacts Programme (UKCIP). *Socio-economic scenarios for climate change impact assessment. A guide to their use in the UK Climate Impacts Programme*. UKCIP, Oxford, 2000.

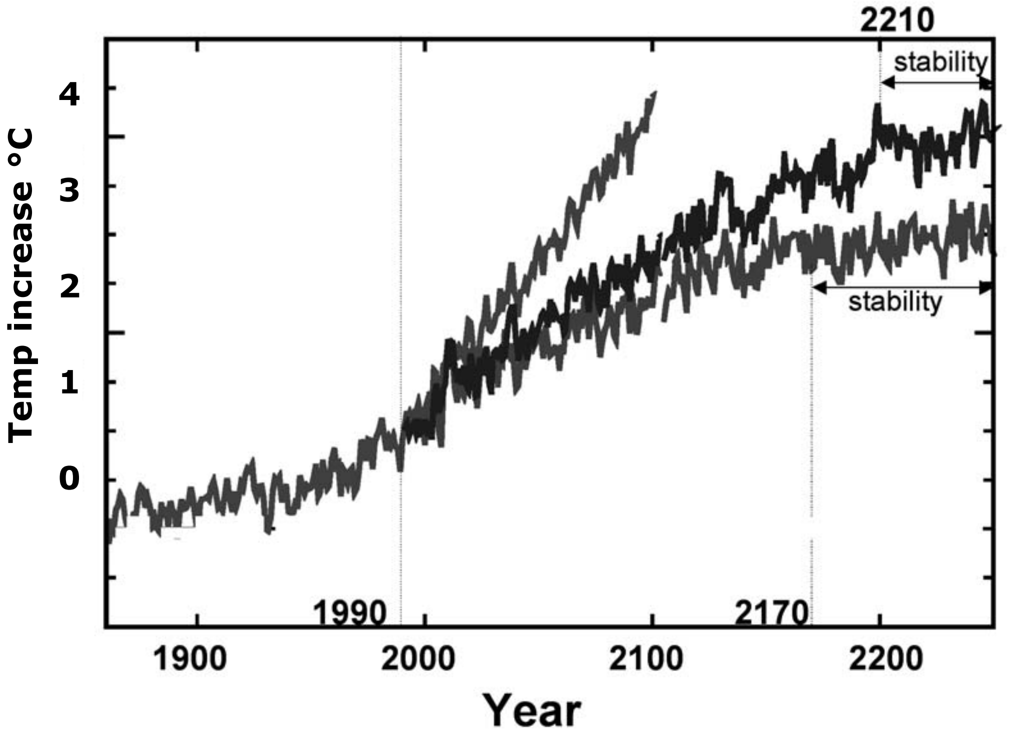
A rise of this magnitude would be faster than anything encountered since the inception of agriculture around 10 000 years ago. Although the causes are controversial, IPCC has concluded that much of the warming observed in the last 50 years can be attributed to human activity (Albritton et al., 2001), principally due to excessive and inefficient combustion of fossil fuels, leading to the build up of greenhouse gases that trap heat within the atmosphere (McMichael, 1993). Patterns of precipitation have also changed: arid and semi-arid regions are becoming drier, while other areas, especially in mid-to-high latitudes, are becoming wetter, with a disproportionate increase in frequency of the heaviest precipitation events.

Fig. 2: Global average near-surface temperatures, 1860-1999



Source: Climatic Research Unit, Norwich, UK.

Fig. 3: The global average temperature rise predicted from the unmitigated emissions scenario (red), and the emission scenario which stabilizes CO_2 concentrations at 750 ppm (blue) and at 550 ppm (green).



Source: Hadley Centre. *Climate change and its impacts: stabilisation of CO_2 in the atmosphere 1999*. Hadley Centre, UK, 1999.

Global warming may alter the range and prevalence of many infections. As described in Box 5, higher ambient air temperatures, along with changes in precipitation and humidity, can affect the biology and ecology of disease vectors and intermediate hosts, the pathogens that they transmit, and consequently the risk of transmission (Githeko et al., 2000). Diseases carried by mosquito vectors are particularly sensitive to meteorological conditions since these insects have fastidious temperature thresholds for survival and are especially susceptible to changes in average ambient temperature (Epstein, 2001a). *Anopheles* spp. mosquitoes can only transmit *Plasmodium falciparum* malaria parasites if the temperature remains above 16°C, while the eggs, larvae and adults of *Aedes aegypti* mosquitoes that spread dengue fever and yellow fever are killed by temperatures below 10°C (Martens et al., 1997). Furthermore, within their survival range, warmth accelerates the biting rate of mosquitoes, and the maturation of parasites and viruses within them (McArthur, 1972), and, since insects have short lifespans, this increases the chances of their having two crucial blood meals – one from an infected person and the second for transmission of the pathogen to another person. The life cycle of the malaria parasite or other pathogen carried by the vector is thus accelerated. The precise effect on transmission requires continued study to determine whether shorter, more intense, lifespans lower or increase transmission, on balance.

Box 5: The scientific evidence for global environmental change

Detecting the influence of the observed (and much larger predicted) changes in climate and weather on infectious diseases transmission is not obvious and straightforward. Firstly, climate change is a gradual process and its effects are hard to distinguish from the much larger natural variations that occur from season to season, or year to year. Secondly, many non-climatic factors may moderate the effects of climate change on the impact of infectious diseases. For example, changes in human behaviour or levels of immunity, better socioeconomic conditions, and improved treatment and control programmes, may all reduce the extent to which a climate-driven increase in pathogen transmission is translated into clinical disease. A cast-iron case for climate change producing a direct increase in infectious disease prevalence would require standardized monitoring of the exposure (climate), the outcome (incidence of a particular infectious disease), and other determinants of disease (e.g. immunity, treatment, socioeconomic factors) over many years.

Such datasets are very rare, particularly for populations in developing countries with poor health and socioeconomic infrastructure, who are the most likely to experience the effects of climate change. There is the added ethical problem of not imposing control measures after such analysis is undertaken to prevent disease. It is therefore not surprising that a recent review of the evidence for climate effects on vector-borne diseases concluded that there was only relatively weak direct evidence for such effects so far, but this was due to ‘absence of evidence’, rather than ‘evidence of absence’ (Kovats et al., 2001). Direct evidence of climate change on infectious diseases may become more obvious with improved disease surveillance, and as changes in climate accelerate. However, as climate change may be irreversible, at least within given timeframes, it seems unacceptable to wait for these to occur before trying to assess the risk. In the meantime, the best estimation of the likely current and future impacts of climate change comes from theoretical consideration of the known effects of climate on disease transmission, and from indirect assessment based on reported effects of climate on infectious diseases in the present or recent past.

In some cases, global warming may be beneficial. For example, the incidence of schistosomiasis may drop if the temperature is too warm to sustain the snail host, and malaria transmission may diminish in an established endemic zone if this becomes too hot and dry. In Senegal, reduced precipitation and drought have dramatically reduced the number of *A. funestus* mosquitoes, and malaria prevalence has dropped by more than 60% over the last thirty years (Faye et al., 1995). In temperate zones, shorter and milder winters may curtail the seasonal excess of cardiovascular and respiratory deaths. Nevertheless, most of the anticipated effects of global warming will be adverse, since shifts in the climate mean and climate variability are likely to perturb the physical and biological systems to which human health is biologically and culturally adjusted (McMichael and Haines, 1997). Overall, global warming is expected to widen the geographical range within which climate is capable of sustaining transmission of several of the TDR infections. For example, if the anticipated changes in temperature are correct, mathematical models predict that the proportion of the world’s population living in areas capable of sustaining malaria transmission will increase from 45% to 60% by the middle of this century (Martens et al., 1997). Currently, countries at the temperature-sensitive edge of transmission (e.g. Italy) have the capacity to control such diseases.

Box 6: Global climate change and vector-borne diseases

Schistosomiasis

Prevalence of schistosomiasis has increased in arid warm regions primarily from expansion of irrigation projects that provide habitats within which the snail intermediate hosts thrive. Global warming could increase water shortage in many agricultural areas, leading to greater demand for irrigation systems. Thus it may potentiate the risk of schistosomiasis in these regions. Warmer temperatures also increase infectivity and development of the parasite within the snail. Where there is a cold season, infection in the snail host becomes dormant and potential transmission diminishes sharply (Shiff et al., 1975; Shiff et al., 1979). Therefore, if the temperature increases, snails could spread schistosomiasis over a longer period during the year (Gillet, 1974; WHO, 1990). Recent modelling of schistosomiasis transmission predicts an additional 5 million cases attributed to climate change by the year 2050 if no action is taken (Martens, 1995).

Onchocerciasis

The blackfly vectors of “river blindness” require fast-flowing water for successful reproduction, and the adult vector can be spread by wind (WHO, 1985). These conditions are dependent on the prevailing local climate. A recent study found that if temperature and precipitation change across portions of West Africa as predicted by some global circulation models, blackfly populations may increase by as much as 25% at their current breeding sites (Mills, 1995). Potential abandonment of agricultural land in river valleys (a common consequence of blindness affecting the able-bodied population) could add to regional food production problems.

African trypanosomiasis

The distribution of tsetse flies depends on vegetation cover. Researchers in sub-Saharan Africa have correlated vegetation type to the population density of tsetse flies using satellite images to predict a large extension of regions at risk for sleeping sickness, assuming a 3°C mean monthly increase in temperature (Rogers and Randolph, 1991; Rogers and Packer, 1993).

Tick-borne infections

Ticks are highly sensitive to climate change. One study in South-East Africa found that only 2°C determined the difference between areas where ticks were present or absent (Rogers and Randolph, 1993). In Sweden, mild winters are reported to have facilitated the northern migration of ticks carrying Lyme disease, leading to more northerly outbreaks of tick-borne encephalitis (Lindgren et al., 2000; Lindgren and Gustafson, 2001). In contrast, some tick vectors, such as those carrying Rocky Mountain spotted fever in the southern United States, prefer cooler temperatures, and some studies suggest that foci of tick borne-borne encephalitis in Europe are dependent on very specific seasonal climatic patterns. Thus, rising temperatures and humidity could cause a decrease in both of these diseases (Haile, 1989; Randolph et al., 2001).

Viral infections

St Louis encephalitis is the commonest cause of viral encephalitis in the United States. Epidemics of this arboviral (transmitted by arthropods) disease generally only occur south of the 20°C June isotherm, but northerly outbreaks have occurred during unseasonably warm years (Shope, 1980). Although higher temperatures decrease survival of the mosquitoes which transmit the virus, this is offset by greater viral transmission rates. Field studies and modelling suggest that temperature increases will cause a significant northern shift in this and other American viral infections transmitted by mosquitoes (Hardy, 1988; Reisin et al., 1993; Reeves et al., 1994). It is also possible that the first appearance of the West Nile virus in the USA in 1999 was a consequence of mosquito proliferation following the extreme summer drought conditions prevailing in the New York area at the time (Lanciotti et al., 1999; Githeko et al., 2000).

The scientific difficulties of obtaining empirical proof that global warming is altering the transmission of infectious diseases are considered in Box 6. Nevertheless, available evidence suggests that changes consistent with climate-change effects on Anopheline mosquitoes are found in parts of the US, and small outbreaks of locally transmitted malaria have occurred during unseasonably hot weather spells (Zucker, 1996; Epstein et al., 1998). Increases in malaria incidence have coincided with record high temperatures and rainfall in Rwanda, although other changes have taken place that may confound this finding (Loevinsohn, 1994). Climate change is one of several factors that may be contributing to the dramatic advance of dengue fever in the last thirty years, along with other aspects of globalization such as increased transport and mixing of dengue viral serotypes. Higher median temperature during the rainy season was a strong predictor of dengue fever prevalence in Mexico (Koopman et al., 1991) while, in the South Pacific region, outbreaks of dengue in areas on the fringe of the endemic zone in 1970-1995 correlated reasonably well with El Niño events (Hales et al., 1999).

Further substantiation comes from the ecological changes occurring at high altitudes. Since temperature varies inversely with elevation above sea level, global warming should generate a change in ecology at high altitude to that characteristic of lower altitudes before climate change. This appears to be happening. In many mountainous regions, glaciers are in retreat and plants preferring lower temperatures have been displaced to higher altitudes (Patz et al., 1996; Epstein, 2001a). Changes in flora are matched by alterations in animal life. For example, malaria is now prevalent in elevated regions where it did not previously exist, such as rural highland areas in Papua New Guinea (Githeko et al., 2000; Epstein, 2001b) while, in Mexico, the first reported cases of dengue at an altitude of 1700 metres occurred during an unseasonably warm summer in 1988 (Herrera-Basto et al., 1992).

Changes in the prevalence or distribution of many other vector-borne parasitic and viral infections have also been linked to global warming, and there are biological reasons for expecting similar alterations in future (Patz et al., 1996). In addition to vectors, many pathogens themselves multiply quicker and are consequently more infectious in warmer temperatures; this is one reason why, for instance, gastroenteritis is more common in the summer. Global warming may therefore increase the incidence of these infections. In Lima, Peru, researchers who analysed the relationship between day-to-day variations in temperature and the incidence of diarrhoea found that, over and above the seasonal pattern, incidence increased by 12% per 1°C temperature increase in the cool season, and by 4% per 1°C in the hotter season, averaging an 8% increase per °C throughout the study. Based on this association, Checkley et al. (2000) estimated that a 0.3°C increase in average temperature over the past 30 years would be associated with a 2.4% increase in diarrhoea over what would have been expected without climate change at this site.

Oceanic warming is one of several factors that may be contributing to a worldwide proliferation of algae blooms in coastal waters. These brackish water environments have direct and indirect influences on human health. For instance, toxic algae can cause gastroenteritis after a shellfish meal; they have also been associated with massive loss of marine life, with nutritional and other consequences. In addition, local variations in oceanic climate may support the proliferation of planktonic populations that harbour human pathogens. *Vibrio cholerae* is known to survive under cover of certain planktonic organisms, and coastal blooms of algae coincided with this pathogen's introduction into offshore waters in Peru in 1991

Box 7: Climate effects on vectorial capacity, basic reproductive number, vector abundance and distribution

Climate affects a variety of biological processes in vectors, influencing their presence or absence at a particular time and place, abundance, and ability to transmit disease. For anthroponotic diseases such as malaria, the overall ability of a vector population to transmit disease can be summarized as the vectorial capacity. This is defined by Garrett-Jones (1964) as:

$$VC = \frac{(M/N)a^2\, bpe^{-nu}}{u}$$

where a = daily biting rate of a female mosquito, b = proportion of infected bites on humans which produce an infection, p = probability that a bloodmeal is taken on a human rather than on an alternative host, M = size of the female mosquito population, N = size of the human population, u = per capita mortality rate of female mosquitoes, and n = intrinsic incubation period (number of days required to produce infective sporozoites within an infected mosquito).

Vectorial capacity is most sensitive to changes in those parameters which are present as squared terms (biting rate) or as exponential terms (mosquito mortality and parasite intrinsic incubation period). These are amongst the parameters that are most sensitive to climate, especially temperature. It is this property which makes vector-borne diseases so sensitive to even small changes in climatic conditions.

Multiplying the vectorial capacity by the number of days a case remains infectious gives the crucial parameter Ro (Anderson and May, 1991), the average number of secondary infections arising from each new infection in a susceptible population. Only if vectorial capacity is sufficient to maintain Ro above one (each case gives rise to at least one secondary case), will disease transmission persist. This climate-influenced property therefore describes the distribution limits of sustainable disease transmission.

Climate also acts on vector reproduction and mortality rates to influence the overall abundance of disease vectors (itself a component of vectorial capacity, M). Although the effects of other factors mean that there is rarely a simple relationship between climate and abundance, vector species usually reproduce and survive best within a defined range of climatic conditions. Abundance will therefore tend to be highest where these conditions are most closely matched, and decrease where and when climate is sub-optimal. The point where conditions are unsuitable for any population to be sustained marks the distribution limits of the particular vector species.

(Tamplin and Carrillo Parodi, 1991). In the Arabian Sea and Bay of Bengal, fluctuations in summer phytoplankton blooms have accompanied variations in the pattern of annual monsoon winds, while outbreaks of cholera in Bangladesh have been associated with variations in sea temperature (Huq et al., 1995; Colwell, 1996).

5.1.2 Global weather change

In the last three decades, periods of drought, heatwaves, thunderstorms and hurricanes have devastated many countries, often with severe public health consequences. The increasing frequency of these extreme weather events (EWEs) has been linked to the build up of heat in the earth's atmosphere and oceans. In particular, ocean warming may be altering climatic norms such as the frequency and intensity of El Niño-Southern Oscillation (ENSO) events, leading to changes in the distribution and spread of many infectious diseases (see Box 8).

