EcoHealth 1, 138–150, 2004
DOI: 10.1007/s10393-004-0004-y

ECOHEALTH

# Impact of Climate Variability on Infectious Disease in West Africa

Madeleine C. Thomson,[1] Stephen J. Connor,[1] Neil Ward,[1] and David Molyneux[2]

[1]*International Research Institute for Climate Prediction (IRI), The Earth Institute at Columbia University, Lamont Campus, Monell Building, 61 Route 9W, Palisades, NY 10964-8000*
[2]*Liverpool School of Tropical Medicine, Pembroke Place, Liverpool L3 5QA, UK*

**Abstract:** The importance of infectious disease as a determinant (as well as an outcome) of poverty has recently become a prominent argument for international and national investment in the control of infectious disease, as can be seen in the recently articulated United Nations (UN) Millennium Development Goals (MDGs). Climate variability and land use change have an enormous impact on health in West Africa, and may yet undermine the potential for achieving the MDGs, in certain economic-ecological zones. However, their underlying role in determining the burden of disease in the region on a yearly or decadal basis has never been systematically studied. In order to improve our understanding of the future impacts of climate change, it may be more effective to start by investigating the impact of inter-annual climate variability, and short-term shifts in climate (e.g., decadal), on disease transmission dynamics. This information may inform both current and future policy decisions with regard to prediction, prevention, and management of adverse climate-related health outcomes. This article reviews current knowledge of changes in the epidemiology of infectious diseases associated with climate variability in West Africa over the last 40 years. Selected examples are considered from bacterial (meningococcal meningitis), protozoan (malaria), and filarial (onchocerciasis and lymphatic filariasis) infections where spatial and temporal disease patterns have been directly influenced by seasonal, inter-annual, or decadal changes in climate.

**Key words:** climate, epidemic, malaria, meningitis, filariasis, disease, West Africa

## INTRODUCTION

While infectious and parasitic diseases are no longer the leading causes of mortality in the developed world, they remain the main cause of mortality in middle and lower income countries (Connor, 2002a), accounting for more than half of all deaths in Africa (Murray et al., 2001). The importance of infectious disease as a determinant (as well as an outcome) of poverty has recently become a prominent argument for international and national investment in the control of infectious disease (WHO, 2001a) as can be seen in the recently articulated United Nations (UN) Millennium Development Goals (MDGs) (Sachs, 2002).

Climate variability and land use change have an enormous impact on health in West Africa, and may yet undermine the potential for achieving the MDGs, in certain

---

*Correspondence to:* Madeleine C. Thomson, e-mail: mthomson@iri.columbia.edu

economic-ecological zones. However their underlying role in determining the burden of disease in the region on a yearly or decadal basis has never been systematically studied. Clearly appropriate evidence-based economic, environmental, and public health policy instruments are needed to reduce the potentially adverse impacts. Developing such evidence in a systematic way is a prerequisite for its effective use in guiding policy development. In the countries belonging to the World Health Organization's sub-region D (all West African countries), respiratory infection, malaria, and human immunodeficiency virus/acquired immunodeficiency syndrome (HIV/AIDS) are leading causes of mortality and Disability Adjusted Life Years, and their effective control is perceived as an essential requirement for sustainable livelihood development in the region.

This article reviews current knowledge of changes in the epidemiology of infectious diseases associated with climate variability in West Africa over the last 40 years. Selected examples are considered from bacterial, protozoan, and filarial infections where spatial and temporal disease patterns have been directly influenced by seasonal, inter-annual, or decadal changes in climate.

## Climate of West Africa

The climate of West Africa ranges from the Saharan desert (bounded by 100 mm mean annual rainfall isohyet) through the Sahelian zone whose southern border is demarcated by the 400 mm isohyet. South of this line is the savanna zone, where the Malian horse empire was founded in the 13th century. Further south, the 1000 m isohyet marks the start of the woodland savanna zone and the northern limits of the tsetse fly (*Glossina morsitans*) belt—a formidable barrier to all those dependant on cattle and horses. Cattle, horses, donkeys, and camels are all susceptible to the often fatal parasitic disease trypanosomiasis (sleeping sickness) transmitted by this fly.

The timing of the rainy season in West Africa is highly predictable and is governed by the movement of the Inter-Tropical Convergence Zone (ITCZ), a discontinuous belt of thunderstorms marking the convergence of the northern and southern hemisphere's surface trade winds which moves northwards and southwards with seasonal changes in the overhead sun. The ITCZ reaches its maximum northward extent around July–August and its southern extent around January–March (during this dry period, the harmattan winds blow Saharan/Sahelian dust southwestwards across the region). The movement of the ITCZ's northern edge is not regular and short-term oscillations of as much as 500–1000 km may occur over a few days. This can cause erratic starts to the onset of the rainy season.

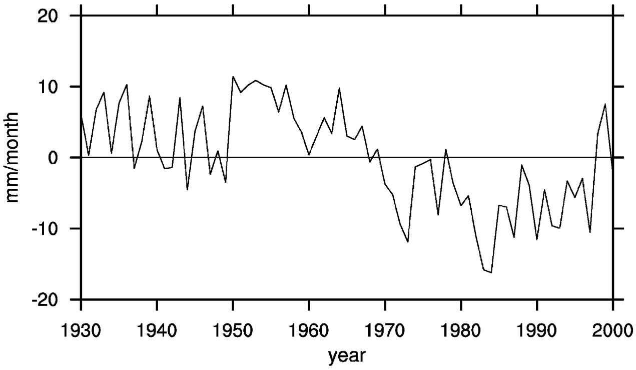

**Figure 1.** Rainfall anomolies in the Sahel (1930–2000). The annual mean average of 41 stations extracted from the global historical climatology network dataset. The anomalies are computed with respect to the climatology of the full period used (1930–2000). Courtesy of Alessandra Giannini, NOAA/National Climate Data Center, Asheville, NC.

Rainfall in West Africa is the most significant determinant of the landscape in terms of natural vegetation and land use activity. The amount of annual rainfall at any geographic location depends heavily on the duration of the rainy season, that is, the mean time in total during which the ITCZ is positioned well north of the particular location thus allowing rainfall to occur.

### *Drought in West Africa*

West Africa provides one of the most dramatic examples worldwide of climate variability that has been directly and quantitatively measured (Hulme, 2001). Averaged over 30-year intervals, annual rainfall across the Sahel/Guinea-savannah fell by between 20 and 30% between the pre-independence period (1930s to 1950s) and the decades since (post-1960s) (Fig. 1). Thus, the famines that struck the region in the 1970s and 1980s were embedded in a drought that has lasted from the 1960s to the present day (with some amelioration in recent years), which not only affected the Sahel but extended southward to the Guinea coast.

It has been observed that most of the rainfall deficit of the dry period 1971–1990 in the Sahel is correlated with a general decrease in the number of rain events rather than a shortening of the length of the rainy season (Le Barbe and Lebel, 1997; Le Barbe et al., 2002). This, along with the fact that the rainfall deficit was equal to 180–200 mm all over

West Africa, indicates that there was no crucial difference in nature between the Sahelian drought and the drought of the Guinean savanna regions. The explanation of such features resides in either an abnormal southward position of the ITCZ and/or a less productive ITCZ during the dry spell. It has been proposed that sulphurous emissions from factories in industrialized countries may have created the conditions for, or exacerbated the extent of, this recent drought by weakening the northwards movement of the ITCZ (Rotstayn and Lohmann, 2002). As a result, the intense thunderstorms which produce the rains needed for the Sahel croplands fail to materialize.