Box 8: El Niño and infectious diseases

The El Niño Southern Oscillation (ENSO) is the most important of the Earth's climate/ocean systems. It produces periodic climate change over the Pacific that is thought to help stabilize the region's climate system. ENSO events consist of a warmer El Niño year, followed by a colder La Niña year. Typically, three more average years follow and the cycle is repeated every five years. Since the 1970s, ENSO events have become more frequent and intense, and in the 1990s, each year of the decade experienced either an El Niño or a La Niña event. The increasing frequency of ENSO events appears to be causing more frequent extreme weather events (EWEs). Time-series regression analysis shows that ENSO events are strongly associated with the number of people affected by natural disasters (Bouma et al., 1997). ENSO years have also been associated with epidemics of infections including malaria, dengue, cholera and viral encephalitis (Kovats, 2000). Other complexes such as the North Atlantic Oscillation may be driving EWEs in different parts of the world (Epstein, 2001b).

EWEs increase infectious diseases in two ways. First, by creating disaster situations where basic public health measures break down and people are crowded together in unhygienic conditions, EWEs encourage the spread of so-called "nuisance" organisms.[10] Epidemics of gastroenteritis, respiratory ailments and typhus commonly follow natural disasters. In Mozambique, floods displaced hundreds of thousands of people and led to major outbreaks of typhoid and cholera (Epstein, 2000), while in the US, intense rains and flooding have overwhelmed sanitation systems and led to outbreaks of waterborne infectious diseases (MacKenzie et al., 1994).

Second, EWEs can alter ecosystems so that they advance the appearance and spread of specific infectious diseases. For example, during 1997-98, the horn of Africa received over forty times the average rainfall. The deluge precipitated 89 000 cases of Rift Valley fever (RVF), including nearly 1000 deaths, as well as clusters of malaria and cholera. Heavy downpours increased the breeding sites for the mosquito vectors of RVF and malaria, and provided perfect conditions for the transmission of nuisance organisms. Since 1950, all known RVF outbreaks have followed periods of abnormally high rainfall (WHO, 1998; Linthicum et al., 1999). Similarly, in 1998, the incidence of malaria, dengue fever and cholera soared after Hurricane Mitch hit Central America (Epstein, 2001a). In addition, if flooding breaches sanitation systems, pathogens, nutrients and pollutants can be flushed into waterways, leading to potentially hazardous coastal algae blooms (McMichael, 1998).

[10] The term "nuisance organism" is used to describe a non-native species introduced into an ecological system which then upsets the balance of that system. In relation to infectious diseases, the term is used to describe infections that contribute to ill health but are usually not life threatening.

EWEs can provoke outbreaks of infectious disease by altering predator-prey relationships. In the South-West US, prolonged drought in 1987-1992 killed off many rodent predators, but when intense rains arrived in 1993, mouse populations rose ten-fold in less than six months. Soon after, a previously unrecognized disease, hantavirus pulmonary syndrome, appeared. The causative Sin Nombre hantavirus was isolated in mice living near patients' homes. When predators returned in a few months, the outbreak abated (Schmaljohn and Hjelle, 1997).

5.1.3 Vulnerability to global climate changes

The health impacts of global climate change will depend not only on the biological consequences of this change but also on the overall vulnerability of societies and populations. In high-income countries, which are more likely to be located at the temperature-sensitive edge of disease transmission, public health measures are sufficiently effective to prevent diseases like malaria from re-emerging even when rising temperatures support the survival of vectors. In contrast, in many low-income countries in tropical climates, already in the midst of transmission zones, public health infrastructures are often much weaker, and the increasing vogue for cutting back government expenditure means this is unlikely to change soon. How these countries cope with the relationship between climate change and disease transmission, therefore, may be more dependent on long-standing challenges for the public health system than on climate change per se. There continues to be debate on the relative vulnerability of populations, with the UN (2001) reporting that lower-income countries would be worst hit by the predicted rises in global temperatures during the next century. Others argue that population responses to ecological changes are usually non-linear, leading to a sudden deterioration or improvement in infection control once a threshold is crossed (Sutherst, 2001). Overall, it is necessary to take into account a range of factors when estimating vulnerabilities to health from climate change.

5.2 Water supply

Water is essential for human life. People must have enough water to drink and produce food, and a dependable source is a prerequisite for reliable, intensive agriculture and industrial growth. Communities which lack sufficient supplies for simple ablution are at risk for high rates of mortality and ill health. However, the amount of water accessible for these needs is severely limited, available freshwater amounting to less than 0.5% of all the water on Earth. Most water is sea water, or is frozen in polar ice, and we are heavily reliant on river flow and rainfall which, in many parts of the world, are intermittent, unreliable and insufficient (World Commission on Dams, 2001).

Today, around 3800 km^3 of water is withdrawn annually from the world's lakes, rivers and aquifers (Gleick, 2000). This is twice the volume extracted 50 years ago. Demand for freshwater supplies is escalating as a result of population and economic growth. The latter has two implications for water demand: firstly, increased economic activity will raise the demand for water-related services; and secondly, both the development brought about by economic growth and the technological changes that accompany it will lead to changes in the pattern of goods and services that a society produces, which changes may themselves increase the demand for water. For instance, countries with large-scale irrigation or water-intensive industries may consume three or four times more water per US$ gross domestic product (GDP) than countries with similar GDP per capita but different production characteristics (World Commission on Dams, 2001).

Increasing pressure on the available stocks of water can lead to growing social tensions, or even to outright conflict, and access to both surface water and groundwater is an increasingly contentious issue. Currently, about two billion people do not have access to sufficient quantities of clean water to fulfil their basic requirements for drinking, sanitation, washing, and food production. Agricultural and industrial growth in many poor countries remain seriously constrained by shortage of reliable water supplies, and there is increasing competition among the three largest users of water in global terms – agriculture

(67% of withdrawals), industry (19%), and municipal and domestic users (9%) (Seckler et al., 1998). Some argue that, if climate change leads to greater weather variability, increased water storage may be necessary to offset the effects of more frequent drought (World Commission on Dams, 2001).

These factors have intensified the pressure to modify natural aquatic environments to meet the increasing demands, and the last half century has seen an explosion in water development projects around the world. By 1949, about 5000 large dams had been constructed worldwide, three-quarters of them in industrialized countries, but by the end of the century, there were over 45 000 large dams in over 140 countries. The World Bank has been the largest single source of funds for large dam construction worldwide (World Commission on Dams, 2001). While population growth and socioeconomic development per se have clearly contributed to these trends, it is increasingly argued that economic globalization too has contributed in recent decades. In particular, policy trends in the utilities sector have brought new players to the increasingly lucrative water services market – trade liberalization has allowed private industry, including TNCs, to play an increasing role in provision of water services around the world. These projects have been subjected to mixed amounts of regulation, yet of all natural habitat changes, water resources developments are potentially the most hazardous to human health. The implications of water projects for the spread of infectious diseases are considered below.

5.2.1 Large dams

Modification of the aquatic environment may alter the local ecology so that the spread of infections, particularly those spread by vectors, is influenced. This has been best studied in the case of large dams.[11] The construction of a large dam can cause profound ecological changes that encourage or discourage vector breeding. For example, a dam will create a water surface that is sometimes extensively exposed to sunlight, with water margins possibly helping malaria mosquitoes to proliferate. Similarly, a large reservoir can create conditions in which the snail hosts of schistosomiasis may survive and multiply. Alternatively, an area of land clearance may destroy the habitat of other vectors, such as blackflies, which spread onchocerciasis.

Changes in the prevalence of vector-borne diseases associated with the construction of large dams have been reported from many regions and settings. Overall, most research suggests that the construction of large dams in tropical areas is associated with increases in prevalence of endemic vector-borne infections (Hunter et al., 1993), some of the best known examples coming from projects to control the waters of the River Nile (see Box 9). Most reservoir and irrigation projects undertaken in malaria endemic areas have led to an increase in malaria transmission and disease, an increase which is more pronounced for dams below 1900 metres altitude than for those above. In Africa, the development of many reservoirs has been associated with big rises in malaria prevalence (Hunter et al., 1993); in Latin America and Asia also, malaria has been the biggest public health problem associated with large water projects. But it is not only malaria. Dramatic increases in schistosomiasis have followed the construction of dams in many African countries due to extensive colonization of the new reservoirs by the snail vectors (Brown and Wright, 1985) while, in parts of the Middle East and Africa, filariasis prevalence has increased following the creation of reservoirs. Similarly, onchocerciasis has become more prominent in some areas of West Africa near to the spillways of newly constructed large dams, although reduced around the inflows, while construction of reservoirs in the Siberian and Volga regions of the former USSR has led to dramatic increases in diphyllobothriasis, an infection caused by a fish tapeworm which leads to severe anaemia (Hunter et al., 1993).

In tropical and subtropical regions, rapid eutrophication[12] of new dams often leads to excessive growth of aquatic weeds that produce toxic cyanobacteria. These have been linked to outbreaks of gastroenteritis and other serious illnesses (Birley, 1995). In 1996, patients with severe kidney disease in the

[11] Large dams are defined as those greater than 15 metres in height or with a reservoir capacity of > 3 million cubic metres.

[12] A condition in an aquatic ecosystem where high nutrient concentrations stimulate blooms of algae.

Brazilian city of Caruaru were directly exposed to cyanobacterial toxins after inadequately treated water was used in dialysis fluid, resulting in more than 50 deaths (Carmichael et al., 2001; Azevedo et al., 2002). In China, the presence of cyanobacterial toxins in drinking water has been associated with a high incidence of primary liver cancer, although high rates of hepatitis B are also recognized as an important factor (Ding et al., 1999).

Box 9: Infection and water projects along the Nile River

The Low Dam at Aswan was constructed in the 1930s to allow perennial irrigation of the Nile Valley. Within twenty years, local prevalence of schistosomiasis rose from about 10% to 75% (Khalil Bey, 1949). In 1942-43, a malaria epidemic in the region followed an invasion by *Anopheles gambiae* mosquitoes from the Sudan, and caused 130 000 deaths (Farid, 1977). Further increases in schistosomiasis prevalence were reported after the creation of the Aswan High Dam at Lake Nasser in the 1960s. Throughout the 1970s and part of the 1980s, local inhabitants continued to show high prevalence of schistosomiasis (Strickland, 1982). This led to fears that endemic schistosomiasis would spread south to the Sudan via infected fishermen. Large-scale application of snail control since the 1970s, however, and other major control efforts, have led to important improvements. Lymphatic filariasis has increased 20-fold in the southern Nile Delta since the 1960s. It is argued by Harb et al. (1993) that this has been primarily due to an increase in breeding sites for *Aedes* mosquitoes, which followed a rise in the water table as a result of extension of irrigation. The spread of Rift Valley fever has been associated with dams and irrigation systems in Egypt and Sudan (Centers for Disease Control and Prevention, 1994a).

5.2.2 Small water projects

Small-scale water developments, such as small dams and irrigation projects, potentially have a much larger overall impact on vector-borne infections. Compared to large reservoirs, small dams cover a far greater total area, are more closely associated with human settlements, and are less well served by health facilities. In addition, breeding sites for mosquitoes tend to be in shallow backwaters (Hunter et al., 1982; Jewsbury and Imevbore, 1988; Hunter et al., 1993). Smaller dams are also less subject to planning, construction and operation regulations. The International Commission on Large Dams does not require dams under 15 metres in height to be registered, and many small irrigation schemes do not even fall under national jurisdiction. In several African countries, small dams have been closely associated with increased rates of malaria, schistosomiasis, dracunculiasis, onchocerciasis and lymphatic filariasis (Hunter et al., 1993).

In many parts of the world, irrigation schemes are created to support rice or sugar cane cultivation. Several studies outside Africa show an association between rice farming and increased prevalence of vector-borne diseases, most commonly malaria and schistosomiasis. In Afghanistan, incidence of vivax malaria increased from 5% to 20% after the Kunduz Valley was developed for cultivation of rice, cotton and vegetables (DukhaNiña et al., 1975). Although similar projects in Kenya, Burundi and Mali were found to be associated with escalating rates of malaria and schistosomiasis (Hunter et al., 1993), more recent evidence from Burundi suggests that irrigation has had less of an effect on malaria than initially believed. Rice cultivation has also been associated with increased risk of Japanese B encephalitis (JBE), particularly if there are adjacent pig populations (*Culex* mosquitoes breed in rice fields and pigs act as maintenance and even amplifier hosts for the virus that causes JBE). For example, the Mahaweli rice development project in Sri Lanka provided breeding sites for mosquitoes, while a separate development project encouraged pig production near the rice fields; epidemics of JBE seriously disrupted the newly settled communities (Birley, 1995). In Burkino Faso, increased prevalence of filariasis and onchocerciasis were noted soon after the creation of rice irrigation schemes in various parts of the country (Hunter et al., 1993).

In some cases, water projects have led to a decrease in prevalence of vector-borne diseases. Land clearance may destroy certain vectors' habitats (although this is seldom a reason per se to develop water resources), but more often, falls in prevalence have followed a deliberate effort to control a particular infection, such as malaria in the Panama Canal and Tennessee Valley Authority projects. Decreased rates of vector-borne infections may also occur when local communities make greater use of pesticides, bednets and antimalarials along with improving living standards and growing prosperity (Service, 1989). Simple developments, such as the provision of a water pump which provides communities with access to clean water for bathing, thus eliminating or reducing their need for contact with natural water bodies, have caused dramatic reductions in rates of infections like schistosomiasis (Tchuente et al., 2001). Such examples of local environmental change can be informative for mediating the health impacts of global changes.

5.2.3 Displacements, disruptions, distant effects and migrations

Water resources developments are often associated with physical and social disruption of communities, which can have significant implications for the burden of infectious diseases. Physical disruption is particularly common following the development of large water projects, and the World Commission on Large Dams estimates the overall global level of physical displacement ranges from 40 to 80 million people (World Commission on Dams, 2001). Displaced communities may be forced to live in cramped and unhygienic conditions, leading to increased incidence of "crowd" infections e.g. gastroenteritis. People may also move to live in previously unsettled areas, such as forests or deserts, where they are exposed to new vector-borne diseases. The destruction of local agriculture or fisheries can cause food shortages and malnutrition, leaving communities more susceptible to many types of infection, such as childhood measles. Social disruption can also have serious implications. In developing countries, many dams are situated in remote areas where poverty and illiteracy are rife, and where, consequently, people are especially at risk of contracting infections if they do not receive education to modify their behaviour. For instance, human waste and effluent can easily contaminate dams. Although water may be cleansed and purified before distribution, if the local inhabitants directly drink or bathe in a reservoir, they are at high risk of developing infectious gastroenteritis.

Water-borne infections can also affect people living at a distance from, but reliant on, the output of a large dam. If pathogens contaminating a water storage facility are not removed before the water is distributed, huge numbers of people spread over a wide area may develop infections. Sometimes the risk of infection may decrease in one community at the expense of another. For instance, a rural reservoir may help decrease the prevalence of epidemic infection in a distant urban population by providing better downstream sanitary facilities, but at the same time, may increase the local infection rate by progressively degrading the water environment and impoverishing the resident community.

People who migrate to live and work at a new water resources development site are at increased risk of contracting infection. In particular, construction workers often show high rates of sexually transmitted diseases. In the Lesotho Highlands Water Project Area, HIV/AIDS rates are far higher in than in surrounding areas. Local communities often feel threatened by transmission of infection from migrant workers arriving to work in their vicinity (World Commission on Dams, 2001). People moving from non-endemic to endemic areas are susceptible to vector-borne infections (Hunter et al, 1993). These issues will be explored further in section 6.3.

It is important to recognize that new water storage, irrigation and hydropower projects may increase economic prosperity, ensuring a more plentiful supply of food, which can reduce the prevalence of many infectious diseases. Development projects can also facilitate greater investment in local health care facilities, which are often set up primarily for the benefit of migratory workers but nevertheless may contribute favourably to the health of indigent communities (Hunter et al, 1993; World Commission on Dams, 2001).

The development community has called for greater intersectoral cooperation when assessing the varied health impacts of future water resources developments (Birley, 1991; Hunter et al., 1993). The World Commission on Dams also called for extensive consultations with a wide range of interested parties during the planning of large water projects. However, in many cases, past experience and other health information are ignored, with negative and avoidable consequences. Even when the risks are apparently understood and due process is followed, planners may underestimate the potential health impacts of water developments and the costs needed to mitigate them. In the late 1980s, the Senegal River Basin Dam Project received the go ahead after feasibility studies suggested that the health consequences were limited and containable. Soon after construction of the Diama Dam at St. Louis, however, an epidemic of Rift Valley fever swept parts of Mauritania, and urinary and intestinal schistosomiasis prevalence rates reached record levels upstream of the Senegal River barrier. Malaria has also been on the increase ever since (Molyneux, 1997). Global demographic and economic forces will require people to continue investing in water resources developments. The challenge is not to oppose the often necessary development of a region's water resources, but to ensure that these are constructed in a way which brings positive, sustainable and equitable health benefits to both local and geographically distant communities.