However, the most favored current hypothesis for the extended drought continues to be large-scale changes in near-global patterns of sea surface temperature (SST) anomalies (Folland et al., 1986) with a possible role of land-surface changes in reinforcing the drought. Anomalies in SST in the world's oceans, including those related to the El Niño Southern Oscillation (ENSO), contribute to rainfall variability in the Sahel (Lamb, 1978; Folland, et al., 1986; Ward, 1998). Lamb et al. (1978) observe that droughts in West Africa correlate with warm SST in the tropical South Atlantic. Examining oceanographic and meteorological data from the period 1901–1985, Folland et al., (1986) found that persistent wet and dry periods in the Sahel were related to contrasting patterns of SST anomalies on a near-global scale. When SST in the northern hemisphere's oceans were cold, rainfall in the Sahel was low. A recent attempt to quantify the importance of the oceanic influence on the variability of the northern African summer monsoon climate (including the Sahel) on interannual to interdecadal timescales has been made (Giannini et al., 2003). Using an ensemble of simulations of the global atmospheric circulation forced with the observed record of SST, but no year-to-year changes in vegetation cover or greenhouse gas concentrations, these authors demonstrate that a warming of the tropical Pacific and Indian Oceans, of the order of 0.2°C or larger, is associated with a negative rainfall anomaly in the Sahel PRINCIPAL component (0.73 mm/day in observations). Furthermore, a negative rainfall anomaly is consistent with local land surface temperature anomalies up to 0.6°C warmer than average. From this work, the authors conclude that SST variability is instrumental in determining the sign of rainfall anomalies in the Sahel, while coherent land-atmosphere interaction acts to amplify them.

The theory that SST anomalies are the driving force behind the drought contrasts dramatically with earlier perceptions of the causes of the Sahelian drought. The responsibility for this regional disaster had been put upon the shoulders of local peasant farmers, whose overuse of the land was deemed to have resulted in reduced vegetation cover, the advance of the desert, and localized impacts on the regional climate regime (McCann, 1999).

Major river systems endow some, but not all, of the countries of West Africa with substantial water resources. One of the first consequences of the decrease in precipitation has been a significant reduction in discharge within these river systems. The fall in precipitation observed before and after the discontinuity ranges between 15 and 30%; for river discharge, the corresponding fall varies between 30 and 60% (Gustard and Cole, 2002). This translates into a decline in surface water resources across the sub-region in recent years, which has serious consequences for the management of these resources. A further consequence is the increasingly rapid degradation of vegetation and associated desertification, mainly in the Sahelian zones, which renders the Sahelian ecosystem even more fragile in the face of predominant socio-economic activities including agriculture and animal husbandry.

Whatever their cause, droughts in the Sahel are not new. In fact, what characterizes rainfall in the Sahel is its variability in space and time from year to year, decade to decade (Nicholson et al., 1990). Human society has adapted to this variability in rainfall supply, for example, through pastoralism, diversification of income, and mobility (Batterbury and Warren, 2001). However such adaptability has not freed the region from vulnerability to periodic famine, the most tragic of which are recorded as having occurred in 1680, 1750, 1820, 1920, 1968, 1973, and 1984 (Egg and Gabas, 1997). In response to the most recent famines, the international community has focused efforts on the development of famine early warning systems to reduce the region's vulnerability to such disasters. These warning systems use information on current household vulnerability to shocks and climate/environmental data in order to assess a region's vulnerability to famine.

The potential value of seasonal climate forecasts to agriculture (Hansen, 2002), disaster management (Dilley and Heyman, 1995; Thomson et al., 2003), and health (WHO, 2001b) has been highlighted and new initiatives are currently underway to assess the value of such information to regional and local decision makers. However, because of limitations in the predictability of SST, in particular equatorial and South Atlantic SST (key determinants of the West African climate), during the spring period, the potential to predict the seasonal rainfall over West Africa prior to May or June is poor (Goddard and Mason, 2002). Forecasts are therefore limited in this region in the lead time they can offer decision makers. While most research to date has focused on the predictability of the rainy season, new efforts to predict the length and character of the dry season are being prompted by health sector interest in view of the potential relationship of low humidity and dust to respiratory infections (Molesworth et al., 2002a).

### *Geographical and Socio-economic Characteristics of West Africa*

There are 15 countries in mainland West Africa (Fig. 2), 3 of which are landlocked. The sub-region stretches from the southern fringes of the Sahara Desert to the Atlantic Ocean along the Gulf of Guinea, from hot dry desert, through semi-arid savannah, to moist humid forests. Generally the West African countries can be currently characterized by: high population growth, young populations, high and weakly controlled urbanization, and weak human development. Periodic war and civil unrest, often driven by the desire to control minerals (Veeken, 1994; Davies, 2000) plague countries which are well endowed with natural resources resulting in large refugee/displaced populations in some countries. While substantial gains have been made in reducing infant mortality in the last 40 years, deaths rates remain high, life expectancy is approximately 50 years, and national Gross Domestic Product (GDP) figures indicate that these countries include some of the poorest populations in the world. Two important factors currently driving both economic and political change are the 10-fold increase of the population over the last century, and the recent opening up of the region to the world economy, as globalization advances (Cour, 2001).

Political and economic activity in West Africa has always been heavily influenced by climate, and historians have delimitated key West African historical zones by rainfall isohyet boundaries which shift periodically. These boundaries impose specific constraints on human activity (McCann, 1999). For instance, while in all West African countries there is a predominance of the agricultural sector in the national economies, the type of agriculture practiced and its potential for economic growth and development is largely governed by the climatically determined ecological zones of the region.

Recent work for the World Bank by the Food and Agriculture Organization (FAO, 2001) identified a number of ecological zones, determined largely by rainfall resources, which characterize particular farming systems (Fig. 3). These include: Pastoral Systems with a high incidence of severe poverty and low potential for poverty reduction; Agro-Pastoral Millet-Sorghum Systems with a high incidence of severe poverty but with a high potential for poverty reduction; and Cereal-Root Crop Mixed Systems with a lower incidence of poverty and a high potential for agricultural growth. The climate and environment in each of the farming system zones described correspond closely to different zones of epidemic disease risk (Fig. 4). Therefore, the development policies and practices that are followed have important implications not only for agricultural development and food security, but also disease transmission risk and vulnerability to severe-disease outcome. Clearly this has profound implications for sustainable livelihoods development in the region over the medium–long term.

## Climate and Health Interactions in the Arid and Semi-arid Farming Zones of West Africa

Climate impacts on health through a number of distinct, direct and indirect, mechanisms. For example, directly through heat stress, UV induced melanomas, etc., or perhaps more significantly, indirectly, through:

a) its role in determining agricultural output and consequently food security, which directly effects nutritional status;
b) its role in the economy via agricultural exports, hydrological power, etc., which affects the ability of individuals and communities to maintain nutritional status, prevent infection (e.g., through the purchase of mosquito nets) and, when necessary, obtain health care. The impact of climate on the economy will also affect the ability of governments to provide health services;
c) its role in determining seasonal and inter-annual demographic processes (e.g., seasonal labor migration and environmental refugees), increasing the likelihood of individuals contracting certain infectious diseases, such as HIV;
d) its impact on the spatial and temporal distribution of climate-related infectious diseases (e.g., malaria, Rift Valley fever, meningococcal meningitis).