5.3 Deforestation and land clearance

Land clearance and deforestation are practices as old as human civilization. In order to provide space for settlements, crop cultivation and commercial activities, humans have cleared almost half of the world's forests in the last 10 000 years (McMichael, 1993). However, the rate of destruction, particularly of tropical rainforests, has increased dramatically in the last half century. Although slowed in some parts of the world, this ecological devastation continues at full force in many regions. The Global Forest Resources Assessment (FAO, 2000) estimates that worldwide forest area declined by 9.4 million hectares annually in the 1990s, with about half occurring in Brazil. If current rates of loss are maintained, countries like Cote d'Ivoire will have little or no tropical forest left in twenty years (FAO, 2001). Habitat destruction involves huge loss of vegetation and animal life, as well as of human settlements and societies. For example, over 90% of Brazilian forest-based cultures disappeared during the twentieth century (McMichael, 1993).

Much of the recent clearance of rainforests has been driven by the need to provide agricultural settlements, fuel and land for growing populations. Population growth is an enduring pressure on many local environments. In addition, the expansion and liberalization of trade has played an important role in making deforestation more financially attractive to countries mired in debt. Increased demand for forest hardwood in wealthy countries has made logging a lucrative trade, and there is rising foreign investment in clearing forests for plantations (FAO, 2001). Pulp milling, mining, hydropower and livestock rearing are highly profitable. To develop their national economies, many countries have cleared land for agriculture or to build roads to improve access to economically important regions. This activity, the most formidable destruction of rainforest in human history, has often yielded minimal or transient economic benefit (McMichael, 1993).

Deforestation influences health in diverse ways. For instance, rainforests play important roles in absorbing carbon dioxide, solar radiation and extreme levels of rainfall. Loss of these functions may lead to more extreme global and local climate conditions. For instance, it is estimated by Sutherst (1998) that forest clearing in Tanzania has increased local temperatures by 5°C, with the potential impacts described below. The intensity and pattern of infectious diseases are influenced because new local habitats inhibit or encourage pathogens, or because land clearance increases or decreases contact between humans and pathogens (Walsh et al., 1993). Reconfigured landscapes can provide new breeding sites for vectors while, because forests are reservoirs of huge numbers and varieties of plant and animal species which curtail the proliferation of other organisms (including disease-transmitting vectors), the disappearance of native species may allow parasites to thrive in previously inhospitable environments. Deforestation is often accompanied by large, economically driven migration to sparsely inhabited areas, and this increases the number of non-immune people living at the high risk forest-fringe interface. In addition, loss of biodiversity affects the chances of discovering new drugs for the treatment of diseases, including infections.

There are similar difficulties to those described previously in conclusively proving that an episode of deforestation has led to an increase or decrease in prevalence of particular infections. Nevertheless, in many parts of the world there is compelling evidence of a changing burden of viral, bacterial and parasitic illnesses due to land clearance. The impact of deforestation and land clearance on different types of pathogens is discussed below.

5.3.1 Deforestation, land clearance and "new" or "emerging" infections

WHO (1996) reported that, since 1975, over thirty "new" or "emergent" human infections have appeared. Most new infections seem to be caused by pathogens already present in the environment, which have been brought out of obscurity, or given selective advantage, by changing ecological or social conditions. The appearance of a completely new agent is a much rarer occurrence. Deforestation or land clearance creates opportunities for emerging pathogens to infect new host populations or even, perhaps, new species. Frequently, the opportunity arises when people enter new habitats and come into contact with animals harbouring zoonotic pathogens (those that are usually found in animals). These pathogens then have a chance of being transferred to humans. A classic example of this occurs when people move to live and work at the edge of a previously unexplored forest. Other animals, typically rodents, proliferate in land cleared of forest and become infected with the "new" virus. They then transmit this disease to humans. Alternatively, emergent infections associated with deforestation may represent existing but previously unknown human infections that are now being recognized more frequently due to an increasing human population, changing land use, or improved diagnosis (Wilson, 1995a). Globalization is contributing significantly to these processes by increasing land clearance within, and migration to, ever more remote areas.

Several new infections have been described in association with the process of deforestation. In 1989, the Guanarito virus was identified after the first recognized outbreak of Venezuelan haemorrhagic fever. Recent deforestation had probably helped to create ideal conditions for this infection to emerge: new settlements provided food and habitats favourable to the proliferation of rats which carried the virus, and human migration to new agricultural fields led to increasing contact between humans and rodents (Tesh, 1994). Across tropical South America, successive outbreaks of Oropouche fever, affecting over 250 000 people during the last thirty years, have been associated with newly deforested agricultural settlements. The midge vector for this arbovirus is believed to thrive in rotting cacao husks and banana stumps, which are commonly found around human camps (Tesh, 1994). Yellow fever, originally a disease of monkeys, probably first spread to humans through penetration of the West African forest rather than through deforestation; it was disseminated to the New World by the slave trade. Lately, however, deforestation has led to increased incidence and distribution of this infection in parts of Africa (Walsh et al., 1993). Outbreaks of disease caused by the Junin virus (Argentine haemorrhagic fever), the Machupo virus in eastern Bolivia, the Sabia virus in Brazil, and the Hantaan virus in East Asia, have been linked to disturbances in rodent ecology following land clearance for agricultural purposes.

5.3.2 Vector-borne infections

5.3.2.1 Malaria

The process of deforestation often produces conditions that are highly conducive to mosquito breeding. Forest ecosystems have a great capacity to absorb and retain moisture, but following deforestation, rainwater runs rapidly off the river beds and collects in stagnant pools and borrow pits. These water bodies and newly dug irrigation canals are exposed to sunlight, creating habitats where mosquitoes breed prolifically; malaria epidemics soon follow. In Sri Lanka, formerly perennial rivers have become heavily silted and run dry during droughts, leaving stale pools in otherwise parched river beds. This has led to epidemics of malaria during the dry season (Walsh et al., 1993). In the last 50 years, some argue that malaria prevalence has increased in many tropical and subtropical regions where forests have been cleared for cultivation (see Box 10).

Box 10: Malaria

Falciparum malaria kills around one million people, mostly children, annually. Despite concerted efforts at malaria eradication and prevention after the end of the Second World War, the disease remains prevalent in many parts of the world. In the early twenty-first century, there are fears that globalization processes are contributing to an increase in malaria in some areas. In many low-income countries, civil and international conflicts, along with economic adversity, have led to the collapse of mosquito control programmes, with disastrous results. In other areas, global warming may extend the range of latitude and altitude at which malaria is transmitted. There is already supportive evidence from descriptions of ecological changes. For instance, the process of deforestation has increased the number of people living in environments where they may come into contact with infectious mosquitoes, and land clearance has created new areas of open land that may allow mosquitoes to spread. Some large-scale water projects may have increased the prevalence of malaria in tropical regions by providing breeding sites, while growing cross-border transport, by land and air, of goods for trade has facilitated the spread of mosquitoes to widely dispersed areas. Rapid and unplanned urbanization may lead to increased availability of clean water breeding sites, while the rising number of tourists to malaria-endemic areas is already putting more people from high-income countries at risk. Parasite resistance to antimalarials, including multidrug resistance, is now at very high levels, and falciparum malaria is nearly universally resistant to chloroquine. This situation has emerged over a period of forty years or so.

The persistence of malaria as a major contributor to the infectious disease burden has led to renewed efforts in prevention and control. Advances in molecular technology have accelerated understanding of malaria as a parasite and a disease, raising hopes for the development of an effective vaccine. It is hoped that new funding structures and bodies, including the Global Fund to Fight HIV/AIDS, Tuberculosis and Malaria, represent increased resources for research and control of this historically under-funded area.

Land clearance can actually reduce malaria transmission by destroying local mosquito habitats, but often other disease-transmitting species may adapt to the changed conditions and become more prominent, setting up new malaria cycles. In Nepal for example, deforestation of the Terai region for agriculture resulted in *Anopheles culicifacies* replacing *Anopheles fluviatilis* as the main vector of malaria. This led to a sharp rise in malaria prevalence (Sharma, 1991). In contrast, replanting forests may facilitate the re-emergence of formerly inhibited species. For instance, cyclic malaria outbreaks in Malaysia were correlated with rubber planting in response to market fluctuations. The vector, *Anopheles maculatus*, was breeding in sunlit streams exposed by replanting (Singh and Tham, 1990). New crops, such as maize in Africa, may also provide an increasing supply of food for malaria vectors, although the consequences for disease transmission are not yet clear (Ye-Ebiyo, 2000).

The process of deforestation can create vast new swathes of open and sometimes eroded land. In specific situations, such areas may act as “motorways”, allowing vector species to migrate to regions they would hitherto have been unable to reach. In Africa and South America, this has increased the distribution of *Anopheles sp*. mosquitoes, allowing malaria to spread to formerly unaffected areas, particularly cities (Coluzzi, 1992). This generally occurs where clean water supplies are available for anophelines to breed in. In urban areas where clean water supplies are not available, notably in India, clean water tanks have served the purpose. In addition, the arrival of many non-immune migrants in new agricultural lands has greatly increased the problem of forest fringe malaria in some areas, as in jungle mining operations in South America and Asia, which have been linked to increased malaria prevalence (Molyneux, 1997).

The effect of deforestation varies according to region. In sub-Saharan Africa, *Plasmodium falciparum* malaria is endemic in both forest and savannah regions and land clearance does not greatly alter the patterns of vector and disease distribution. However, deforestation often intensifies existing transmission of an infection for the reasons mentioned above. In Asia, the epidemiology of malaria differs between forested and open areas. In forests, non-falciparum malaria is generally more prevalent and forest communities have high levels of immunity to the disease. At the forest edge, however, *Plasmodium falciparum* malaria is much more common, and many dwellers are migrants with low levels of immunity. Malaria is therefore most common at the forest interface. Deforestation exacerbates the problem by extending the forest fringe and drawing non-immune migrants to work in its vicinity (Walsh et al., 1993).

5.3.2.2 Chagas disease

Land clearance has helped to spread Chagas disease across much of South America. The triatomine bugs that spread the infection have demonstrated excellent adaptability to man-made conditions. First settling into thatched housing when this appeared in pre-Columbian times, the bugs then exploited the ever-increasing amounts of open land that became available following the arrival of Europeans, and established themselves as widespread domestic vectors in arid and semi-arid regions of the continent. In the last 100 years, deforestation and economic adversity have caused social and ecological impoverishment with much poor quality housing. This has provided the bugs with excellent conditions in which to breed and spread infection. As a result, Chagas disease is now prevalent across a wide geographical range and has established itself in urban settings in South America (Schofield, 1988; Barrett et al., 1979). Human excursion into virgin forests raises the prospect of zoonotic variants of Chagas’ disease spreading to people (Walsh et al., 1993), although the disease is being pushed back in many areas as a result of effective control programmes.

5.3.2.3 Leishmaniasis

Since some forms of leishmaniasis (e.g. cutaneous leishmaniasis in South America) are typically found in forest environments, it might be expected that land clearance would reduce their prevalence. But in fact, reduction in the pathogen’s and vector’s habitat is usually more than compensated for by the increasing number of people living in the newly cleared areas close to the remaining forest. During the 1980s, the population of the Brazilian city of Amazonias nearly doubled in size, and a severe housing shortage followed. People were encouraged to settle in housing estates in newly cleared forest and the incidence of cutaneous leishmaniasis rocketed (Walsh et al., 1993). Zoophilic vectors of leishmaniasis (those spreading the disease between animals) have demonstrated a high degree of adaptability to human blood, and are able to transmit the infection to people, increasing the incidence of leishmaniasis in many developing countries (Molyneux, 1997; Molyneux, 2001; Desjeux, 2001). In French Guyana, reduction in the prevalence of leishmaniasis was achieved by controlling the number of intermediate hosts and their movement between the forest and the settlements (several wild animals act as intermediate hosts for leishmaniasis), and by locating the settlements far enough from the forest edge to be beyond the range of vectors and intermediate hosts straying from the forest (Walsh et al., 1993).

5.3.2.4 Other vector-borne diseases

The prevalence of onchocerciasis should be decreased by deforestation as its vectors favour the forest habitat. This has occurred in East Africa, where transmission by the vector *Simulium neavei* has been reduced, decreasing the prevalence of river blindness (Walsh et al., 1993). However, in West Africa the vectors *Simulium sirbanum* and *Simulium damnosum* have spread southwards following deforestation; this has greatly increased the risk of infection in newly-colonized areas (Walsh et al., 1993; Molyneux, 1997).

Lyme disease, an ancient but previously rare bacterial infection, has returned to prominence in North America, Europe and temperate Asia. This is thought to have followed the reversion of farmland to woodland, which led to expansion of the deer population that carries the tick vector of the bacteria. Crucially, the deer's natural predators were destroyed during clearance of the forests for agriculture over a century ago. In addition, transportation improvements have increased access to the forests (Steere, 1994).

5.3.3 Pharmacological implications of loss of biodiversity

Deforestation is leading to massive destruction of plant life, eliminating many plant species which contain substances that could be developed as future therapeutic agents. Plants are an extremely important source of medicinal compounds. In technologically advanced countries, around 50% of prescription drugs derive from natural compounds; this proportion is far greater in more traditional societies (McMichael, 1993, Grifo, 1998). Many antibiotics, such as streptomycin, neomycin and amphotericin, originate from tropical soil fungi. Other plants produce toxins, which have been used to control agricultural pests and disease vectors (e.g. the blackfly that transmits onchocerciasis) (McMichael, 1998). Thus, decreasing biodiversity is threatening our prospects for developing new drugs, insecticides and herbicides. This is particularly worrying in light of the enormous challenges posed by the global rise in antimicrobial resistance and the emergence of new infectious diseases.

6 GLOBAL DEMOGRAPHIC CHANGE AND INFECTIOUS DISEASE

6.1 Globalization and population mobility

6.1.1 Trends in population mobility

Population mobility is not a new phenomenon - humankind has been on the move since Homo erectus migrated beyond the African continent in one million BC. Since ancient times, there have been relentless movements of people in search of new sources of food, water and security. Mass migrations, both voluntary and forced, have also followed economic hardship, conflict and environmental disasters. Nonetheless, despite this continual migration, large-scale movement of populations across continents is a relatively recent phenomenon. The arrival of Europeans in the Americas in 1492 can be seen, in some ways, to have ushered in a new phase of population mobility. Over the next 500 years, millions of people would come to live and work thousands of miles from their place of birth, including:

- 15 million slaves transported from Africa to the Americas during the eighteenth and nineteenth centuries;
- more than 30 million people moved as indentured workers after the abolition of international trade in slaves in 1850 (Stalker, 2000);
- about 59 million people who migrated from Europe in search of economic opportunities in the Americas, Australia, New Zealand and South Africa between 1849 and 1939.

Global migration is thus part of an ongoing historical process. What has characterized population movement since the middle of the twentieth century is the unprecedented volume, speed, and geographical range of travel (Collin and Lee, 2003). All regions of the world have seen increasing numbers of people on the move, albeit driven by widely varying forces. Population movement can occur for a variety of reasons and over several timescales ranging from the daily commute to permanent migration. International migration, or the movement of people between countries, now accounts for approximately 130 million people (2% of the world's population) per year. By 2000, up to 185 million people were living outside their country of birth, compared with 75 million in 1965 (UNFPA, 2003). At least half of these migrants were living in low-income countries.[13] Furthermore, internal migration (movement within a single country) occurs at even greater magnitude. In the mid 1980s, one billion people, or about one sixth of the world's population, moved within their own countries.[14]

6.1.2 The causes of population mobility

The extensive research[15] on population mobility (both short and long-term) suggests that people often move in search of a better life and employment prospects, or to escape an insecure situation. Therefore, disparities in income and employment opportunities, along with political instability and conflict, and environmental degradation, can be key reasons why people leave home (UNFPA, 2003). For the relatively

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[13] The number may be much higher as few of these countries are able to provide reliable migration data (see: UNFPA, 1999, http://pstalker.com/migration/index.htm# - accessed 24/09/02).

[14] Distinguishing between international and internal migration may be misleading as the latter often occurs across great distances where cultural and territorial differences are as important as those between countries. Many scholars now argue that international and internal migration are part of the same process and should be analysed jointly (Castles, 2000; Skeldon, 1997).