Many of these indirect mechanisms interact, and when climatic anomalies coincide with societal vulnerability, disastrous drought and famine can occur (e.g., in West Africa in the early 1970s and early 1980s). These situations

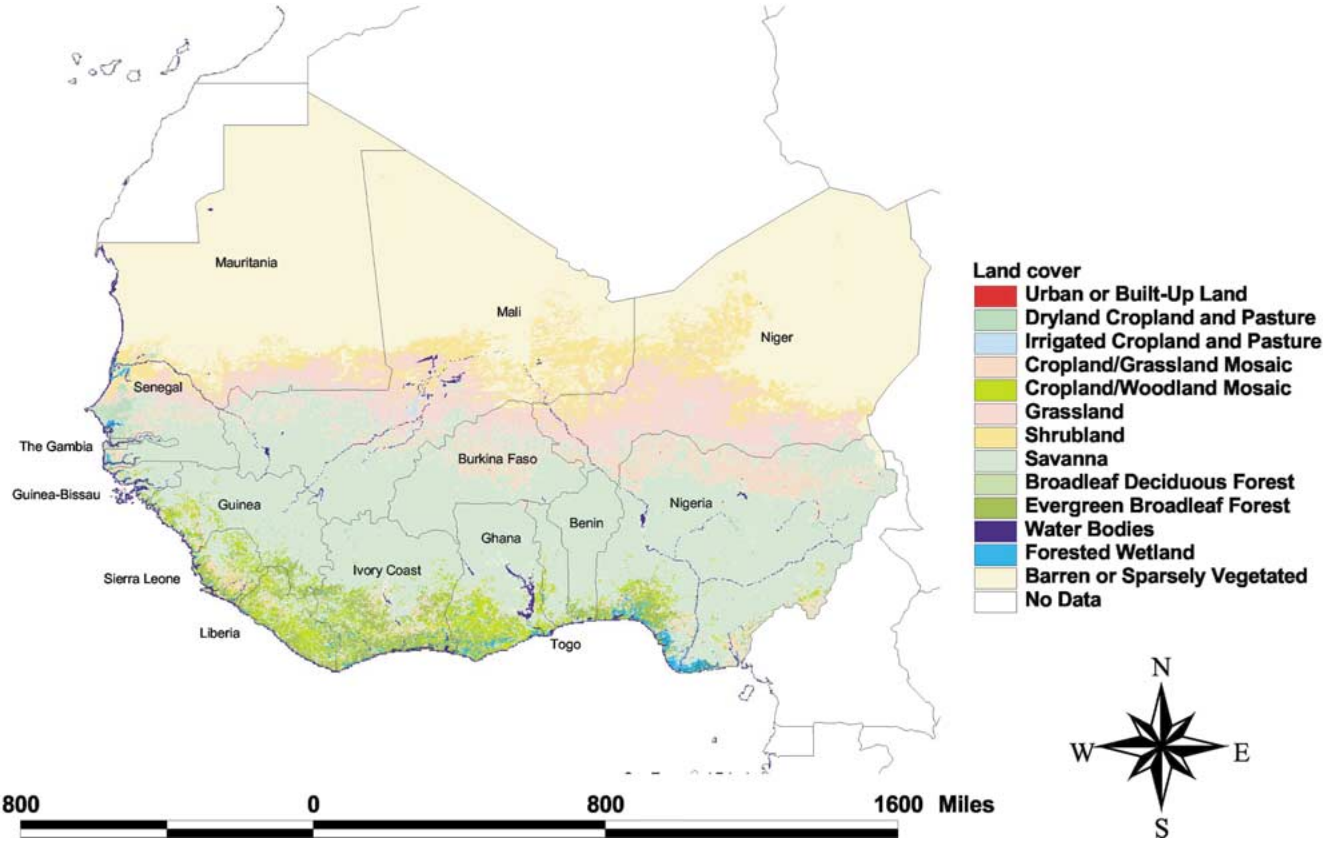

**Figure 2.** The countries in the World Health Organization (WHO) epidemiological block for West Africa overlaid on the US Geological Survey landcover map.

result in further social disruption and population displacement, with the major cause of mortality during such disasters being epidemics of infectious diseases (Prothero, 1994). Furthermore, some of the linkages are bidirectional. For example, while agricultural production and food security impact on health, infectious disease episodes impact on agricultural production, affecting the availability of labor at critical times in the annual agricultural calendar.

### *Predicting Infectious Disease Transmission*

There is currently extensive interest in predicting the possible impacts of climate change on the major infectious diseases (Colwell et al., 1998; Kovats et al., 2001; Patz and Reisen, 2001). However, considerable uncertainty is associated with such predictions. While there is widespread acceptance that the climate is changing (Houghton et al., 2001), the future impact of such change on the actual weather patterns in particular geographic regions remains largely speculative (McCarthy et al., 2001). Furthermore, while many infectious disease vectors and agents are known to vary in their spatial and temporal distribution, as a function of climate processes (Thomson and Connor, 2000), the detailed parameterization of key variables, such as vector survivorship, are made difficult by the paucity of relevant empirical data which relate to disease transmission under field conditions in Africa.

This, combined with the many nonlinearities in the transmission dynamics of infectious diseases and the importance of nonclimatic factors in determining the outcome of transmission, make predicting the impact of climate change on specific health outcomes a contentious one (Martens et al., 1997; Rogers and Randolph, 2000). In order to improve our understanding of the future impact of climate change, it may be more effective to start by investigating the impact of inter-annual climate variability, and short-term shifts in climate (e.g., decadal), on disease transmission dynamics, since this information may inform both current and future policy decisions with regard to prediction, prevention, and management of adverse climate-related health outcomes. Consequently, research aimed at the use of seasonal climate forecasts by health services in Africa needs to emphasize the importance of