[15] For example, see: Boyle P et al. *Exploring contemporary migration*. Harlow, Essex, Longman, 1998; Castles S and Miller MJ. *The age of migration: international population movements in the modern world*. London, MacMillan, 1998; Skeldon R. *Migration and development: a global perspective*. Harlow, Essex, Longman, 1997.

affluent, travel per se has been a source of pleasure for centuries. Globalization is contributing to these trends in several ways.

Macroeconomic policies adopted to integrate countries into the global economy, such as structural adjustment programmes (SAPs), can lead to economic instability and insecurity, especially for the low-skilled and poor. Similarly, increased trade in cash crops can threaten the livelihoods of rural communities through the loss of arable land (UNFPA), encouraging populations to relocate to urban and peri-urban areas. National and regional differences in wage levels can lead to movement of workers within and across countries. For example, in 1997 an Indonesian worker was paid US$ 0.28/day compared to US$ 2.00 or more per day in neighbouring Malaysia. Similarly, greater "knowledge equivalence" (increasing uniformity of expertise) worldwide means that demand for skilled workers in high-income countries can be satisfied by recruiting educated migrants from other high-income countries or, increasingly, from poorer countries. The latter has led to concerns over the "brain drain" from low and middle-income countries to high-income countries as gaps in their labour markets, including for health workers, are filled. In many cases, these movements are undocumented. The International Labour Organization (ILO) estimates that around 130 million people were migrant workers in 2000, with an additional 10-15 million people working as undocumented migrants. Overall, economic growth as a consequence of globalization processes has variable impacts on the economic status of different population groups. As Stalker writes, "In a world of winners and losers, the losers do not simply disappear, they seek somewhere else to go" (Stalker, 2000). Similarly, the "winners" may migrate elsewhere too, seeking improved life chances but draining local communities of much needed human capacity.

Short-term movement of people for leisure purposes has also grown rapidly since the late twentieth century, with visits becoming more frequent and farther afield. According to the World Tourism Organization (2002), the global total of international arrivals worldwide reached 699 million in 2000, representing an annual increase of 7.9%. Among these, more people are taking transcontinental journeys, with the number of long-haul travellers expected to reach 377 million by 2020.

In short, an integral feature of current forms of globalization is enhancement of population mobility. Advances in global communication and transport systems have made people more aware of the world and the means of travel, and they are travelling farther and more frequently. Migration to new lands has become easier, less permanent, and "less daunting and traumatic" (Stalker, 2000).

6.1.3 Population mobility and infectious disease

Population mobility produces many kinds of health impact, which affect the migrant and/or host populations positively or negatively. Historically, the most direct impact has been the spread of infectious disease. Human migration has been a source of epidemics throughout history, and several of these have influenced the outcome of war or changed whole societies (Wilson, 1995b). Indeed, efforts in international health cooperation during the nineteenth century were focused on preventing infections spreading from one country to another (Gushulak, 2000).

There are several reasons why population mobility and the incidence and spread of infections are closely linked. First, the conditions which lead people to migrate are akin to those which favour the emergence of new infections and the breakdown of structures and systems to control well understood infections. Poverty, overcrowding, repression and economic failure, for example, not only encourage people to move but often lead to breakdown of public health infrastructure, and of provision of housing, safe and sufficient drinking water, sanitation, and education. Second, the process of migration can present significant psychological, socioeconomic and even physical challenges. In particular, mass migration itself increases the risk of infection if displaced people or refugees are malnourished, have inadequate water and sanitation, and are overcrowded. In some cases, this leads to unregulated and inappropriate use of antibiotics, which can contribute to the emergence and spread of drug-resistant organisms (Minas, 2001). On arrival also, migrants can be more susceptible to a range of infectious diseases, such as those associated with poor housing (tuberculosis and respiratory infections). Third, migration brings people into contact with new microbes and vectors, as well as new gene pools, immunological make-ups, cultural preferences, behavioural patterns and technologies, all of which influence the risk of infection.

The link between infectious diseases and population mobility must thus be understood in relation to the different forms, conditions and patterns of migration, which have very different influences on the distribution and spread of infectious diseases. This is illustrated below by contrasting mass movements of refugees and displaced persons with planned and longer-term migration. Infections associated with the growth in short-term travel, either for business or pleasure, will be considered in the context of changes in transportation technology.

6.2 Refugees and displaced persons

Interstate war, internal conflicts, political and economic instability and natural disasters can lead to mass migration of people. The Black Death was probably introduced to Europe through war with armies in Asia Minor; it then spread rapidly across the continent along the trade routes. The last 50 years has seen huge increases in the number of refugees and internally displaced persons (forced to leave their homes and seek refuge in another part of their home country). Although it is difficult to demonstrate a direct link with the processes of globalization, worldwide economic, political and environmental change can contribute indirectly to the conditions leading to conflict and how they are resolved. Most notable is the geopolitical realignment of many countries (e.g. Yugoslavia) following the end of the Cold War, in some cases, resulting in the resurfacing of historical internecine tensions.

Since refugees, by definition, must move quickly to escape an insecure situation, they often must live in ad hoc interim accommodation. Most of the world's 6.9 million displaced people and refugees reside in refugee camps or temporary shelters in low-income countries. In these often overcrowded environments, where provision of sanitation, clean water, food and health care is typically inadequate, where barriers to vectors and animals carrying infectious diseases are usually absent or insufficient, and where person-to-person contact is amplified, epidemic infections are common, and often devastating. For example, after almost one million people fled from Rwanda to Zaire in 1994, around 50 000 died within a month due to epidemics of cholera and dysentery which broke out in the refugee camps (Centre for Disease Control and Prevention, 1995b). Many other contagious bacterial infections such as TB, respiratory infections, meningitis and skin infections, as well as intestinal helminth infections, are common in refugee camps. Conditions also favour the outbreak of vector-borne diseases, since refugees often travel from their homes in non-endemic regions and may not be immune to the local pathogens. As well, in squalid conditions, people are unable to protect themselves from disease vectors. Malaria epidemics in refugee camps are well documented, for instance, in Afghanistan and Pakistan (Molyneux, 1997). The course of infection in a 1997 outbreak of anthroponotic cutaneous leishmaniasis (ACL) in an Afghan refugee settlement in northwestern Pakistan, in which over one-third of the inhabitants developed active lesions (Rowland et al., 1999), was thought to be infected migrant carriers from Kabul. Louse-borne infections, such as epidemic typhus and relapsing fever, are classically associated with refugee camps and cause high mortality (Center for Disease Control and Prevention, 1994a). In addition, when large numbers of people live in close proximity, rapid mixing of different strains of bacterial or viral DNA is facilitated, which may encourage the emergence of new infections or multidrug resistant pathogens.

6.3 Long-term migration

In contrast to movement which follows unexpected events, more permanent migration can lead to contact between populations from geographically or environmentally remote regions. Since human populations often show different degrees of susceptibility to specific infectious agents, this form of migration can accelerate and amplify the spread of infections to new communities and areas. Variation in susceptibility to infections results from differences in the regional prevalence of particular diseases as well as from differences in genetic diversity of the human populations. Populations with a less heterogeneous genetic mix are usually more susceptible to new infections. In a well-known historical example, up to half the indigenous population of the Americas died from epidemics of influenza and smallpox within a few decades of contact with Europeans following Columbus' arrival in the Americas in 1492 (McNeill, 1976). Isolation had left these populations susceptible to new infections as they had evolved from relatively small gene pools. In modern times, the re-emergence of TB in urban areas of many high-income countries has been attributed to migrant populations from South Asia who, upon arrival, face living conditions that enable the infection to spread (Gushulak, 2000). It is important also to better understand the long-term impact of migration of parasite genes, notably drug resistance, which may prove more important than the movement of pathogens per se.

6.3.1 Migration to or within low-income countries

The health impacts of migration to and within low-income countries have been given limited attention. Yet considerable evidence suggests that the consequences are at least as severe as, and probably worse than, those of migration to high-income countries due to the weaker health infrastructure and social conditions. There is greater risk of experiencing serious epidemics caused by isolated cases of imported disease, and outbreaks can be amplified at places where large numbers of people gather, such as at markets and social events. Migrating populations may also fall victim to severe epidemics if travelling brings them into contact with new infections. Another risk factor is temporary migration of people from non-endemic to endemic regions; the migrants can then import diseases to a non-immune population on their return home. For example, migrants returning from a food distribution centre, established in an area with endemic visceral leishmaniasis, to their homes in a non-endemic zone of southern Sudan led to a severe outbreak of anthroponotic visceral leishmaniasis (AVL), with around 100 000 deaths in a population of less than one million (Seaman et al., 1992, 1996). The community's resistance to infection was further weakened by malnutrition. Similarly, migration was a major factor behind other recent outbreaks of visceral and cutaneous leishmaniasis (Desjeux, 2001). In Brazil, cases of zoonotic visceral leishmaniasis (ZVL) almost doubled between 1998-99 following mass migration within the north-eastern provinces (Desjeux, 2001), while in East Africa, migration increased the spread of AVL.

In low-income countries, economic migration has played a crucial in the evolution of the HIV/AIDS epidemic. Research shows that internal and cross-border migrants, particularly male migrant workers, are at greater risk of HIV infection, and are more likely to spread the infection upon their return home. The basic living and working conditions of migrant workers have been accompanied by changes in sexual behaviour that heighten their risk of contracting sexually transmitted diseases (STDs). This is then often compounded by poor access to health care and preventative services (Minas, 2001). The migrant labour system in apartheid South Africa, for example, permitted miners to travel and work in urban areas but denied this right to their families. A flourishing market for commercial sex workers emerged, facilitating the spread of HIV/AIDS and other STDs to rural areas. Other research has highlighted the association between mobile armed forces, including peacekeeping forces, and the spread of HIV/AIDS (Minas, 2001).

Large-scale projects designed to stimulate economic growth, but with ecological consequences, are another common cause of migration in low-income countries. For instance, extensive migration often accompanies water resources projects as people are drawn to the economic opportunities created during construction and operation of the new development. In the early phases, much of this is temporary migration and involves single males. Apart from occupational hazards, these workers risk infections associated with crowding, poverty and sexual behaviour. Consequently, TB, gastroenteritis and STDs are common infections. Later, vector-borne diseases become more prominent as people move from non-endemic to endemic areas. People may be susceptible to parasitic diseases (e.g. malaria) that flourish at water project sites in tropical climates (Hunter et al., 1993); famously, construction of the Panama Canal was delayed for decades as a result of malaria, which decimated successive teams of engineers and labourers. Large lakes can also provide migratory routes for people, some of whom may spread infections from endemic to previously unaffected areas. In Ghana, the movement of people across Lake Volta led to the first cases of trypanosomiasis in southern parts of the country (Hunter et al., 1993); similar problems have followed deforestation and other land clearance projects (see above). In addition, the economically-driven movement of domestic animals can spread vectors and pathogens. In Australia, this has extended the range of tick species that act as vectors of a variety of pathogens (Petney, 2001).

6.3.2 Migration to developed countries

More research has been carried out on the impact of population mobility on infectious diseases in high-income countries than in low-income countries, although the literature is narrowly framed. Epidemics are less common in developed countries because public health infrastructure is more able to prevent, detect and treat imported diseases. In these settings, migration is more important in facilitating the spread of "non-classical" infectious diseases, of which there are two main categories (Gushulak, 2000). First are certain chronic infections which are more prevalent in immigrant communities and which may present after an immigrant has settled into the host country. The danger is that the individual may unknowingly spread the infection to others; this is particularly worrying if the index case is resistant to conventional antibiotic treatment, as in multidrug-resistant TB. The increasing prevalence of this disease in many high-income countries over the past decade has occurred largely as a result of immigration; other examples are hepatitis B and C and *Helicobacter pylori* infection. Diseases such as African trypanosomiasis and Chagas disease cannot be transmitted further without their vector or intermediate host and may simply present some time after entry, sometimes posing diagnostic difficulties to a health service with little experience of the infection. Some chronic infections may produce significant burdens on health care services in the country of destination if associated with serious long-term sequelae (e.g. schistosomiasis leading to chronic renal failure).

A second type of problem occurs when an infection, formerly eradicated or rendered unimportant in the host country following vaccination or other health prevention programme, is re-introduced by immigrants from regions where it remains endemic or highly prevalent. Levels of immunity in the host community are often low or absent, leaving its members susceptible to new and virulent diseases. These problems are often exacerbated by lack of awareness and expertise on the part of the local health practitioners in diagnosing and treating such infections. It may be difficult to persuade people to accept vaccination programmes for diseases thought to be extinct or rare. Examples of infections which have the potential to cause epidemics if reintroduced into areas where the population's level of immunity is low include measles and diphtheria.

6.4 Urbanization

6.4.1 The growth in urban populations and the influence of globalization

Over the last 200 years, the proportion of the world's population living in large towns or cities has grown from around 5% to 50%. If current trends in migration and population growth continue, urban areas will be home to two-thirds of the world's people (around 7 billion) by 2030. Since 1945, the greatest growth has been in the developing world where a number of "megacities" have emerged (more than 10 million inhabitants). The populations of Mumbai, Mexico City and Sao Paolo are now each approaching twenty million. Urban population growth is a function of both rural emigration and the expansion of existing city populations, the relative importance of which varies by region. In Latin America, metropolitan growth has largely reflected increased migration as a consequence of industrialization and the search for economic opportunities. In sub-Saharan Africa, currently the least urbanized region of the world yet the region undergoing the most rapid transition, urbanization has followed rural impoverishment (McMichael, 2000).

Globalization has substantially influenced the pace and nature of urbanization in the developing world. In many regions, the pace of change has meant that urban growth has frequently been unplanned and poorly managed. Trade liberalization and SAPs have forced many countries to focus on exporting agricultural commodities, in the process of which many small landholdings have been amalgamated to create economies of scale or become mechanized, displacing subsistence farmers and farm workers. While rural employment has become more unstable in some countries, urban employment opportunities have emerged, for instance, in the growing tourism industry or in the production of manufactured goods that rely on cheap labour. Although these processes of change are not dissimilar to the trends in urbanization experienced in Europe during the Industrial Revolution, the more rapid pace and scale of transition being experienced in much of the developing world today is exceeding the capacity of many governments to effectively plan and manage it.

6.4.2 Urbanization and infectious disease

Urbanization can affect infectious diseases positively or negatively. Compared to rural areas, health care, education and social services are in general more accessible in cities, and unemployment tends to be lower. In the developing world, average urban population health frequently contrasts favourably with that seen in rural communities; rates of common childhood infections are often considerably lower in urban compared to rural populations (Sastry, 1997). However, average indicators tend to mask the huge health inequalities found in urban populations, and rates of infectious and other diseases are higher among the urban than the rural poor. It is this deprived metropolitan population which is expanding enormously on account of the massive and unregulated urbanization taking place in many developing countries.

Rapid and unplanned population growth places huge strains on a city's infrastructure. Often designed to protect the public health of a small urban elite, this infrastructure is difficult to expand to meet the needs of a much larger population, especially those living in shanty towns and slums at urban peripheries. In many developing countries, the technical difficulties are compounded by lack of political will (Chaplin, 1999) and available resources. The latter may have been accentuated by structural adjustment programmes, whereby urban workers often lose out more than rural smallholders (Loewenson, 2000).

Overcrowding, poor housing, inadequate sanitation and solid waste removal, and unsafe drinking water are, therefore, common in rapidly urbanizing areas. Estimates suggest that 50% of the world's urban population lives at the level of "extreme deprivation", and 70% in some cities (Stephens, 1995). At least one quarter of people living in urban areas in developing countries do not have access to adequate safe water, and 30-50% of solid wastes generated in developing world urban centres are left uncollected (WHO/UNICEF, 2000). Air pollution in Delhi exceeds anything found in the cities of the developed world (World Resources Institute, 1999). Socioeconomic inequalities are rife; in poorer countries, urban health care services are typically grossly over-stretched, and their provision may be distorted to cater for the needs of the rich urban elite. While rural migrants may bring new infectious diseases to the city, they are themselves at higher risk of developing infections to which they have not previously been exposed. And as metropolitan areas mushroom and encroach on new biological environments, they increase the chances of the inhabitants becoming exposed to non-urban infections. Compared to rural societies, urban life is associated with greater mobility, inter-mixing and risk-taking behaviour, all of which increase the potential for transmission of infectious diseases, while urban areas both contribute, and are especially vulnerable, to the effects of global climate change. In summary, residents of urban environments face multiple threats from new and established diseases, and may themselves be the creators and amplifiers of epidemics that, in time, could affect non-urban populations.