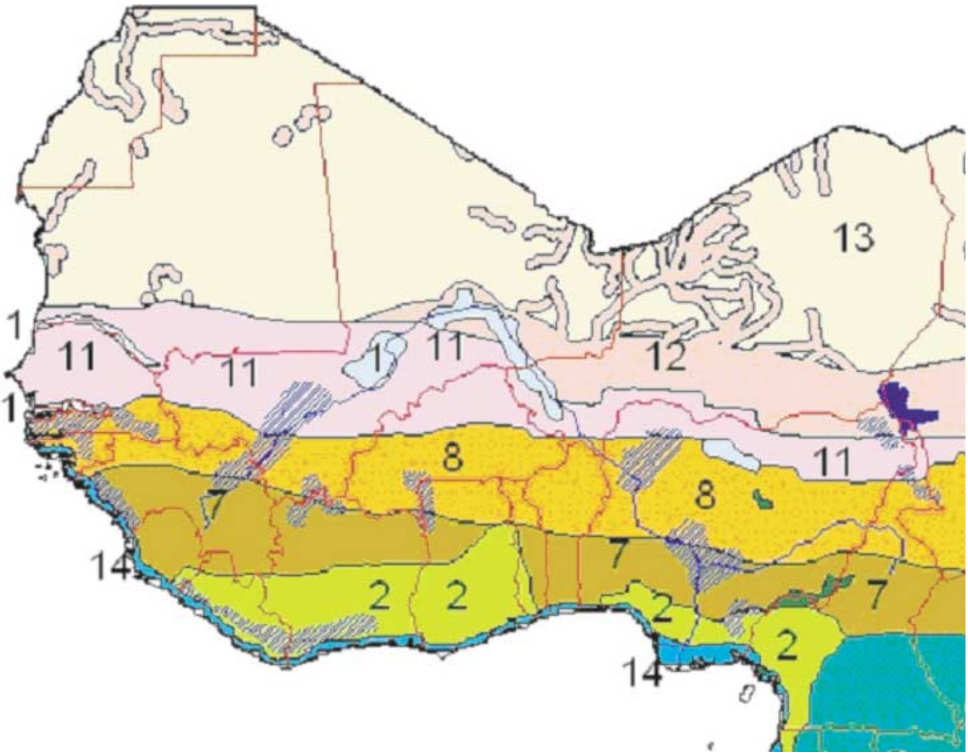

**Figure 3.** Farming systems in West Africa:1, irrigated; 2, tree crop; 7, root crop; 8, cereal-root crop mixed; 11, agro-pastoral millet/sorghum; 12, pastoral; 13, sparse (arid); 14, coastal artisanal fishing. From FAO (2001).

understanding the probabilistic nature of future climate/disease predictions (Thomson et al., 2000b) [Palmer et al., manuscript in preparation].

Many of the infectious diseases that contribute to the very high child mortality rates in West Africa occur within a ‘‘climate envelope’’ (for example: malaria, Rift Valley fever, yellow fever; relapsing fever, lymphatic filariasis, onchocerciasis) and are further restricted in their distribution by the microclimate/environment which supports their transmission (Thomson and Connor, 2000). However, transmission of such diseases in the region may vary in intensity between years as a result of inter-annual variation in climate and human vulnerability (Table 1). Many of these diseases are vector-borne, but climate may also be a major determinant of the variability of nonvector-borne diseases such as diarrheal disease, airborne infections such as measles (Brewster and Greenwood, 1993), and meningococcal meningitis (Cheesbrough et al., 1995; Molesworth et al., 2002b). Furthermore, climate ‘‘shocks’’ may change an individual’s exposure to infectious disease through migration (Prothero, 2001) and changes in behavior (Findley, 1994). A number of examples are presented below.

### *Malaria*

The most obvious result of rainfall decline on infectious disease transmission in West Africa is the associated change in malaria prevalence and incidence across the region. A greater than 80% decline in malaria prevalence rates have been observed in the semi-arid areas of northern Senegal and Niger from the early 1960s to the mid 1990s. This reduction is presumably associated with a loss of vector breeding sites, a shortening or reduction in intensity of the malaria transmission season as a result of lower vector survivorship and a loss of specific vector species. Previous studies have indicated that the different cytotypes of *Anopheles gambiae* s.s. are highly climate sensitive (Toure et al., 1994; Thomson et al., 1997). Observations of malaria prevalence rates before and after the droughts which occurred since the 1970s, indicate that in the Sahel (Niayes region, Senegal), endemic malaria decreased drastically after the disappearance of the principal mosquito vector, *Anopheles funestus*, due to the destruction of its larval sites by cultivation (Mouchet et al., 1996). No reestablishment of this species was observed in the Niayes region after the very wet year of 1995, however, the presence of this vector has been noted more recently in the irrigated areas of northern Senegal (Konate et al., 2001).

It has recently been proposed that climate and geography are more significant than poverty per se in determining levels of malaria burden, and that a reduction in malaria is likely to proceed a reduction in poverty (Sachs and Malaney, 2002). The major reductions in malaria transmission in the Sahel that have occurred have not,

**Figure 4.** Climate envelopes for malaria (Connor, 2002a) and meningitis epidemics (Molesworth et al., 2002b) in West Africa.

however, always resulted in a reduction in poverty, as many countries in the region currently rank at the bottom of the development indices. As well as climatic variability, other factors such as poor governance, conflict, international debt, poor terms of trade, and restricted access to the international markets have undermined the region's development agenda.

Changes in malaria endemicity as a result of the Sahelian drought have affected large areas of semi-arid West Africa as regions have moved from endemic to epidemic. This change presents a major obstacle to the development of regional malaria risk maps (Kleinschmidt et al., 2001) as prevalence rates may change dramatically over a few years. The increasing epidemic nature of malaria transmission has, however, been acknowledged in terms of developing control strategies for the region, with new efforts to develop malaria early warning systems based on routinely available meteorological station- or satellite-based information on excess rainfall (WHO, 2001b). Evidence supporting the use of rainfall-driven malaria early warning systems in West Africa is slowly building (Ndiaye et al., 2001). However, rainfall alone may not be a sufficient indicator of malaria transmission in those parts of the Sahel where its impact on the local ecology is governed by hydrological process associated with topography and soil type. In such a situation, an early warning system based on the water levels in rivers or dams may be more valuable—as has been proposed for the Senegal River basin (Faye et al., 1998). Support for the use of hydrological monitoring comes also from Sudan where river flooding is a key trigger for local increases in malaria cases (El Sayed et al., 2000). The flooding of rivers will depend on the rainfall distribution and timing in the entire river catchment rather than on local rainfall. It has been noted that the extent to which flooding is associated with increases in malaria cases is dependent on the timing of the floods in relation to other factors such as local rainfall and humidity (Najera, 1999). Changes in the presence of surface water as a result of the development of irrigation schemes along the major river systems in West Africa has important implications for malaria transmission. Expectations that the consequent increases in available breeding sites for malaria vectors will result in an inevitable increase in malaria transmission in the vicinity of such schemes has not, however, always been borne out (Ijumba and Lindsay, 2001). The explanation for this finding is still unresolved but, in some cases at least, can be attributed to displacement of the most endophilic and anthropophilic malaria vector *Anopheles funestus* by *An. arabiensis* with lower vectorial capacity.

### *Lymphatic Filariasis*

The ecological determinants of lymphatic filariasis infection are not well understood, although a generalized ecological distribution was proposed by Brengues in the 1970s (Brengues, 1975); see Figure 5. The parameters used to create Brengues' filariasis map were elevation, vegetation cover, and annual rainfall. The importance of understanding the geographical determinants of this disease have reemerged with the development of efforts to control

**Table 1.** Major Causes of Morbidity and Mortality in West Africa Which Are Directly Linked to Climate Either through Climate Envelopes (1), Seasonality (2), Decadal (3), and Inter-annual Variability (4): Evidence from the Current Literature

| Disease (and causative organism) | Mode of transmission/vector | Potential climate/environmental determinants | Documented relationship to climate |
|---|---|---|---|
| Malaria (*Plasmodium* sp.) | Mosquitoes (*Anopheles* sp.) | Rainfall, humidity, temperature, surface water, NDVI | Climate envelope (Kleinschmidt et al., 2001); climate seasonality (Brewster and Greenwood, 1993); climate shifts (Trape, 1999); climate inter-annual variability (Julvez et al., 1992; Ndiaye et al., 2001) |
| Rift Valley fever (*Phlebovirus*) | Mosquitoes (*Aedes* sp.) | Rainfall, humidity, temperature | Climate inter-annual variability (Thonnon et al., 1999) |
| Yellow fever (*Flavivirus*) | Mosquitoes (*Culex* sp.) | Surface water, NDVI | Climate inter-annual variability (Thonnon et al., 1999; TraoreLamizana et al., 1996) |
| Lymphatic filariasis (*Wuchereria bancrofti* in Africa) | Mosquitoes (*Anopheles* sp., *Aedes* sp., *Culex* sp.) | Rainfall, humidity, temperature, surface water, NDVI | Climate envelope (Lindsay and Thomas, 2000; Gyapong et al., 2002) |
| Relapsing fever (*Borrelia*) | Soft ticks (*Ornithodorus*) | Rainfall, humidity, temperature, NDVI | Climate shifts (Trape, 1999) |
| River blindness (*Onchocerca volvulus*) | Blackflies (*Simulium* sp.) | Wind, river discharge | Climate inter-annual variability (Thomson et al., 1996) |
| African eye worm (*Loa loa*) | Blackflies (*Chrysops* sp.) | Forest canopy, forest soils | Climate envelope (Thomson et al., 2000a) |
| Guinea worm (*Dracunculus medinensis*) | Blackflies (*Cyclops* sp.) | Surface water | Climate envelope (Hunter, 1997); climate shifts (Hunter, 1997); climate inter-annual variability (Hunter, 1997) |
| Sleeping sickness (*Trypanosoma brucei gambiensis*) | Tsetse (*Glossina* sp.) | Gallery forests, savannah woodland | Climate envelope (Rogers, 1991) |
| Schistosomiasis/bilharzia (*Schistosoma* sp.) | Snails (e.g., *Bulinus africanus*) | Surface water | Climate envelope (Hunter, 2003) |
| Diarrheal diseases (rotavirus and other viral and parasitic infections) | Filth flies (e.g., *Musca* sp. and mechanical transmission) | Poor sanitation associated with water shortages | Climate seasonality (Brewster and Greenwood, 1993) |
| Cholera (*Vibrio cholerae*) | Filth flies (e.g., *Musca* sp. and mechanical transmission) | Poor water sources, flooding of cess pits, algal blooms | Climate seasonality (Naidoo and Patric, 2002) |
| Pneumonia (viral, bacterial, mycoplasmas, and other causes) | Airborne aerosol | Cold temperatures | Climate seasonality (Brewster and Greenwood, 1993) |
| Meningococcal meningitis (*Neisseria meningitides*) | Airborne aerosol | Absolute humidity, dust, temperature | Climate envelope (Lapeyssonnie, 1963; Molesworth et al., 2003; Cheesbrough et al., 1995); climate seasonality (Brewster and Greenwood, 1993; Molesworth et al., 2001) |
| Trachoma (*Chlamydia trachomatis*) | *Musca sorbens* and mechanical transmission | Temperature, humidity | Climate envelope (Emerson et al., 2000) |

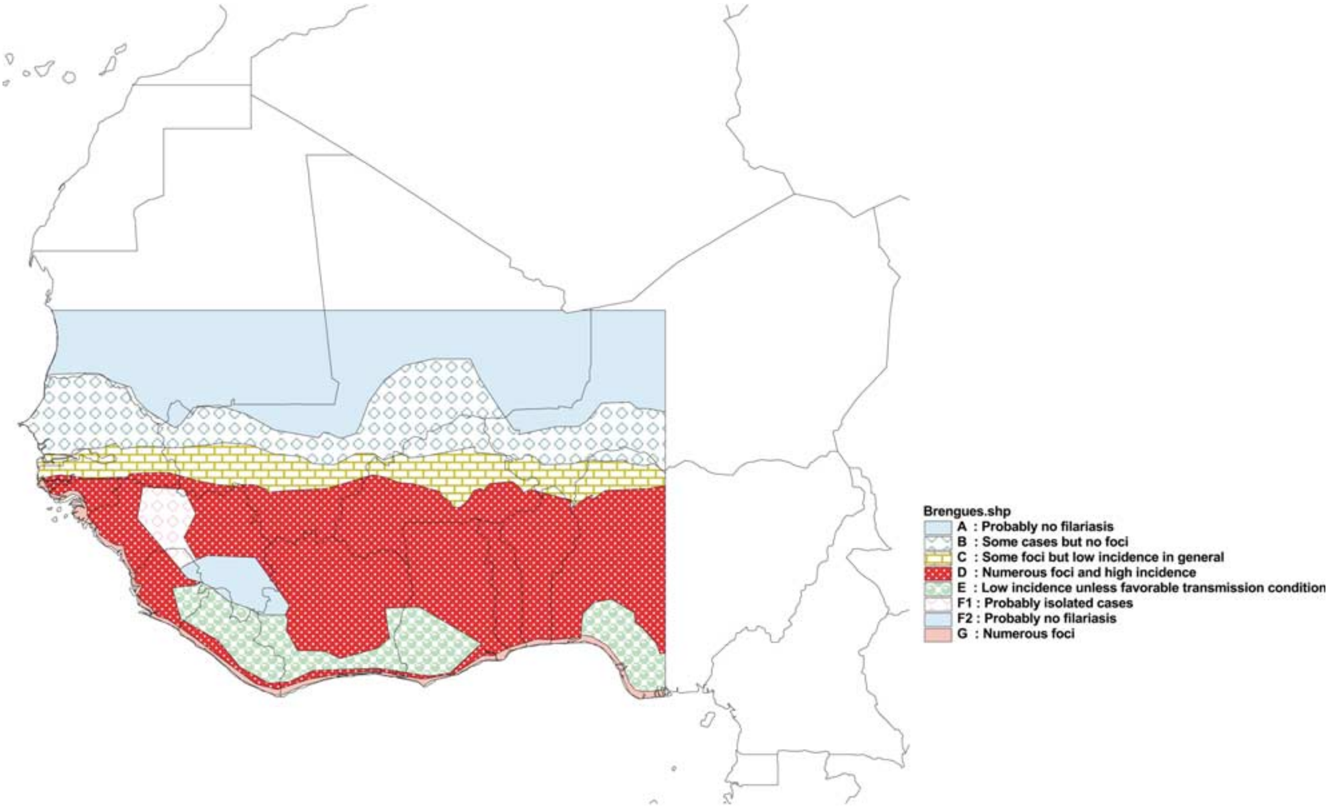

**Figure 5.** Zonation map of lymphatic filariasis endemicity in West Africa based on ecological criteria (Brengues, 1975).

lymphatic filariasis in Africa as part of a global program for its elimination as a public health problem (Molyneux and Zagaria, 2002). The results of a recent study of the spatial distribution of prevalence rates of *Wucheria Bancrofti*-(the causative agent of lymphatic filariasis) has shown that this disease is largely absent from some of the Guinea coastal countries such as Togo and Benin—despite these countries being highly endemic for malaria (Gyapong et al., 2002). The apparent contrast in the frequency of human infection between *W. Bancrofti* and *P. falciparum* is all the more striking since both parasites are transmitted by the same mosquito vector (namely members of the *Anopheles gambiae* species complex). Gyapong and colleagues speculate that differences in the spatial distribution of these two diseases may be related to differences in the cytotypes of the vectors since high prevalence levels of filariasis seem to be coincident with the spatial distribution of Mopti and savannah forms of *Anopheles gambiae s.str*. Given that malaria infection rates have changed dramatically over the Sahel as a result of reduced rainfall, it would seem unlikely that filariasis transmission by *Anopheles gambiae* s.l. has not also been affected. There is however no evidence to date which can be used to substantiate such a claim.