6.4.2.1 The urban physical environment

The poor and unhygienic conditions prevailing in many cities of the developing world are ideally suited to the transmission of infections through the air, human waste or insect vectors. This is because many of the bacteria and viruses responsible for so-called "crowd infections" would be unable to establish sustained outbreaks of disease without a sufficient density of non-immune people (McMichael, 1993). Thus, cities have historically been great concentrators of infections. Much more needs to be understood about whether globalization is accelerating the trends towards urbanization and thus increasing the transmission of diseases. For example, outbreaks of respiratory, gastrointestinal, meningeal and skin infections are common in urban settings. Rates of certain epidemic infections, such as acute diarrhoea (the second biggest killer of children under five years old worldwide) are very high in urban communities where there is lack of sufficient housing, sanitation and clean water (Harpham and Stephens, 1991). In most urban settlements of the developing world, where children comprise a high proportion of the population, the impact of infections is particularly heavy. Other, less obviously hazardous features of the urban environment may also contribute to the spread of infections. For instance, distribution of sewage-contaminated vegetables from urban gardens led to the dissemination of cystercercosis in Mexico City (Vasquez Tsuji et al., 1996). Overcrowding, high levels of air pollution and, in particular, malnutrition, can increase city dwellers' susceptibility to respiratory infections; consequently, TB and other chronic respiratory diseases can be highly prevalent. Finally, within many cities there are huge variations between the deprived and the privileged populations in mortality from infection (Akerman et al., 1994; Stephens, 1995). The key question to be addressed is the extent to which all of these conditions are being enhanced by globalization.

Similarly, urbanization impacts on vector-borne diseases. The expansion of urban areas can actually reduce the prevalence of parasitic infections by destroying the breeding grounds of some vectors (e.g. mosquitoes for malaria). However, it can also increase disease by creating new opportunities for vectors and hosts to flourish. For instance, non-biodegradable plastic containers in which rainwater collects have provided urban breeding sites for *Aedes aegypti* mosquitoes which, in turn, spread dengue fever (Barrera, 1995). *Aedes albopictus* is thought to have reached cities through the importation of used car tyres; mosquito eggs deposited in these tyres at source have been transported to areas previously unaffected by dengue (see Box 9) (Gubler, 1998a). These developments have contributed to a major expansion in urban dengue over the last forty years (Gibbons, 2002). Urban areas may also encroach on rural environments where insect or arthropod vectors thrive, facilitating the exposure of increasing numbers of urban inhabitants to, for example, malaria, filariasis, dengue (see Box 11) and schistosomiasis in parts of South America and Africa. Other infections have similarly spread from rural to urban areas. For example, *Anopheles* and *Culex* mosquitoes, and *Bulinus* snails, are believed to be responsible for urban endemic foci of malaria, filariasis and schistosomiasis respectively in several tropical and subtropical regions (Phillips, 1993), although more research is needed to confirm this. *Culex* mosquitoes have long been partial to organically polluted waters and have thus thrived in urban areas where stagnant pools are available for breeding, but whether the changes in available breeding sites have occurred as a consequence of globalization processes needs more study. In Pará State, Brazil, rapid urbanization, deprivation, and poor housing provided new habitats for the vector *Lutzomyia longipalpis*. These vectors infected dogs that, in turn, created a new reservoir of zoonotic visceral leishmaniasis, which now constitutes the main source of infection for humans (Mott, 1990).

Cities are major contributors to global environmental change at a macro level, due to the annexation of non-urban habitats, production of industrial waste, and individual activities of their vast numbers of inhabitants. These transformations have implications for the impact of infectious diseases, as previously described. Global warming, for instance, may be contributing to the recent appearance of certain infectious diseases in urban areas where they did not previously exist. In addition, since most urban settlements are located within 75 miles of the sea, city dwellers are especially vulnerable to the effects of extreme weather events, such as hurricanes and floods (Wilson, 1995b). These catastrophes may overwhelm or damage basic urban public health infrastructures, leading to epidemics of waterborne infections e.g. cholera and typhoid.

Box 11: Dengue

Dengue fever is caused by several flaviviruses and is responsible for an estimated 50-100 million episodes of illness annually, including 24 000 deaths from dengue haemorrhagic fever. In the past 60 years, the incidence, distribution and clinical severity of dengue has increased dramatically. In South-East Asia, for instance, cases have increased almost 20-fold since the 1950s. Currently, more than two-fifths of the world's population lives in areas potentially at risk from dengue. As well as population growth, other, more subtle, forces have played a role in this increase. Uncontrolled urbanization has led to inadequate management of water and waste, providing a range of large water stores and disposable, non-biodegradable containers that become habitats for the larvae of the mosquito vectors. Similarly, trade in car tyres has facilitated the spread of mosquito vectors to new regions. Air travel has allowed humans to import new serotypes of the virus; the exposure of humans to multiple serotypes is thought to cause the more severe immune reactions that characterize dengue haemorrhagic fever. Tourism places residents of non-endemic countries at risk; in some studies, up to 8% of travellers returning with febrile illnesses were found to have dengue. Man-made environmental changes, such as the construction of new dams, may cause increases in incidence, and global warming is also a potential threat. Despite advances in biotechnology, there is still no dengue animal model, and a vaccine may yet be many years away.

6.4.2.2 The urban social environment

Rapid and large-scale urbanization increases susceptibility to infection through changes in the social environment. Traditional, often rural based, cultural restraints can be challenged, leading to greater risk-taking behaviours in the urban environment. This is exacerbated by the greater human contact such an environment affords. In many cities, the growing intensity and diversity of sexual activity and use of illicit drugs has escalated the incidence of STDs. Increasing human travel to and from urban settings also facilitates the spread of disease. In combination, these factors may have played an important role in the rapid and extensive spread of HIV/AIDS during the 1980s and 1990s (Minas, 2001).

With the erosion of traditional family structures, single women now head many households in urban parts of the developing world. These women are often forced to work long hours in low-paying jobs to support their families. However, if young children are left unsupervised, they are more liable to behave in ways that increase their chances of developing infections – by drinking water from unsafe sources or playing in unclean surroundings for example. This is not to suggest that rural life is without risk from such infections. In fact, traditional rural practices may readily contribute to the spread of infections.

6.4.2.3 Rural-urban migration

Migration of rural people can add to the urban burden of infectious disease in several ways. Firstly, if rural migrants travel from non-endemic areas they will be susceptible to infections that are endemic in the destination city. For example, rural migrants are reported to be at high risk of acute urban schistosomiasis in Cairo and Belo Horizonte, and of urban cutaneous leishmaniasis in Afghan cities such as Kabul (Mott, 1990), although more recent evidence is needed to confirm these trends. Secondly, urban inhabitants may be at risk from new infections brought in by rural immigrants. For vector-borne infections, the exact impact depends on whether:

- migrants themselves are infected by the pathogen in question;
- the city is endemic for the disease (i.e. whether or not urban dwellers are likely to be immune);

- migrants carry the vector(s) or intermediate host(s) of the disease.

In the least complex scenario, a non-infected rural migrant may bring the infected vector or intermediate host of an infection into a non-endemic city. This vector can then contaminate the urban environment, leading to infections among city inhabitants. Fishermen's buckets, for example, serve as effective transport media for snails. Outbreaks of Chagas disease, filariasis and schistosomiasis are all thought to have followed entry of their respective insect vector or intermediate host into metropolitan areas. It is also possible that new species of parasite could be introduced into urban areas if suitable vectors for their transmission are already present. New species of *Schistosoma*, *Leishmania*, and filarial worms, and new zymodemes of *T. cruzi* have been described in urban areas (Mott 1990). However, transmission of these parasites can only be sustained if the urban environment supports survival and multiplication of their vectors, facilitating continued spread between humans. A more complex scenario is presented by an infected rural migrant who enters a non-endemic urban area without vectors. Here there is little chance of the disease being transmitted through conventional transmission mechanisms, but there is a risk that the infection could spread through donation of contaminated blood, and staff at blood banks in urban areas need to be aware of this possibility. In some parts of South America for example, over 50% of blood transfusion products are serologically positive for Chagas disease (Shumunis, 1985). Again, all of the linkages need to be explored in greater detail in relation to globalization processes. To the extent that globalization is accelerating rural-urban migration, there is a need to address the conditions under which such migration takes place in order to reduce the risk for disease.

A yet more complex scenario arises when an infected rural migrant, or a rural migrant bringing an infected vector, moves into a non-endemic urban area. In either case, transmission of a disease can be initiated or increased. This has led to the creation of peri-urban endemic foci of schistosomiasis in cities such as Dar es Salaam, Harare and Sao Paulo. It has also facilitated transmission of Chagas disease in the shanty towns of cities in Latin America, and probably contributed to the appearance of malaria and dengue fever in several African, Asian and South American cities (Mott, 1990).

7 GLOBAL TECHNOLOGICAL CHANGE AND INFECTIOUS DISEASE

During the past 100 years, enormous advances in technology have revolutionized most aspects of human activity, including commerce, communications, travel, engineering and health care. These developments have been both the products and the crucial driving forces of globalization (Scholte, 2000). Like other historical transformations, the modern technological revolution offers huge possibilities for improving as well as harming human health. This section considers the impact of three technologies crucial to the process of globalization: information and communication, transportation, and medical technologies.

7.1 Information and communication technologies

Technological change since the last quarter of the twentieth century has been dominated by unprecedented advances in information and communication technologies (ICTs). ICTs have fundamentally altered the speed and nature of communications in personal and professional settings, transforming societies and economies. They are increasingly recognized as a pre-requisite for economic and social development, and optimists claim that their arrival heralds widespread economic, financial, educational and health benefits for poorer countries.

There are several ways in which ICTs can reduce disease and the threat of infections in particular. First, with the improvements in satellite and media technology, news about natural disasters and other catastrophic events that threaten health on a grand scale now travels quicker and with greater immediacy across the globe than before. This means that international and domestic responses to these events can ideally be organized more rapidly and perhaps more appropriately than in the past.

Second, the Internet is an invaluable means of providing access to continuing medical education and lifelong learning far from well-funded centres of excellence. Information about current best clinical practice, for instance, can be made available to professionals working in remote areas, and some medical websites offer training packages or information about existing services and support groups. The provision of such information benefits both professionals and consumers (Cooke and Holmes, 2001; Williamson and Mayberry, 2001). Thus, expert advice on how to treat a case of multidrug resistant TB will help the patient and the professional responsible, and will have a wider beneficial impact on public health.

Third, advances in communications along with medical technologies have raised hopes that they may be used to deliver a variety of previously unavailable services to poor and remote locations. This is exemplified by the growth of "telemedicine", whereby emergency clinical advice and specialized consultations are provided from a geographically remote site (Fraser and McGrath, 2000). There is growing enthusiasm for its use as a means of tackling geographical health inequalities, and a number of encouraging pilot projects are up and running. Nevertheless, there are real challenges in sustaining these services in regions where health expenditure per capita is severely limited (Wright, 1999; Sharma, 2000).

Fourth, the growing sophistication and availability of geographical information systems is helping to improve measures to control outbreaks of infectious diseases in many countries (Aron and Patz, 2001). A geographical information system (GIS) is a combination of hardware and software used to store, edit, analyse and display geographically or spatially referenced data. When these data provide relevant information about individual cases of infectious disease, GIS can provide a tool to investigate and control outbreaks. GIS programmes are already contributing to the management and control of many vector-borne diseases where local capacity is appropriately developed, such as schistosomiasis in China

(Xiaonong et al., 2002), and guinea worm, onchocerciasis, lymphatic filariasis, malaria and sleeping sickness in Africa (Molyneux, 2001). GIS programmes are an essential tool for forecasting epidemics which follow ENSO events (Kovats, 2000). In addition, information and communication technologies are being implemented in some countries to coordinate and improve responses to epidemics and other health threats developing in emergency situations, for instance in the Maharashtra Emergency Earthquake Rehabilitation project in India (Chandrasekhar and Ghosh, 2001).

The use of ICTs in developing countries is limited by affordability, access, and education. Despite the decline in costs following the dramatic increases in memory and processing technology,[16] ICTs remain unaffordable in many parts of the world. Indeed, it is increasingly acknowledged that the "digital divide" between information-rich and poor countries is actually widening (Castells, 2000; Edejer, 2000). This is evidenced by the huge variations seen in internet access between and within countries (Brodie et al., 2000).[17] The need for highly trained personnel to make use of such technologies is critical, and the UN Secretary General, Kofi Annan (2001), has repeatedly expressed concern about "the growing gap between information haves and have nots", announcing the creation of a taskforce, the UN Information Technology Service (UNITeS), to provide access to medical information.

The Warana project in India starkly illustrates the problems of extending the use of ICTs to medical settings in low-income countries. Through this project, 70 villages were computerized and connected to the internet at a cost of about US$ 600 000. Estimates suggest that replicating this across the remaining 550 000 villages in the country would consume around 12.5% of India's GDP (Bhatnagar and Schaware, 2000). Thus, an overemphasis on ICT projects could divert resources from basic public health activities such as provision of clean water, sanitation, primary education and basic health care. Indeed, Chandrasekhar and Ghosh (2001) argue that only ICT projects demonstrating favourable cost-benefit ratios should be funded.

7.2 Transportation technologies

7.2.1 The growth in short-term travel

Advances in transportation technology, in particular the advent of fast trains and jet aircraft, have played a crucial role in facilitating dramatic increases in population mobility during the last 50 years. People can now move across national borders and continents with much greater speed and economy than in the past. Section 6.1 discusses the links between infectious diseases and travel for long-term purposes, which is often driven by people's need to escape economic or political hardship. This section considers the impact of short-term travel, for tourism or work purposes, as well as for the transportation of traded goods and services.

Significantly, the increase in short-term travel is not simply a function of greater efficiency of planes, trains and automobiles, but also of increase in personal wealth, allowing ever greater numbers of people to travel abroad. This affordability, combined with greater curiosity about the world, has led to an explosion in international tourism. In 2001, there were almost 700 million international tourist arrivals. By 2010, tourism is expected to be the world's largest industry and its success is seen as vital to the future economic prospects of many low-income countries (World Tourism Organization). Instead of single, longer trips, there is a growing tendency for people to make several, shorter trips to multiple destinations. More and more of these journeys extend to tropical regions and sometimes to relatively unexplored destinations (Clift and Page, 1996). Increasing numbers of travellers are at the extremes of age,

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[16] The cost of a megabyte of storage fell from US$ 5257 in 1970 to US$ 0.17 in 1999.

[17] In 2000, 3% of the world's population, mainly concentrated in the US (40%) and European Union (25%), had internet access (Castells, 2000). In low-income countries, connections remain very limited and few have satellite linkages. In 1999, the number of fixed telephone lines connected to the worldwide web was 22 per thousand in India compared to 125 in the US (Chandrasekhar and Ghosh, 2001).

or have serious chronic illnesses and complex treatment regimes, posing new challenges to health professionals in the home and destination countries (Habib and Behrens, 2000). Business travel has increased in parallel with the growth in international tourism, and globalization of financial services, trade and industry, as exemplified by the rise of multinationals, has made international mobility of personnel vital.

Along with other aspects of globalization, improvements in transportation have facilitated huge increases in the speed and volume of cargo moved across the world each day. Airfreight was originally regarded as a by-product of passenger transportation, its capacity dependent on passenger traffic. But over the last three decades, as all-cargo aeroplanes have become commonplace, airfreight has formed an increasingly important part of international trade (Pedersen, 2000). Indeed, the rapid growth of trade in flowers and food from Africa and Asia to Europe and North America has been organized largely through air transport.

7.2.2 Short-term travel and infectious diseases

Ill-health can occur during or after a journey, and can affect the traveller or the population of the host or destination countries. Most people who die while abroad do so from injuries and accidents, not infections. However, of all travel-related illnesses, infections perhaps pose the greatest threat to global health since they can be rapidly spread to large numbers of people living in widely dispersed areas and communities across the world. It is well recognized that human and cargo traffic facilitates the movement of pathogens across the world (Aron and Patz, 2001) and, since most infectious diseases have an incubation period exceeding 36 hours, and any part of the world can now be reached within this timeframe, the potential for rapid geographical spread is apparent. Much research has investigated the health implications of international travel for residents of high-income countries. In contrast, the impact of travel on developing countries is under-researched and warrants further attention.