### *Onchocerciasis*

Prior to the 1970s, onchocerciasis (known as river blindness) was a neglected disease. Its devastating effects where largely borne by those rural populations of West Africa living near the fast flowing rivers of the Sahel. When the Onchocerciasis Control Programme (OCP) was started in 1974, some of West Africa's richest river lands were uninhabited. In villages sited in river valleys near to the breeding sites of the blackfly vector of onchocerciasis (*Simulium damnosum* s.l.), it was not unusual to find 60% of the adults afflicted with the disease and 3–5% blind. Communities were forced to abandon their villages en masse. Today, more than 20 years and US $600 million after the program was first launched, the disease has been controlled through one of the most successful public health campaigns in history (Benton et al., 2002). The governments of 11 African nations and 24 donor agencies combined their resources and energies to spray the rivers where the blackflies breed, and to develop and distribute the anti-helminthic drug ivermectin for treatment or prevention of the disease. Villages once emptied by river blindness have been rapidly resettled—bringing new challenges to the delivery of health care in the region (Richards et al., 2001).

Understanding the spatial and temporal distribution of the vectors of onchocerciasis has been key to their successful control (Boakye et al., 1998), given that the *S. damnosum* species complex comprises many distinct sibling species with varying capacities to transmit the pathogen, *Onchocerca volvulus*. The distribution of the different members of the *Simulium damnosum* species complex is generally related to phtyogeographic zones, forest and savannah, but seasonal changes in their distribution occurs on an annual cycle as the monsoon winds and their accompanying rainfall aid dispersal and result in enhanced river flow and the creation of breeding sites. According to Baker et al. (1990), members of the *S. damnosum* complex move average distances of 15–20 km daily and may migrate over a total distance of 400–500 km. Unusual migrations of savannah species of *S. damnosum* s.l. (the species most commonly associated with the blinding form of the disease) into the forest zones have been observed (Thomson et al., 1996), and this has led to speculation on the possible role of deforestation and rainfall decline on the distribution of different species of *S. damnosum* s.l. (Walsh et al., 1993). Rainfall has also had a more direct impact on the control program through its role in determining river flow and, therefore, the amount and type of insecticide required to treat specific areas (Hougard et al., 1993).

With the extension of the control of onchocerciasis into countries hitherto not included (through the African Programme for Onchocerciasis Control, APOC), a new obstacle has been placed in the way of effective disease control by the presence of another filarial worm, *loa loa*, in forested West and Central Africa. This is a consequence of recent reports of severe and fatal encephalopathic reactions to ivermectin in individuals with high *loa loa* microfilarial counts. Consequently, mapping the spatial distribution of *loa loa* has become a priority for APOC in order to modify its treatment protocols appropriately (Thomson et al., 2000a).

### *Meningococcal Meningitis*

*Neisseria meningitidis* (the meningococcus) is responsible for endemic and epidemic meningococcal disease throughout the world. In Africa, meningococcal meningitis often occurs as extensive epidemics—with many thousands of deaths, particularly in the so-called meningitis belt of sub-Saharan Africa. This belt is defined as an area between latitudes 4° and 16° north where high incidence and recurring epidemics of cerebrospinal meningococcal meningitis coincide with the 300–1100 mm mean annual rainfall isohyets south of the Sahara (Lapeyssonnie, 1963); see Figure 4. Thus, the belt comprises much of semi-arid sub-Saharan Africa and, in particular, the Sahel epidemic waves occur every 5–10 years in the Sahel region of the sub-Sahara and are mostly due to group A meningococci.

Risk factors for invasive disease and epidemic outbreaks are not completely understood, but it is likely that a combination of conditions is necessary for an epidemic to occur; immunity, transmission of a virulent strain of meningococcus, poor living conditions, and population movements and crowding are all considered important. Concurrent infections have also been implicated. In addition, environmental factors may play a key role. Asymptomatic carriage of the meningococcus in the nasopharyngeal mucosa is common in the semi-arid zones of Africa, systemic infection causes invasive disease, and most cases result from infection recently acquired from exposure to carriers (Molesworth et al., 2002b).

The geographic predominance of epidemics in the belt region and their seasonal occurrence at dry, dusty times of year, ceasing with the onset of the rains (Molesworth et al., 2001) suggest that environmental conditions are important, although the mechanisms by which they may work are poorly understood. It has been postulated that low humidity and dust may damage the mucosal barrier, and/or inhibit its immune defense mechanism, thus increasing mucosal invasion and the risk of overt disease; indoor overcrowding in adverse environments (intense dust events) may enhance the spread of infection (Greenwood et al., 1987). In a recent review of the spatial and temporal occurrence of meningococcal meningitis epidemics across Africa, it has been clearly shown that the Sahel bears the greatest epidemic burden of meningococcal meningitis with over two-thirds of documented outbreaks and high attack rates (Molesworth et al., 2002b). A recent analysis of epidemic distribution and environmental data indicates that the absolute humidity profiles and land-cover types can be used to distinguish between areas with high and low risk of epidemics, and also that population density and dust may be implicated in some regions (Molesworth et al., 2003).

An increase in epidemic occurrence in the southern extent of the meningitis belt may be related to an increase in dust storms in the region (Molesworth et al., 2002a), which may be a consequence of the recent drought periods.

## DISCUSSION

Climate has had an enormous impact on health in West Africa. However, its underlying role in determining the burden of disease in the region on a yearly or decadal basis is not mentioned in key health policy documents, such as those that reflect the framework and indicators promoted for monitoring the achievements of Roll Back Malaria (RBM) (Remme et al., 2001). Its absence is all the more remarkable given that the stated aim of RBM is "to halve the burden of malaria through interventions adapted to local needs and strengthening of the health sector." If observations indicating that climate variation alone may be responsible for changes in prevalence rates of 50% in some areas, then indicators of the effectiveness of RBM interventions (which do not incorporate climate variability as a confounding factor) may be either overly optimistic or pessimistic as a result.

This is considerable evidence that many infectious diseases such as malaria occur within a climate "envelope" and vary between years in intensity as a result of interannual variation in climate and vulnerability. There is a clear need for researching and documenting more closely the extent to which morbidity and mortality from infectious disease, and their broad socio-economic impacts, is determined by climate, and whether or not climate/environmental information (such as seasonal forecasts or rainfall or vegetation monitoring) can, in practice, improve decision making for control purposes in the affected countries.

Currently, there is much interest in developing adaptation strategies for poor countries to cope with the likely impacts of climate change, and yet we know little about how shifts in climate have affected health outcomes in the recent past. Whether or not the recent drought in West Africa is part of the natural cycle of climate variability or indicative of anthropogenic climate change, we can learn much from the region's experience in terms of impacts and adaptation to extreme shifts in the region's climate over a relatively short period of time.

## ACKNOWLEDGMENTS

The authors thank Alessandra Giannini for providing Figure 1, and Valerie Obsomer for providing the digital data used in Figures 4 and 5, respectively. M.C.T., S.J.C., and N.W. are supported by a grant/cooperative agreement number NA67GP0299 from the National Oceanic and Atmospheric Administration.