Travellers are exposed to a variety of pathogens at holiday or business destinations; these may include infections they have not previously encountered and therefore are not immune to. Classic examples are gastroenteritis due to *Giardia*, cholera or dysentery; hepatitis A and B; malaria; yellow fever; and many vector-borne parasitic diseases. Migrants who travel on holiday to their country of birth are especially at risk of endemic vector-borne diseases, particularly malaria, since they may erroneously believe that their previous residence in the country confers them with immunity despite many years of absence. Fifty per cent of all cases of malaria in the UK between 1987 and 1992 occurred in UK immigrants of a decade or more who had travelled back to their country of origin (Habib and Behrens, 2000). Travellers are more likely to indulge in risky sexual behaviour, and they have a higher than average chance of contracting STDs, including HIV/AIDS (Clift and Carter, 2000). Of particular concern is the growth of sex tourism, which has major implications for both resident and visiting populations. Means of transport can themselves facilitate the spread of contagious infections: epidemics of tuberculosis, influenza and cholera have been disseminated on commercial aeroplane flights, and cruise ships have been associated with outbreaks of Legionella pneumonia (Centers for Disease Control and Prevention, 1994b and 1995a; Wilson, 1995b).

The number of travellers affected by infections is increasing and, as overseas trips become shorter, the infections are increasingly declaring themselves after the traveller has returned home. In 1996, 10 000 cases of malaria were reported in the European Union, all of which were imported from abroad (Heymann and Rodier, 1998). Fatal cases of yellow fever have been reported in returning Swiss and American tourists who had travelled to endemic countries without receiving vaccination (Gubler, 1998a). Cases of schistosomiasis associated with travelling are also on the increase. In addition, tourists and other travellers may return to spread new infections to residents of their home country. Although cases of rare and exotic diseases, such as viral haemorrhagic fevers (e.g. Ebola, yellow and Lassa fevers), are the subject of enormous media interest, outbreaks of gastrointestinal or respiratory diseases, such as hepatitis A or *Cryptosporidium*, are far more common (Gubler, 1998b). In Europe and North America, several studies have shown that TB may infect communities which have had some contact with an infected traveller; young adults from ethnic minorities who have spent time visiting relatives in endemic areas are particularly at risk (Behrens and Grabowski, 1995). People may return from overseas carrying pathogens that are particularly virulent or unusually resistant to antibiotics. In the UK, for example, a multidrug resistant strain of *Klebsiella pneumoniae* appears to have been transferred, by an asymptomatic woman, from a hospital in Bahrain to Oxford, where it caused outbreaks in two British hospitals (Cookson et al., 1995). There is a similar risk that resistant strains may be spread to developing countries by travellers from wealthy regions, perhaps even before the relevant antibiotic has been introduced in the destination country. This may lead to epidemics of difficult and expensive to treat infections, such as MDR-TB or methicillin-resistant *Staphylococcus aureus*, which could be devastating where health care facilities are inadequate (Ayliffe, 1997).

Some infections are associated with specific types of travel. For instance, outbreaks of meningitis have repeatedly struck pilgrims to the holy places of Islam during the annual pilgrimage known as the Haj (see Box 12). This extraordinary mixing of people from all over the world, over two million in 2001,

Box 12: Infectious disease and the Haj

The annual Muslim pilgrimage to Mecca, known as the Haj, represents the greatest example of people coming together at regular intervals in the world today. The scale of this event has increased dramatically over the last 50 years. On average, every decade since 1949 has seen a 100% increase in the number of pilgrims and, by 2001, close to two million people were visiting Mecca each season. The proportion of pilgrims arriving from abroad has also grown substantially; in 2001, over 75% were foreign. These increases are a consequence of many factors including the development and expansion of facilities at the holy site, greater wealth among travellers, and increasing ease of travel (around 88% of international pilgrims now arrive by air). Three aspects of the Haj are relevant to the global spread of infectious diseases. First, the huge influx of pilgrims brings great numbers of potentially infectious and susceptible individuals into close contact with each other. Second, the arrival of travellers from widely dispersed communities expedites the mixing of many different pathogens; each Haj season, Saudi Arabia hosts pilgrims from more than 140 countries. Third, air travel facilitates the rapid dissemination of newly acquired infections around the world.

The best described health consequences of the Haj are the regular epidemics of meningococcal disease which occur during and after the event. Cases linked to the pilgrimage have been reported in most parts of the world, and have led to secondary epidemics continuing for up to two years in the destination country. Universal availability of conjugated quadrivalent meningococcal vaccine, which should be achieved in the near future, is expected to significantly reduce the threat of these outbreaks. However, there are other infectious hazards. The close contact among pilgrims facilitates the spread of aerosolized and airborne infections. Acute respiratory tract infection is very common, especially when the Haj season falls in winter, as in recent years. Outbreaks of cholera in Central Asia have also been traced to the return of pilgrims from Saudi Arabia, while blood-borne infections (e.g. hepatitis) can be spread by the practice of shaving many men's heads with the same razor. Extensive slaughter of animals at the end of the Haj threatens epidemics of zoonoses, and outbreaks of Rift Valley fever have been reported. All these infections can be disseminated by the pilgrims' return to their countries of origin, and lead to secondary epidemics. Growing international collaboration among medical experts and advances in technology are helping to counter the risks of what has become a global annual event.

often in intensely crowded situations, facilitates extensive human exposure to new pathogens and rapid spread of epidemics. In 1987, a Group A strain of *Neisseria meningitidis* was introduced by pilgrims from southern Asia and later transmitted by other pilgrims to sub-Saharan Africa, where it caused secondary epidemics in the following two years (Moore et al., 1989). On average, approximately seven out of every 100 000 pilgrims are reported to develop meningitis. The first epidemic of W-135 meningococcal disease was reported during the Haj in 2000. Cases spread rapidly to European and African countries as pilgrims returned home (Issa et al., 2003).

Travel-related illness may give rise to public health concerns that precipitate a disastrous fall in tourist revenue. Following the death of a single British tourist from malaria, an estimated 101 000 UK tourists cancelled or postponed visits to Kenya over the next two years, costing the country approximately UK£69 million in foreign earnings, or around 33% of its health budget. Efforts to prevent travel associated diseases may thus produce significant economic benefits to host countries (Behrens and Grabowski, 1995).

7.2.3 Transport of goods and infectious diseases

Transport of certain non-human goods can present the risk of, directly or indirectly, spreading human infections. Direct risks arise when people are exposed to materials which may themselves contain dangerous pathogens. For example, animal tissues transported for scientific purposes may contain dangerous organisms that can spread to human handlers. In Marburg, Germany, seven people died after handling blood and tissues sent from African green monkeys in Uganda; a newly discovered pathogen was isolated and later named the Marburg virus (Wilson, 1995a). In several other cases, severe viral disease in humans has followed exposure to animals transported across borders. These dangers seem especially relevant as researchers consider using animals as the source of tissues and organs for transplantation (Fishman, 1994).

The transporting vehicles can themselves spread pathogens to new areas. The dissemination of mosquito vectors for dengue fever through the international trade in used car tyres, causing increased risk of infection in previously non-endemic tropical urban environments and warmer temperate areas, has already been described (Gubler, 1998a; Gubler, 1998b). Shipping has introduced vast numbers of non-indigenous species to new areas through transport in ballast water. For example, the pathogen *Vibrio cholerae* was isolated in ballast, bilge and sewage from cargo ships in Latin America, suggesting that sea freight may have introduced an epidemic of cholera to South America (Anderson, 1991; WHO, 1992). Mosquitoes can survive on international flights and have probably been responsible for cases of malaria in destination countries.

Transport of materials can also indirectly increase the risk of infection if ecosystems are altered in ways that facilitate breeding of pathogens or vectors that spread disease. For instance, plant species introduced to alien environments may provide new protective habitats for mosquito vectors, causing outbreaks of malaria. Plant pathogens spread by transport can decimate crops leading to famine; when a population is malnourished, infectious diseases and their severity are likely to rise sharply (Wilson, 1995b).

7.3 Medical technologies

New medical technologies and techniques are disseminated across the world with increasing speed, and more people than ever can potentially benefit from scientific advances. This is not just a consequence of advances in ICTs, but also of greater scientific collaboration and interchange of ideas, the latter themselves features of globalization. For instance, there is much interest and considerable international collaboration in the development of new vaccines. Although vaccines already prevent more than 3.2 million deaths per year, the benefits of existing products have not been fully realized, particularly in developing regions (WHO, 1996; Hillcoat, 1998). Nevertheless, there are currently no vaccines for many of the most important infections in tropical regions. Although developments in biotechnology, for example advances in DNA sequencing technology, have raised hopes for prevention of many of these infections (Jordan Report, 1998), many obstacles prevent the full application of modern technologies to address the problems. Most importantly, there is currently little financial incentive for pharmaceutical companies, who are responsible for most new developments, to invest in such projects. They highlight the competing cost pressures of other initiatives, the expected low prices which could be charged for products developed primarily for poorer clients, and uncertainties about patent protection and product liability in developing and developed countries respectively, as key reasons (Lang and Wood, 1999). A variety of non-profit initiatives have attempted to rectify this lack of investment, including grants provided by the Gates Foundation and the TDR programme (Schwartz and Rabinovich, 1999).

Advances in technology are often offset by new vulnerabilities (Wilson, 1995b). Modern medical techniques applied with inadequate training and resources have had disastrous consequences. For example, hospital outbreaks of Ebola disease in the Congo and of Lassa fever in Nigeria both followed the use of insufficiently sterilized needles and surgical implements (Centers for Disease Control and Prevention, 1995b; Fisher-Hoch et al., 1995; Wilson, 1995b). Trade in blood products has spread viral and other infections between countries. Widespread and inappropriate use of antibiotics has led to dramatic increases in antimicrobial resistance. Use of vaccines derived from animal sources may transfer unknown infections from animals to humans. The intentional distribution of anthrax spores in the United States in the autumn of 2001 highlighted the threat posed by the use of infectious agents for terrorist purposes (Polyak et al., 2002). Alarmingly, in some cases terrorist groups have recruited scientists, physicians, and engineers, and even built laboratories for the development of toxins (Olson, 1999). Since 2001, the regulatory framework surrounding the exchange of pathogens for scientific purposes has tightened significantly. What is less known is the extent to which trade, legal or illicit, notably following the end of the Cold War, has spread potentially dangerous samples more widely. Economic and political instability in the former Soviet Union, for example, has led to fears that such materials are no longer stored in a secure environment and some even cannot be wholly accounted for. Appropriate regulation of such substances by all countries is clearly needed.

8 CONCLUSIONS

Despite the contested nature of globalization and the continued debates about its scope, pace and driving forces, there is a clear need for better conceptual and empirical understanding of the specific impacts of globalization. In this paper, the links between globalization and infectious diseases are broadly explored in relation to four spheres of change – economic, environmental, demographic, and technological. By no means is this review exhaustive. The aim of the paper is to explore the complex causal relationships that may be arising, and it is shown that globalization has, potentially, both positive and negative consequences for the infectious disease burden. The existing literature remains limited, although it is expanding and illustrative of the wide-ranging issues for research and policy. This review offers a number of conclusions.

First, *globalization appears to be causing profound, sometimes unpredictable, changes in the ecological, biological and social conditions that shape the burden of infectious diseases in certain populations*. There is accumulating evidence that changes in these conditions have led to alterations in the prevalence, spread, geographical range and control of many infections, particularly those transmitted by vectors. There is also a weight of theoretical, experimental and empirical research suggesting the potential for much greater change in the future. The changes have been both positive and negative, in different cases increasing or decreasing the infectious disease burden. Furthermore, different facets of globalization overlap and interlock, so that the same process is often responsible for a range of impacts on infectious diseases, and the prevalence of a specific infection may be influenced by several aspects of globalization concurrently. Thus global warming may, at the same time, increase the geographical range of many vector-borne diseases, and the incidence of bacterial gastroenteritis in some parts of the world, but decrease the occurrence of age-related pneumonia in others. Similarly, the distribution, transmission and control of malaria can be affected by transborder trade, climate change, processes of deforestation, dam-building, and travel. There is a need for greater understanding of these complex linkages through case studies, computer modelling, and improved surveillance systems.

Second, *individuals and population groups show varying degrees of gains and losses from economic globalization, and thus differential vulnerability to infectious diseases*. Studies of globalization processes show, increasingly, that the processes of change are impacting on the lives of individuals and populations in many different ways. Crude assessments of globalization as "good" or "bad" are neither accurate nor useful for more effective management of global change. There is strong evidence that economic globalization, at least in its current forms and in the medium term, is creating greater inequalities within and across countries. While many are reaping economic benefits, the poor, on the whole, appear to be getting poorer (UNDP, 1999). Infectious diseases affect the poor disproportionately because of inequities in basic living conditions (e.g. clean water, housing, sanitation), in the availability of and access to health care, in standards of diet and nutrition, and in migration patterns. Furthermore, while globalization offers opportunities to improve the application and dissemination of ICTs for health purposes, including infectious diseases surveillance and reporting, and health information systems, these technologies are also inequitably shared. There is a need to directly tackle the disproportionate risks posed by globalization to certain populations, and to ensure that the opportunities available are more widely shared. More detailed analyses of the links between globalization and infectious diseases are needed, therefore, to tease apart the complex causal relations and relate them to the conditions faced by specific individuals and populations. An assessment of the degree of vulnerability faced by different people can then form the basis of appropriate policy response.

Third, *epidemiology in general and surveillance in particular offer useful analytical tools and methods for identifying and measuring transborder patterns of infectious disease arising as a consequence of globalization*. The study of infectious diseases has never been restricted to the nation-state as a unit of analysis. Indeed, epidemiology can define a population across a wide spectrum of variables (age, sex, socioeconomic status), many of which are not delineated by territorial space. Such approaches are needed in studying how globalization may be changing the distribution of health and disease both within and across countries and regions of the world. The spread of SARS in 2002-2003, for example, followed a pattern of infection that spanned continents, socioeconomic status, sex and ethnic origin. There is a need to further develop epidemiological analysis of global health as a means of defining and measuring this emerging burden from infectious disease.

Fourth, *attention to the linkages between globalization and infectious diseases so far shows a disproportionate focus on selected acute and epidemic infections*. While there are clearly real risks from such diseases, which pose challenges to the provision of effective responses by national and international public health systems, it is important to give appropriate consideration to the wide range of infections potentially affected by globalization processes. Drawing on the wide-ranging literature, this report discusses many vector-borne, waterborne, and airborne diseases as well as zoonoses affected by globalization. Both epidemic and endemic conditions are included. There is a need to recognize and respond to a broader range of infectious disease impacts than currently.

Fifth, *due to inequalities between the industrialized and developing world in capacity and access to disease surveillance and monitoring systems, there is a danger that the infectious disease burden faced by poorer countries can be underestimated*. There is a particular need to develop surveillance systems that can be used effectively in low-tech, developing world contexts in order that true impact can be accurately identified. It is also imperative to ensure that, when changes in disease patterns are detected, the information is transmitted to those able to implement appropriate actions.

Sixth, *the impact of globalization on infectious diseases described in this report supports the need for appropriate forms of global governance on key issues to improve systems for prevention, control and treatment*. National level efforts and international health cooperation, notably through the International Health Regulations (IHR), remain the cornerstones of effective infectious disease policy. However, these efforts must go beyond the state to incorporate non-state actors such as nongovernmental organizations and the private sector. One of the key shortfalls of the IHR is, for example, the reliance on governments to voluntarily provide information on disease outbreaks. Where this is not forthcoming, WHO does not have the authority or capacity to enforce compliance from sovereign states. The adoption of a resolution at the World Health Assembly in May 2003 to invigorate efforts to revise the IHR, acknowledges the need for a more integrated global system of infectious disease surveillance, monitoring and reporting. A further area of regulatory concern is antibiotic use. There is a clear collective need for international standards of practice, and for regulatory mechanisms to enforce such practice, in order to reduce the inappropriate use of antimicrobials. Cooperation of the international pharmaceutical industry and private health service providers is required. More generally, there is a need to put greater responsibility on global actors, notably TNCs, for their actions, which may contribute to the infectious disease burden both directly and indirectly. Greater scrutiny of local and global environmental impacts, employment conditions, and other practices is needed in terms of their potential health impacts.

Seventh, *there is need for enhanced training on the global dimensions of infectious diseases*. Medical practitioners would benefit from greater understanding of the potentially changing profile of infectious diseases as a result of increased population mobility, intensified trade in goods and services, climate change and other factors linked to globalization. Current curricula in industrialized countries focus on the infections prevailing in their domestic populations, with specialist training offered for the "exotic" world of tropical diseases. While evidence suggests that globalization is unlikely to dramatically alter the profile of most infections faced by high-income countries, there is a need for greater appreciation of the changing risks from imported infections, antimicrobial resistance, and new and emerging diseases (e.g. SARS). Perhaps, more importantly, there is an urgent need for greater resources to enhance capacity in low and middle-income countries. The needs for training are wide-ranging and include surveillance and monitoring of infections, clinical practice, epidemiological research, and use of new ICTs. In many cases, international training exchange programmes are required to enable the sharing of experiences and ideas across national contexts.