## REFERENCES

Baker RHA, Guillet P, Seketeli A, Poudiougo P, Boakye D, Wilson MD, et al. (1990) Progress in controlling the reinvasion of windborne vectors into the western area of the Onchocerciasis Control Program in West-Africa. *Philosophical Transactions of the Royal Society of London. Series B: Biological Sciences (London).* 328:731–750

Batterbury S, Warren A (2001) The African Sahel 25 years after the great drought: assessing progress and moving towards new agendas and approaches. *Global Environmental Change* 11:1–8

Benton B, Bump J, Seketeli A, Liese B (2002) Partnership and promise: evolution of the African river-blindness campaigns. *Annals of Tropical Medicine and Parasitology* 96:5–14

Boakye DA, Back C, Fiasorgbor GK, Sib APP, Coulibaly Y (1998) Sibling species distributions of the Simulium damnosum complex in the West African Onchocerciasis Control Programme area during the decade 1984–93, following intensive larviciding since 1974. *Medical and Veterinary Entomology* 12:345–358

Brengues J (1975) *La Filariiose de Bancroft en Afrique de L'Ouest,* Paris: Orstom, pp 299

Brewster DR, Greenwood BM (1993) Seasonal-variation of pediatric diseases in the Gambia, West-Africa. *Annals of Tropical Paediatrics* 13:133–146

Cheesbrough JS, Morse AP, Green SDR (1995) Meningococcal meningitis and carriage in western Zaire—a hypoendemic zone related to climate. *Epidemiology and Infection* 114:75–92

Colwell R, Epstein P, Gubler D, Hall M, Reiter P, Shukla J, et al. (1998) Global climate change and infectious diseases. *Emerging Infectious Diseases* 4(3):451–452; available: http://www.cdc.gov.ncidod/EID/Vol4No3/colwell.htm

Connor SJ (2002a) Managing health and disease in developing countries. In: *Arnold Companion to Development Studies*, Desai V, Potter R (editors), London: Arnold, pp 396–400

Connor SJ (2002b) The use of environmental information systems (EIS) for malaria control planning in Africa. *Faculty of Medicine*, Liverpool, UK: University of Liverpool (unpublished thesis)

Cour JM (2001) The Sahel in West Africa: countries in transition to a full market economy. *Global Environmental Change* 11:31–47

Davies VAB (2000) Sierra Leone: Ironic tragedy. *Journal of African Economies* 9:349–369

Dilley M, Heyman BN (1995) ENSO and disaster: droughts, floods and El Niño/southern oscillation warm events. *Disasters* 19:181–193

Egg J, Gabas JJ (editors), (1997) *Preventing Food Crisis in the Sahel: Ten Years of Network Experience in Action: 1985–1995,* Paris: OECD

El Sayed BB, Arnot DE, Mukhtar MM, Baraka OZ, Dafalla AA, Elnaiem DE, et al. (2000) A study of the urban malaria transmission problem in Khartoum. *Acta Tropica* 75:163–171

Emerson PM, Bailey RL, Mahdi OS, Walraven GEL, Lindsay SW (2000) Transmission ecology of the fly Musca sorbens, a putative vector of trachoma. *Transactions of the Royal Society of Tropical Medicine and Hygiene* 94:28–32

Food and Agriculture Organization (FAO) (2001) "*Global Farming Systems Study: Challenges and Priorities to 2030*" In: Dixon J, Guilliuer A, Gibbon D (editors), *Synthesis and Global Overview*, available: http://www.fao.org/farming systems/

Faye O, Gaye O, Konate L, Molez J, Feller-Dansokho E, Herve J (1998) Prediction and prevention of malaria epidemics in the valley of the Senegal River. *Sante* 8:347–352

Findley SE (1994) Does drought increase migration—a study of migration from rural Mali during the 1983–1985 drought. *International Migration Review* 28:539–553

Folland CK, Palmer TN, Parker DE (1986) Sahel rainfall and worldwide sea temperatures. *Nature* 320:602–607

Giannini A, Saravanan RR, Chang P (2003) Oceanic forcing of Sahel rainfall on interannual to interdecadal time scales. *Science* 302:1027–1030

Goddard L, Mason SJ (2002) Sensitivity of seasonal climate forecasts to persisted SST anomalies. *Climate Dynamics* 19:619–631

Greenwood BM, Greenwood AM, Bradley AK, Williams K, Hassanking M, Shenton FC, et al. (1987) Factors influencing susceptibility to meningococcal disease during an epidemic in the Gambia, West-Africa. *Journal of Infection* 14:167–184

Gustard A, Cole GA (2002) *FRIEND, a global perspective 1998–2002,* Wallingford, UK: Centre for Ecology and Hydrology

Gyapong JO, Kyelem D, Kleinschmidt I, Agbo K, Ahouandogbo F, Gaba J, et al. (2002) The use of spatial analysis in mapping the distribution of Bancroftian filariasis in four West African countries. *Annals of Tropical Medicine and Parasitology* 96:695–705

Hansen JW (2002) Realizing the potential benefits of climate prediction to agriculture: issues, approaches, challenges. *Agricultural Systems* 74:309–330

Hougard JM, Poudiougo P, Guillet P, Back C, Akpoboua LKB, Quillevere D (1993) Criteria for the selection of larvicides by the Onchocerciasis-Control-Program in West-Africa. *Annals of Tropical Medicine and Parasitology* 87:435–442

Houghton JT, Ding Y, Griggs DJ, Noguer M, Van der Linden PJ, Xiaosu D (2001) *Climate Change 2001: The Scientific Basis Contribution of Working Group 1 to the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC),* Cambridge, UK: Cambridge University Press

Hulme M (2001) Climatic perspectives on Sahelian desiccation: 1973–1998. *Global Environmental Change* 11:19–29

Hunter JM (1997) Geographical patterns of guinea worm infestation in Ghana: an historical contribution. *Social Science & Medicine* 44:103–122

Hunter JM (2003) Inherited burden of disease: agricultural dams and the peristence of bloody urine (Schistosomiasis hematobium) in the Upper Eastern Region of Ghana, 1959–1997. *Social Science & Medicine* 56:219–234

Ijumba JN, Lindsay SW (2001) Impact of irrigation on malaria in Africa:paddies paradox. *Medical and Veterinary Entomology* 15:1–11

Julvez J, Develoux M, Mounkaila A, Mouchet J (1992) Malaria diversity in the Sahelo-Saharan region—a Review of the situation in Niger, West Africa. *Annales De La Societe Belge De Medecine Tropicale* 72:163–177

Kleinschmidt I, Omumbo J, Briet O, van de Giesen N, Sogoba N, Mensah NK, et al. (2001) An empirical malaria distribution map for West Africa. *Tropical Medicine & International Health* 6:779–786

Konate L, Diop A, Sy N, Faye MN, Deng Y, Izri A, et al. (2001) Comeback of Anopheles funestus in Sahelian Senegal. *Lancet* 358:336

Kovats RS, Campbell-Lendrum DH, McMichael AJ, Woodward A, Cox JS (2001) Early effects of climate change: do they include changes in vector-borne disease? *Philosophical Transactions of the Royal Society of London. Series B: Biological Sciences (London)* 356:1057–1068

Lamb PJ (1978) Large-scale tropical Atlantic surface circulation patterns associated with Subsaharan weather anomalies. *Tellus* Series A, 30:240–251

Lapeyssonnie L (1963) La méningite cérébro-spinale en Afrique. *Bulletin of the World Health Organization* 28(Suppl 1):3–114