Eighth, *the findings of this report support the need for greater attention to be paid to the impacts on the infectious disease burden of policy decisions taken in other sectors* such as trade and investment, large infrastructure projects (e.g. dam building), migration, agriculture, transportation and communications. More often, infectious diseases are recognized as a consequence of human activities undertaken as part of globalization processes, rather than as a factor to be considered part of the early planning and management of globalization. There is a need to integrate health impact assessment (HIA) as part of decision-making processes in many other sectors, and to establish long-term monitoring after policy decisions or infrastructure changes are implemented in order to provide better evidence of the health impacts of such changes. HIA should play a much wider role in the planning, management and evaluation of many policy areas. This includes not only major infrastructure projects, but also more insidious changes in practice such as economic and trade policy.

Finally, it is clear that *improving action on the impact of globalization on infectious disease on an a priori basis is a highly cost-effective policy intervention*. It is increasingly recognized that the long-term sustainability of globalization requires greater attention to the social (including health) costs of current forms of globalization. What needs to be understood more fully is that resources committed to infectious diseases prevention, treatment and control, in a globalizing world, is a worthwhile investment. As demonstrated by the outbreak of plague in Surat, India, cholera in Peru, and SARS in Asia and elsewhere, the economic costs of infectious disease outbreaks are potentially magnified in the context of globalization. As well as the costs of prevention, treatment and control of the disease, countries risk losing substantial revenues from reduced trade, investment and tourism. Furthermore, economic costs can be imposed indiscriminately. In the case of SARS, countries throughout SE Asia, regardless of the number of cases reported, suffered significant loss of earnings. Given the integrated nature of the global economy, including capital flows, population mobility, and trade in goods and services, there is shared interest in investing greater resources in strengthening global capacity surrounding infectious diseases.

REFERENCES

Akerman M, et al. Health and environment: an analysis of intra-urban differences focusing on the city of Sao Paulo, Brazil. *Revista de Saude Publica*, 1994, 28:320-325.

Albritton DI et al. *IPPC Working group I for policy makers, third assessment report, climate change 2001: the scientific basis*. Cambridge, UK, Cambridge University Press, 2001.

Altekruse SF et al. Emerging foodborne diseases. *Emerging Infectious Diseases*, 1997, 3:285-293.

Anderson C. Cholera epidemic traced to risk miscalculation. *Nature*, 1991, 354 (6351):255.

Anderson RM, May RM. *Infectious diseases of humans: dynamics and control*. Oxford, Oxford University Press, 1991.

Aron JL, Patz JA. *Ecosystems change and public health: a global perspective*. Baltimore and London, John Hopkins University Press, 2001.

Ayliffe GA. The progressive intercontinental spread of methicillin-resistant *Staphylococcus aureus*. *Clinical Infectious Diseases*, 1997, 24:S74-79.

Azevedo SM et al. Human intoxication by microcystins during renal dialysis treatment in Caruaru-Brazil. *Toxicology*, 2002, 181-182:441-446.

Baris E, McLeod K. Globalization and international trade in the twenty-first century: opportunity for and threats to the health sector in the south. *International Journal of Health Services*, 2000, 30:187-210.

Barrera R et al. Public service deficiencies and *Aedes aegypti* breeding sites in Venezuela. *Bulletin of the Pan American Health Organization*, 1995, 29:193-205.

Barrett TV et al. An outbreak of acute Chagas' disease in the Sao Francisco valley region of Bahia, Brazil: triatomine vectors and animal reservoirs of *Tryponosoma cruzi*. *Transactions of the Royal Society of Tropical medicine & Hygiene*, 1979, 73:703-709.

Behrens RH, Grabowski P. Travellers' health and the economy of developing nations. *Lancet,* 1995, 346:1562.

Beneson AS (ed). *Control of communicable diseases manual 16th edition*. Washington DC, American Public Health Association, 1995.

Bhatnagar S, Schaware R. *Information and communication technology in development: cases from India*. New Delhi, Sage Publications, 2000.

Birley MH. *Guidelines for forecasting the vector-borne disease implications of water resource development*. Geneva, World Health Organization, 1991.

Birley MH. *The health impact assessment of development projects*. London, HMSO, 1995.

Bouma MJ et al. Global assessment of El Nino's disaster burden. *Lancet*,1997, 350:1435-1438.

Boyle PJ et al. *Exploring contemporary migration*. Boston, Addison-Wesley, 1998.

Brodie M et al. Health information, the Internet, and the digital divide. *Health Affairs*, 2000, 19:255-265.

Brown DS, Wright CA. Schistosomiasis: bilharzia. In: Grove AT, *The Niger and its neighbours*, pp 295-317. Rotterdam, a.a. Balkema, 1985.

Brugha R. Antiretroviral treatment in developing countries: the peril of neglecting private providers. *British Medical Journal*, 2003, 326:1382-1384.

Carmichael WW et al. Human fatalities from cyanobacteria: chemical and biological evidence for cyanotoxins. *Environmental Health Perspectives*, 2001, 109:663-668.

Carpenter M. Health for some: global health and social development since Alma Ata. *Community Development Journal*, 2000, 35:336-351.

Castles S. International migration at the beginning of the twenty-first century: global trends and issues. *International Social Science Journal*, 2000, 165:269-281.

Castles S, Miller M. *The age of migration: international population movements in the modern world*. New York, Guilford Press, 1998.

Castells M. *Information technology and global development*. Keynote address at the Economic and Social Council of the United Nations, 2000.

Centers for Disease Control and Prevention. Rift Valley fever--Egypt, 1993. *Morbidity & Mortality Weekly Report*, 1994(a), 43:693, 699-700.

Centers for Disease Control and Prevention. Update: outbreak of Legionnaires' disease associated with a cruise ship. *Morbidity & Mortality Weekly Report*, 1994(b), 43:574-575.

Centers for Disease Control and Prevention. Exposure of passengers and flight crew to *Mycobacterium tuberculosis* on commercial aircraft, 1992-1995. *Morbidity & Mortality Weekly Report*, 1995(a), 44:137-140.

Centers for Disease Control and Prevention. Update: outbreak of Ebola viral hemorrhagic fever – Zaire. *Morbidity & Mortality Weekly Report*, 1995(b), 44:468-469.

Chandrasekhar CP, Ghosh J. Information and communication technologies and health in low income countries: the potential and the constraints. *Bulletin of the World Health Organization*, 2001, 79:850-855.

Chaplin SE. Cities, sewers and poverty: India's politics of sanitation. *Environment and Urbanization*, 1999, 11:145-158.

Checkley W et al. Effects of El Nino and ambient temperature on hospital admissions for diarrhoeal diseases in Peruvian children. *Lancet*, 2000, 355:442-450.

Clift S, Carter S. *Tourism and sex*. London and Washington, Pinter, 2000.

Clift S, Page S. *Health and the international tourist*. London, Routledge, 1996.

Collin J, Lee K. *Globalization and transborder health risk in the UK*. London, The Nuffield Trust, 2003.

Coluzzi M. Malaria vector analysis and control. *Parasitology Today*, 1992, 8:113-18.

Colwell RR. Global climate and infectious disease: the cholera paradigm. *Science*, 1996, 274:2025-2031.

Cooke FJ, Holmes A. Email health support service is already operating in Africa. *British Medical Journal*, 2001, 322:51-52 [comment].

Cookson B et al. International inter- and intrahospital patient spread of a multiple antibiotic-resistant strain of *Klebsiella pneumoniae*. *Journal of Infectious Diseases*, 1995, 171:511-513.

Cornea GA. Globalization and health: results and options. *Bulletin of the World Health Organization*, 2001, 79:834-841.

Desjeux P. The increase in risk factors for leishmaniasis worldwide. *Transactions of the Royal Society of Tropical Medicine & Hygiene*, 2001, 95:239-243.

Dicken P. *Global Shift: transforming the world economy*. 3rd edition, London, Sage, 1998.

Dikhanov Y, Ward M. *Measuring the distribution of global income*. Background paper for Poverty Net, Washington, World Bank, 2001.

Ding WX et al. Genotoxicity of microcystic cyanobacteria extract of a water source in China. *Mutation Research*, 1999, 442: 69-77.

Dobson A, Carper R. Biodiversity. *Lancet*, 1993, 342:1096-1099.

DukhaNiña NN et al. The malaria problem and malaria control measures in northern Afghanistan. First Report. Malaria in Afghanistan. *Meditsinskaia Parazitologiia i Parazitarnye Bolezni*, 1975, 44:338-344.

Edejer TT. Disseminating health information in developing countries: the role of the internet. *British Medical Journal*, 2000, 321:797-800 [comment].

Endtz HP et al. Quinolone resistance in campylobacter isolated from man and poultry following the introduction of fluoroquinolones in veterinary medicine. *Journal of Antimicrobial Chemotherapy*, 1991, 27:199-208.

Epstein PR. Climate change and emerging infectious diseases. *Microbes & Infection*, 2001(a), 3:747-754.

Epstein PR. Infectious diseases. In: Mann T, *Encyclopaedia of global environmental change*, Chichester, Wiley, 2001(b): 357-363.

Epstein PR. Is global warming harmful to health? *Scientific American*, 2000, 283:50-57.

Epstein PR et al. Biological and physical signs of climate change: focus on mosquito-borne disease. *Bulletin of the American Meteorological Society*, 1998, 78:409-417.

FAO. *Global forest resources assessment 2000*. Rome, Food and Agricultural Organization, 2000. www.eldis.org/static/DOC6658.htm

FAO. *The state of the world's forests*. Rome, Food and Agriculture Organization, 2001.

Farid MA. Irrigation and malaria in arid lands. In: Worthington EB, *Arid land irrigation in developing countries. Environmental problems and effects*, Oxford, Pergamon, 1977: 413-429.

Faye O et al. Drought and malaria decrease in the Niayes area of Senegal. *Sante*, 1995, 5:299-305.

Feachem RG. Globalization is good for your health, mostly. *British Medical Journal*, 2001, 323:504-506.

Fisher-Hoch SP et al. Review of cases of nosocomial Lassa fever in Nigeria: the high price of poor medical practice. *British Medial Journal*, 1995, 311:857-859.

Fishman JA. Miniature swine as organ donors for man: strategies for prevention of xenotransplant-associated infections. *Xenotransplantation*, 1994, 1:47-57.

Fraser HS, McGrath SJ. Information technology and telemedicine in sub-saharan Africa. *British Medical Journal*, 2000, 321:465-466.

Garrett-Jones C. Prognosis for the interruption of malaria transmission through assessment of the mosquito's vectorial capacity. *Nature*, 204:1173-1175.

Gibbons RV, Vaughn DW. Dengue: an escalating problem. *British Medical Journal*, 2002, 324:1563-1566.

Gillet JD. Direct and indirect influences of temperature on the transmission of parasites from insects to man. In: Taylor AER and Muller R, *The effects of meteorological factors upon parasites*, Oxford, Blackwell Scientific Publications, 1974: 79-95.

Githeko AK et al. Climate change and vector-borne diseases: a regional analysis. *Bulletin of the World Health Organization*, 2000, 78:1136-1147.

Gleick PH. *The world's water: the biennial report on freshwater resources*. Washington DC, Island Press, 2000.

Global Forum for Health Research. *The 10/90 report on health research*. WHO, Geneva, 1999.

Goesling B. Changing income inequalities within and between nations: new evidence. *American Sociology Review*, 2001, 66:745-761

Grifo F. The influence of historical and global changes upon the patterns of infectious diseases. In: Greenwood, B and De Cock K, *New and resurgent infections: prediction, detection and management of tomorrow's epidemics*, Chichester, New York, J Wiley and Sons, 1998: 17-31.

Gubler DJ. Population growth, urbanization, automobiles and aeroplanes: the dengue connection. In: Greenwood B and De Cock K, *New and resurgent infections: prediction, detection and management of tomorrow's epidemics*, Chichester, New York, J Wiley and Sons, 1998(a): 118-129.

Gubler DJ. Resurgent vector-borne diseases as a global health problem. *Emerging Infectious Diseases*, 1998(b), 4:442-450.

Gushulak B, MacPherson DW. Population mobility and infectious diseases: the diminishing impact of classical infectious diseases and new approaches for the 21st century. *Clinical Infectious Diseases*, 2000, 31:776-780.

Gwatkin DR et al. The burden of disease among the global poor. *Lancet*, 1999, 354: 586-9.

Habib NA, Behrens R, Schumunis RH. Travel health and infectious disease. In: Parsons L and Lister G, *Global health: a local issue*, London, Nuffield Trust, 2000: 124-133.

Hadley Centre. *Climate change and its impacts: stabilisation of CO2 in the atmosphere 1999*. Hadley Centre, UK.

Haile DG. Computer simulation of the effects of changes in weather patterns on vector-borne disease transmission. In: Smith JB, Tirpak DA, eds., *The potential effects of global climate change in the United States*, Appendix G: Document 230-05-89-057, Washington, DC, US Environmental Protection Agency, 1989.

Hales S et al. Potential effect of population and climate changes on global distribution of dengue fever: an empirical model. *Lancet*, 2002, 360:830-834.

Hales S et al. El Nino and the dynamics of vectorborne disease transmission. *Environmental Health Perspectives*, 1999, 107:99-102.

Harb M et al. The resurgence of lymphatic filariasis in the Nile delta. *Bulletin of the World Health Organization*, 1993, 71:49-54.

Hardy JL. Susceptibility and resistance of vector mosquitoes. In: Monath TP (ed). *The arboviruses: epidemiology and ecology*, I. Boca Raton, Fla, CRC Press, 1988.

Harpham T, Stephens C. Urbanization and health in developing countries. *World Health Statistics Quarterly - Rapport Trimestriel de Statistiques Sanitaires Mondiales*, 1991, 44:62-69.

Held D et al. *Global transformations, politics, economics and culture*. Stanford, Stanford University Press, 1999.

Herrera-Basto E et al. First reported outbreak of classical dengue fever at 1,700 meters above sea level in Guerrero State, Mexico, June 1988. *American Journal of Tropical Medicine & Hygiene*, 1992, 46:649-653.

Heymann DL, Rodier GR. Global surveillance of communicable diseases. *Emerging Infectious Diseases*, 1998, 4:362-365.

Hillcoat BL. Rare diseases and "orphan" drugs." *Medical Journal of Australia*, 1998, 169:69-70.

Hunter J M et al. *Parasitic diseases in water resources development*. Geneva, World Health Organization, 1993.

Hunter JM et al. Man-made lakes and man-made diseases. Towards a policy resolution. *Social Science & Medicine*, 1982, 16:1127-1145.

Huntingdon S. *The clash of civilizations and the remaking of world order*. New York, Free Press, 2002.

Huq A et al. Coexistence of Vibrio cholerae O1 and O139 Bengal in plankton in Bangladesh. *Lancet*, 1995, 345:1249.

Intergovernmental Panel on Climate Change. Climate change, 1995. *The science of climate change: contribution of Working Group 1 to the second assessment report of the Intergovernmental Panel on Climate Change*. New York, Cambridge University Press, 1996.

Issa M et al. Neisseria meningitidis serogroup W-135 isolated from healthy carriers and patients in Sudan after the Hajj in 2000. *Scandinavian Journal of Infectious Diseases*, 2003, 35:230-233.

Jacob JT. The influence of local changes in the rise of infectious diseases. In: Greenwood DC, *New and resurgent infections: prediction, detection and management of tomorrow's epidemics*, Chichester, John Wiley & Sons, 1998: 12-15.

Jetten TH, Focks DA. Potential changes in the distribution of dengue transmission under climate warming. *American Journal of Tropical Medicine and Hygiene*, 1997, 57:285-297.

Jewsbury JM, Imevbore AMA. Small health dam statistics. *Parasitology Today*, 1988, 4:57-58.

Jordan Report. *Accelerated development of vaccines 1998*. National Institute of Allergy and Infectious Diseases, Washington, 1998.

Kaferstein FK et al. Foodborne disease control: a transnational challenge. *Emerging Infectious Diseases*, 1997, 3:503-510.

Khalil Bey M. The national campaign for the treatment and control of bilharziasis from the scientific and economic aspects. *Journal of the Royal Egyptian Medical Association*, 1949, 32:820.

Koffi Annan. Address to: *Confederation of Indian Industry, Hyderabad, India*, 2001.

Koopman JS et al. Determinants and predictors of dengue infection in Mexico. *American Journal of Epidemiology*, 1991, 133:1168-1178.

Kovats RS. El Nino and human health. *Bulletin of the World Health Organization*, 2000, 78:1127-1135.

Kovats RS et al. Early effects of climate change: do they include changes in vector-borne diseases? *Philosophical Transactions of the Royal Society of London Series B-Biological Sciences*, 2001, 356:1057-1068.

Labonte R. *Brief to the World Trade Organization: World Trade and Population Health*. IUHPE Board of Trustees, 1999.

Lanciotti RS et al. Origin of the West Nile virus responsible for an outbreak of encephalitis in the northeastern United States. *Science*, 1999, 286:2333-2337.

Lang T. Trade, public health and food. In: McKee MG, Stott R, *International cooperation in health*, pp: 81-108, London, Oxford University Press, 2001.

Lang T. Diet, health and globalization: five key questions. *Proceedings of the Nutrition Society*, 1999, 58:335-343

Lang J, Wood SC. Development of orphan vaccines: an industry perspective. *Emerging Infectious Diseases*, 1999, 5:749-756.

Lee K. Globalization and health policy: A review of the literature and proposed research and policy agenda. In: Bambas A et al, eds., H*ealth & human development in the new global economy*. Washington D.C., Pan American Health Organization, 2000:15-41.

Lee K, Patel P. Far from the maddening cows: the global dimensions of BSE and vCJD. In: Lee K, ed., *Health impacts of globalization: towards global governance*, London, Palgrave Macmillan, 2002: 47-60.

Lee K. *Globalization and health, an introduction*. London, Palgrave Macmillan, 2003.

Lehmann JP. Developing economies and the demographic and democratic imperatives of globalization. *International Affairs*, 2001, 77:69-82.

Lindgren E, Gustafson R. Tick-borne encephalitis in Sweden and climate change. *Lancet*, 2001, 358:16-18 [comment].

Lindgren E et al. Impact of climatic change on the northern latitude limit and population density of the disease-transmitting European tick Ixodes ricinus. *Environmental Health Perspectives*, 2000, 108:119-123.

Linthicum KJ et al. Climate and satellite indicators to forecast Rift Valley fever epidemics in Kenya. [comment]. *Science*, 1999, 285:397-400.

Loevinsohn ME. Climatic warming and increased malaria incidence in Rwanda. *Lancet*, 1994, 343:714-718.

Loewenson R. *Social development and social services under globalization in Zimbabwe*. Paper prepared for the 1999 Zimbabwe Human Development Report, Harare, 2000.

MacKenzie WR et al. A massive outbreak in Milwaukee of cryptosporidium infection transmitted through the public water supply. *New England Journal of Medicine*, 1994, 331:161-167.

Maclehose L et al. Responding to the challenge of communicable disease in Europe. *Science*, 2002, 295:2047-2050.

Martens WJM et al. Climate change and future populations at risk of malaria. *Global Environmental Change*, 1999, 9:89-107.

Martens WJM. *Modelling the effect of global warming on the prevalence of schistosomiasis*. Bilthoven, Rijksinstituut Voor Volksgezondheid En Milieu (RIVM), 1995.

Martens WJM et al. Sensitivity of malaria, schistosomiasis and dengue to global warming. *Climatic Change*, 1997, 35:145-156.

May R. Changing diseases in changing environments. In: Cartledge B, *Health and the Environment*, Oxford, Oxford University Press, 1994.

McArthur RH. *Geographical ecology*. New York, Harper and Row, 1972.

McMichael AJ. The urban environment and health in a world of increasing globalization: issues for developing countries. *Bulletin of the World Health Organization*, 2000, 78:1117-1126.

McMichael AJ. *Planetary overload: global environmental change and the health of the human species*. Cambridge, Cambridge University Press, 1993.

McMichael AJ. *Human frontiers, environments, and disease: past patterns, uncertain futures*. Cambridge, Cambridge University Press, 2001.

McMichael AJ. The influence of historical and global changes upon the patterns of infectious diseases. In: Greenwood B and De Cock K, *New and resurgent infections: prediction, detection and management of tomorrow's epidemics*, Chichester; New York, J Wiley and Sons, 1998: 17-31.

McMichael AJ et al. Climate change. In: Ezzati M et al, *Comparative quantification of health risks: global and regional burden of disease due to selected major risk factors*. Geneva, World Health Organization, 2003.

McMichael AJ, Githeko A. Human Health. In: McCarthy JJ et al, Intergovernmental Panel on Climate Change (IPPC), *Climate change 2001: third assessment report, impacts, adaptations and vulnerability of climate change*. Cambridge, UK, Cambridge University Press, 2001.

McMichael AJ, Haines A. Global climate change: the potential effects on health. *British Medical Journal*, 1997, 315:805-809.

McNeill WH. *Plagues and peoples*. New York, Garden City, 1976.

Mills DM. A climatic water budget approach to black fly population dynamics. *Publications in Climatology*, 1995, 48:1-84.

Minas IH. Migration, equity and health. In: *International co-operation and health*, Oxford, Oxford University Press, 2001: 151-174.

Molyneux DH. Vector-borne infections in the tropics and health policy issues in the twenty-first century. *Transactions of the Royal Society of Tropical Medicine & Hygiene*, 2001, 95:233-238.

Molyneux DH. Patterns of change in vector-borne diseases. *Annals of Tropical medicine & Parasitology*, 1997, 91:827-839.

Moore PS et al. Intercontinental spread of an epidemic group A Neisseria meningitidis strain. *Lancet*, 1989, 2:260-263.

Mott KE et al. Parasitic diseases and urban development. *Bulletin of the World Health Organization*, 1990, 68:691-698.

Murray CJ, Lopez AD. *The global burden of disease a comprehensive assessment of mortality and disability from diseases, injuries, and risk factors in 1990 and projected to 2020*. Cambridge, Mass, Harvard University Press, 1996.

Murray CJ, Lopez AD. Global mortality, disability, and the contribution of risk factors: Global Burden of Disease Study [see comments]. *Lancet*, 1997(a), 349:1436-1442.

Murray CJ, Lopez AD. Mortality by cause for eight regions of the world: Global Burden of Disease Study [see comments]. *Lancet*, 1997(b), 349:1269-1276.

Navarro V. Health and equity in the world in the era of globalization. *International Journal of Health Services*, 1999, 29:215-26.

Olson KB. Aum Shinrikyo: once and future threat? *Emerging Infectious Diseases*, 1999, 5:513-516.

Patz JA et al. Global climate change and emerging infectious diseases. *Journal of the American Medical Association*, 1996, 275:217-223.

Pecoul B et al. Access to essential drugs in poor countries, a lost battle? *Journal of the American Medical Association*, 1999, 281:361-367.

Pedersen PO. *The Changing structure of transport under trade liberalisation and globalization and its impact on African development*. Copenhagen, Centre for Development Research: Working paper 00.1, 2000.

Petney TN. Environmental, cultural and social changes and their influence on parasite infections. *International Journal for Parasitology*, 2001, 31:919-932.

Phillips DR. Urbanization and human health. *Parasitology*, 1993, 106: S93-107.

Polyak CS et al. Bio terrorism-related anthrax: international response by the Centers for Disease Control and Prevention. *Emerging Infectious Diseases*, 2002, 8:1056-1059.

Ravallion M. Good and bad growth: human development reports. *World Development*, 1997, 25:627-630.

Reeves WC et al. Potential effect of global warming on mosquito-borne arboviruses. *Journal of Medical Entomology*, 1994, 31:323-332.

Reisin WK et al. Effects of temperature on the transmission of Western equine encephalomyelitis and St Louis encephalitis viruses by Culex tarsalis. *Journal of Medical Entomology*, 1993, 30:151-160.

Rogers DJ, Packer MJ. Vector-borne diseases, models, and global change. *Lancet*, 1993, 342:1282-1284 [comment].

Rogers DJ, Randolph SE. The global spread of malaria in a future, warmer world. *Science*, 2000, 289:1763-1766. Erratum in: Science, 2000, 289:2284.

Rogers DJ, Randolph SE. Mortality rates and population density of tsetse flies correlated with satellite imagery. *Nature*, 1991, 351:739-741.

Rogers DJ, Randolph SE. Distribution of tsetse and ticks in Africa: past, present and future. *Parasitology Today*, 1993, 9:266-271.

Rowland M, et al. An outbreak of cutaneous leishmaniasis in an Afghan refugee settlement in north-west Pakistan. *Transactions of the Royal Society of Tropical Medicine & Hygiene*, 1999, 93:133-136.

Sanders D, Chopra M. Globalization and the challenge of health for all: a view from sub-Saharan Africa. In: Lee K, *Health impacts of globalization: towards global governance*. London, Palgrave Macmillan, 2002.

Sastry, N. What explains rural-urban differentials in child mortality in Brazil? *Social Science & Medicine*, 1997, 44:989-1002.

Satcher D. Emerging infections: getting ahead of the curve. *Emerging Infectious Diseases*, 1995, 1:1-6.

Schmaljohn C, Hjelle B. Hantaviruses: a global disease problem. *Emerging Infectious Diseases*, 1997, 3(2):95-104.

Schofield CJ. Biosystematics of the Triatominae. *Biosystematics of haematophagous insects*, ME Service, Oxford, Oxford University Press, 1988: 285-312.

Scholte JA. *Globalization, a critical introduction*. London, Palgrave Macmillan, 2000.

Schumunis G. Chagas disease and blood transfusion. In: Dodd RY, Barker LF eds., *Infection, immunity and blood transfusion*, New York, Liss, 1985: 127-45.

Schwartz B, Rabinovich NR. Stimulating the development of orphan (and other) vaccines. *Emerging Infectious Diseases*, 1999, 5:832.

Seaman J et al. The epidemic of visceral leishmaniasis in western Upper Nile, southern Sudan: course and impact from 1984 to 1994. *International Journal of Epidemiology*, 1996, 25:862-71.

Seaman J et al. Visceral leishmaniasis in southern Sudan: status of healthy villagers in epidemic conditions. A*nnals of Tropical Medicine & Parasitology*, 1992, 86:481-486.

Seckler D et al. *World water demand and supply*, 1990 to 2025: scenarios and issues. Research Report 19. Colombo, International Water Management Institute, 1998.

Service MW. *Irrigation: boon or bane*? Baco Raton, FL, CRC Press, 1989.

Sharma DC. Remote Indian villages to benefit from telemedicine project. *Lancet*, 2000, 355:1529.

Sharma VP, Kondrachine AV. F*orest malaria in southeast Asia: proceedings of an informal consultative meeting*. New Delhi, WHO/MRC, 1991.

Shiff CJ et al. Seasonal patterns in the transmission of *Schistosoma haematobium* in Rhodesia, and its control by winter application of molluscicide. *Transactions of the Royal Society of Tropical Medicine & Hygiene*, 1979, 73:375-80.

Shiff CJ et al. Seasonal influence on the production of Schistosoma haemotobium and S. mansoni cercariae in Rhodesia. *International Journal for Parasitology*, 1975, 5:119-123.

Shope RE. Arbovirus-related encephalitis. Yale *Journal of Biology & Medicine*, 1980, 53: 93-9.

Singh YP, Tham A. *Case history of malaria control through the application of environmental management in Malaysia*, 1990, (WHO/WBC/88.960).

Sivaraman S. *AIDS-Thailand: crisis inflicts more pain on people with HIV*. InterPress News Service, 17 June 1998. www.aegis.com/news/ips/1998/IP980605.html

Skeldon R. *Migration and development: a global perspective*. Essex, Addison Wesley Longman, 1997.

Stalker P. *Workers without frontiers - the impact of globalization on international migration*. Geneva, International Labour Office and Lynne Rienner Publisher, 2000.

Steere AC. Lyme disease: a growing threat to urban populations. *Proceedings of the National Academy of Sciences of the United States of America*, 1994, 91:2378-2383.

Stephens C. The urban environment, poverty and health in developing countries. *Health Policy & Planning*, 1995, 10:109-121.

Strickland GT. Providing health services on the Aswan High Dam. *World Health Forum*, 1982, 3:297-300.

Sutherst RW. Implications of global change and climate variability for vector-borne diseases: generic approaches to impact assessments. *International Journal for Parasitology*, 1998, 28:935-945.

Sutherst RW. The vulnerability of animal and human health to parasites under global change. *International Journal for Parasitology*, 2001, 31:933-948.

Swerdlow DL, Altekruse SF. Food-borne diseases in the global village: what's on the plate for the 21st century. In: Schield MW et al., *Emerging infections 2*, Washington D C, American Society for Microbiology, 1998.

Tamplin ML, Carrillo Parodi C. Environmental spread of *Vibrio cholerae* in Peru. *Lancet*, 1991, 338:1216-1217.

Tchuente LA et al. Impact of installation of a water pump on schistosomiasis transmission in a focus in Cameroon. *Transactions of the Royal Society of Tropical Medicine & Hygiene*, 2001, 95:255-256.

Tesh RB. The emerging epidemiology of Venezuelan hemorrhagic fever and Oropouche fever in tropical South America. In: Wilson ME et al, *Disease in evolution: global changes and emergence of infectious diseases*, New York, New York Academy of Sciences, 1994.

TDR http://www.who.int/tdr/

UKCIP. *Socio-economic scenarios for climate change impact assessment*. A guide to their use in the UK Climate Impacts Programme. UKCIP, Oxford, 2000.

UNAIDS. *Report on the global HIV/AIDS epidemic 2002*, UNAIDS, 2002.

UNAIDS. *AIDS epidemic update December 2001*, Geneva, UNAIDS/WHO, 2001.

UNAIDS. *The UNAIDS report. Joint United Nations Programme on HIV/AIDS*, Geneva, 1999.

United Nations. *Climate change 2001: impacts, adaptation and vulnerability*. New York, United Nations, 2001.

UNFPA. *Migration and urbanization*, New York, UN Population Fund, 1999.

UNFPA. *The state of the world's population 2003*. New York, UN Population Fund, 2003.

UNDP. *Human development report 1999*. New York, UN Development Programme, 1999.

United Nations Conference on Environment and Development (UNCED). *Agenda 21 Principle 15*. Rio de Janeiro, 1992.

Vasquez Tsuji O et al. Soil contamination with Toxocara sp. eggs in public parks and home gardens from Mexico City. *Boletin Chileno de Parasitologia*, 1996, 51:54-8.

Wade R. Global inequality. *The Economist*, 2001, 28 April: 93-27.

Walsh JF et al. Deforestation: effects on vector-borne disease. *Parasitology*, 1993, 106:S55-75.

Wilkinson R. *Unhealthy societies: the afflictions of inequality*. London, Routledge, 1996.

Williamson A, Mayberry J. Getting our journals to developing countries. *Postgraduate Medical Journal*, 2001, 77:554-555.

Wilson ME. Infectious diseases: an ecological perspective. *British Medical Journal*, 1995(a), 311:1681-1684.

Wilson ME. Travel and the emergence of infectious diseases. *Emerging Infectious Diseases*, 1995(b), 1:39-46.

Woodward D et al. Globalization and health: a framework for analysis and action. *Bulletin of the World Health Organization*, 2001, 79:875-81.

World Commission on Dams. *Dams and development: a new framework for decision-making*. The World Commission on Dams Report, 2001.

WHO. *Ten years of onchocerciasis control in West Africa: review of work of the OCP in the Volta River Basin area from 1974 to 1984*. Geneva, World Health Organization, 1985.

WHO. *Potential health effects of climatic change*. Geneva, World Health Organization, 1990.

WHO. Cholera in the Americas. *Weekly Epidemiological Record*, 1992, 67:33-39.

WHO. *The world health report 1996: fighting disease, fostering development*. Geneva, World Health Organization, 1996.

WHO. *Anti-tuberculosis drug resistance in the world: the WHO/IUATLD global project on anti-tuberculosis drug resistance surveillance 1994-1997*. Geneva, World Health Organization, 1997.

WHO. El Nino and its health impacts. *Weekly Epidemiological Record*, 1998, 73:148-152.

WHO. *World health report 2002*, Geneva, World Health Organization, 2002.

WHO/UNICEF. *Global water supply and sanitation assessment 2000*. Geneva, World Health Organization, 2000.

World Resources Institute. Rising energy use: Health effects of air pollution. In: *World Resources 1998-99*, Washington DC, WRI, 1999.

World Tourism Organization: http://www.world-tourism.org/

Wright D. The sustainability of telemedicine projects. *Journal of Telemedicine & Telecare*, 1999, 5:S107-111.

Xiaonong Z et al. Schistosomiasis control in the 21st century. Proceedings of the International Symposium on Schistosomiasis, Shanghai, 4-6 July 2001. *Acta Tropica*, 2002, 82:95-114.

Ye-Ebiyo Y et al. Enhanced development in nature of larval Anopheles arabiensis mosquitoes feeding on maize pollen. *American Journal of Tropical Medicine & Hygiene*, 2000, 63:90-93.

Zucker JR. Changing patterns of autochthonous malaria transmission in the United States: a review of recent outbreaks. *Emerging Infectious Diseases*, 1996, 2:37-43

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