Le Barbe L, Lebel T (1997) Rainfall climatology of the HAPEX-Sahel region during the years 1950—1990. *Journal of Hydrology* 188–189:43–73

Le Barbe L, Lebel T, Tapsoba D (2002) Rainfall variability in West Africa during the years 1950–90. *Journal of Climate* 15:187–202

Lindsay SW, Thomas CJ (2000) Mapping and estimating the population at risk from lymphatic filariasis in Africa. *Transaction of the Royal Society of Tropical Medicine and Hygiene* 94:37–45

Martens WJM, Jetten TH, Focks DA (1997) Sensitivity of malaria, schistosomiasis and dengue to global warming. *Climatic Change* 35:145–156

McCann JC (1999) Climate and causation in African History. *The International Journal of African Historical Studies* 32:261–279

McCarthy JJ, Canziani OF, Leary NA, Dokken DJ, White KS (2001) *Climate Change 2001: Impacts, Adaptation & Vulnerability Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC),* Cambridge, UK: Cambridge University Press

Molesworth AM, Djingary MH, Thomson MC (2001) *Seasonality of Meningococcal Disease in Niger, West Africa: a Preliminary Investigation. GEOMED '99,* Paris: Elsevier

Molesworth AM, Cuevas LE, Morse AP, Herman JR, Thomson MC (2002a) Dust clouds and spread of infection. *Lancet* 359:81–82

Molesworth AM, Thomson MC, Connor SJ, Cresswell MC, Morse A, Shears P, et al. (2002b) Where is the Meningitis Belt? *Transactions of the Royal Society of Tropical Medicine and Hygiene* 96:242–249

Molesworth AM, Cuevas LE, Connor SJ, Morse AP, Thomson MC (2003) Environmental risk and meningitis epidemics in Africa. *Emerging Infectious Diseases* 9(10):1287–1292

Molyneux DH, Zagaria N (2002) Lymphatic filariasis elimination: progress in global programme development. *Annals of Tropical Medicine and Parasitology* 96 (Suppl):S15–S40

Mouchet J, Faye O, Julvez J, Manguin S (1996) Drought and malaria retreat in the Sahel, West Africa. *Lancet* 348:1735–1736

Murray C, Lopez A, Mathers C, Stein C (2001) *The Global Burden of Disease 2000 Project, Aims, Methods, and Data Sources,* Geneva: World Health Organization

Naidoo A, Patric K (2002) Cholera: a continuous epidemic in Africa. *Journal of the Royal Society for the Promotion of Health* 122:89–94

Najera JA (1999) *Malaria Control: Achievements, Problems & Strategies,* Geneva: World Health Organization

Ndiaye O, Le Hesran JY, Etard JF, Diallo A, Simondon F, Ward MN, Robert V (2001) Variations climatiques et mortalité attributée au paludisme dans la zone de Niakhar, Sénégal de 1984–1996. *Cahiers Santé* 11:25–33

Nicholson SE, Davenport ML, Malo AR (1990) A comparison of the vegetation response to rainfall in the Sahel and East-Africa, using normalized difference vegetation index from Noaa Avhrr. *Climatic Change* 17:209–241

Patz JA, Reisen WK (2001) Immunology, climate change and vector-borne disease. *Trends in Immunology* 22:171–172

Prothero RM (1994) Forced movements of population and health-hazards in tropical Africa. *International Journal of Epidemiology* 23:657–664

Prothero RM (2001) Migration and malaria risk. *Health Risk & Society* 3:19–38

Remme JHF, Binka F, Nabarro D (2001) Toward a framework and indicators for monitoring roll back malaria. *American Journal of Tropical Medicine and Hygiene* 64:76–84

Richards FO, Boatin B, Sauerbrey M, Seketeli A (2001) Control of onchocerciasis today: status and challenges. *Trends in Parasitology* 17:558–563

Rogers DJ (1991) Satellite imagery, tsetse and trypanosomiasis in Africa. *Preventive Veterinary Medicine* 11:201–220

Rogers DJ, Randolph SE (2000) The global spread of malaria in a future, warmer world (vol 289, pg 1763, 2000). *Science* 289:2283–2284

Rotstayn LD, Lohmann U (2002) Tropical rainfall trends and the indirect aerosol effect. *Journal of Climate* 15:2103–2116

Sachs J, Malaney P (2002) The economic and social burden of malaria. *Nature* 415:680–685

Sachs JD (2002) A new global effort to control malaria. *Science* 298:122–124

Thomson MC, Connor SJ (2000) Environmental information systems for the control of arthropod vectors of disease. *Medical and Veterinary Entomology* 14:227–244

Thomson MC, Davies JB, Post RJ, Bockarie MJ, BeechGarwood PA, Kandeh J (1996) The unusual occurrence of savanna members of the Simulium damnosum species complex (Diptera: Simuliidae) in southern Sierra Leone in 1988. *Bulletin of Entomological Research* 86:271–280

Thomson MC, Connor SJ, Milligan P, Flasse SP (1997) Mapping malaria risk in Africa: what can satellite data contribute? *Parasitology Today* 13:313–318

Thomson MC, Obsomer V, Dunne M, Connor SJ, Molyneux DH (2000a) Satellite mapping of *Loa loa* prevalence in relation to ivermectin use in west and central Africa. *Lancet* 356:1198–1198

Thomson MC, Palmer T, Morse AP, Cresswell M, Connor SJ (2000b) Forecasting disease risk with seasonal climate predictions. *Lancet* 355:1559–1560

Thomson MC, Abayomi K, Barnston AG, Levy M, Dilley M (2003) El Nino and drought in southern Africa. *Lancet* 361:437–438

Thonnon J, Picquet M, Thiongane Y, Lo MA, Sylla R, Vercruysse J (1999) Rift valley fever surveillance in lower Senegal river basin: update 10 years after the epidemic. *Tropical Medicine and International Health* 4:580–585

Toure YT, Petrarca V, Traore SF, Coulibaly A, Maiga HM, Sankare O, et al. (1994) Ecological genetic-studies in the chromosomal form mopti of Anopheles-Gambiae S-Str in Mali, West-Africa. *Genetica* 94:213–223

TraoreLamizana M, Fontenille D, Zeller HG, Mondo M, Diallo M, Adam F, et al. (1996) Surveillance for yellow fever virus in eastern Senegal during 1993. *Journal of Medical Entomology* 33:760–765

Trape JF (1999) Changements climatiques et maladies infectieuses: le cas du paludisme et de la borreliose a tiques. *Médecine et Maladies Infectieuses* 29:296–300

Veeken H (1994) Letter from Sierra-Leone: Sierra-Leone: people displaced because of diamonds. *British Medical Journal* 309:523–525

Walsh JF, Molyneux DH, Birley MH (1993) Deforestation—effects on vector-Borne disease. *Parasitology* 106(Suppl):S55–S75

Ward MN (1998) Diagnosis and short-lead time prediction of summer rainfall in tropical North Africa at interannual and multi-decadal timescales. *Journal of Climate* 11:3167–3191

World Health Organization (WHO) (2001a) *Macro-economics and Health,* Geneva: WHO

World Health Organization (WHO) (2001b) *Malaria Early Warning Systems, Concepts, Indicators and Partners, A Framework for Field Research in Africa,* Geneva: WHO