# Environmental Change, Global Warming and Infectious Diseases in Northern Australia

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*We are increasing our clinical surveillance for new and increasing infectious diseases that may relate to environmental changes occurring in the short term and global warming over the longer term. It is predicted that with global warming the tropical north of Australia will become both hotter and wetter. This is likely to expand the receptive area within Australia for mosquito-borne diseases such as malaria and the arboviruses, Murray Valley encephalitis (MVE), Japanese encephalitis, and dengue. Melioidosis has recently been diagnosed in two people in Central Australia (below the "normal" endemic area of the Top End). Changing weather, together with environmental change from agricultural practices may well result in melioidosis becoming more common in parts of Australia other than the Top End. Leptospirosis has been increasingly diagnosed in north Queensland and the Top End, with several people critically ill. The crisis in East Timor has increased the movement of people and cargo between East Timor and Darwin and there has been the predicted increase in imported cases of malaria and dengue. The introduction of Japanese encephalitis to the Torres Strait and subsequently the Australian mainland is of great concern. The large numbers of feral pigs across northern Australia provide a potential amplifying host for this virus, which can result in destructive and fatal neurological disease (very similar to MVE virus disease). A new focus of scrub typhus has emerged in Litchfield Park south of Darwin, probably reflecting tourist exposure to bacteria present for millennia in a rodent-mite cycle.*

**Key Words:** *Global Warming, Tropical Infections, Melioidosis, Murray Valley Encephalitis Virus, Japanese Encephalitis Virus, Dengue, Malaria, Leptospirosis, Scrub Typhus*

## Climate, Environment and Infections

Both environmental change and climatic factors can influence the emergence and reemergence of infectious diseases. In addition there are important human determinants such as population changes, and in particular large movements of people during times of political instability, war and famine. Mosquito-borne diseases such as malaria, dengue and viral encephalitides are currently considered the most likely to be affected by both climate variations and potential climate change (Patz et al. 1996). Changes in temperature, total rainfall and rainfall patterns will change the geographic range of disease carrying mosquitoes and increase mosquito longevity, reproduction and biting rates. Increased temperature and humidity will also decrease the time for the pathogens to develop to an infectious stage within the mosquito (the extrinsic incubation period) (Githeko et al. 2000; Patz et al. 1996; Rogers & Packer 1993).

The combinations of increased temperature, increased rainfall and environmental changes with destruction of natural vegetation are likely to extend the range and increase the incidence of various environmental pathogens such as *Burkholderia pseudomallei*, the causative agent of melioidosis, and leptospirosis (Currie 2000). A rise in sea surface temperature and sea levels is predicted to increase a number of important water-borne diseases that are associated with temperature-sensitive marine ecosystems (Kovats 2000; Patz et al. 1996). These include cholera, which has been found to be widely distributed in marine environments, often associated with zooplankton and sometimes entering a viable but nonculturable state (Colwell 1996). Warmer water favours the growth of dinoflagellates, which are associated with coastal algal blooms such as red tides, and with toxic shellfish poisoning.

Stratospheric ozone depletion permits an increased amount of harmful ultraviolet (UV) radiation to enter the biosphere. The effect of UV radiation on DNA and proteins is thought to account for its effect on human health (Tong 2000). In addition to increased skin cancers such as melanoma and increased cataracts, potential effects of UV radiation on the immune system are of concern. These include decreased antigen processing at the skin and mucosal level and altered immune cell populations and cytokine production. It has been proposed that associated with this there may be a reduction in vaccine efficacy (Tong 2000).

There has recently been interest in the potential for microorganisms, including human pathogens, to survive in dust particles and travel thousands of kilometers within clouds (McCarthy 2001). It has been noted that the amount of African dust crossing the Atlantic and arriving in the Caribbean has been related to weather conditions, with a substantial increase during past severe droughts in Africa. Whether this weather-related phenomenon is resulting in the spread of infectious diseases currently remains speculative.

## Natural Climate Variability

There is an important distinction between current climate variability and potential climate change. The most important global climate system correlating with year-to-year variations in weather is the El Niño Southern Oscillation (ENSO). ENSO is a cycle of warming and cooling of the sea surface. Its two extremes are El Niño (warm event for the Peruvian coast) and La Niña (cool event) (Kovats 2000). The changes in sea temperature in the Pacific Ocean are paralleled by changes in atmospheric pressure across the Pacific basin (the Southern Oscillation). El Niño events occur every 2-7 years and last for 1-2 years. They are associated with extreme weather conditions, including floods in some countries such as in South America, and droughts in others such as Australia, Indonesia and Papua New Guinea (Kovats 2000; Nicholls 1993). There has been a strong association between ENSO and natural disasters globally such as floods, droughts, cyclones, hurricanes and volcanic eruptions (Bouma et al. 1997). In general the effects are more marked during El Niño years than La Niña years, with the rate of persons affected by natural disasters worldwide being greatest in the two years after each El Niño commences. However, there are important regional differences, with those parts of the world which usually receive less rain during El Niño events (such as Australia, Indonesia and Papua New Guinea) tending to become wetter during La Niña events (Githeko et al. 2000; Kovats 2000). Regional variations also occur in the likelihood of tropical storms and cyclones (Bouma et al. 1997). Similarly, disease risk variations are also evident. While some areas have an increased risk of malaria epidemics during a typical El Niño year, others have decreased malaria (Githeko et al. 2000; Loevinsohn 1994).

## Climate Change

While the link between variation in climate as evidenced by ENSO and natural disasters and disease is clearly established, the potential magnitude of the additional impact of predicted global climate change remains to be quantified. However, there has recently been consensus amongst most climatologists that climate changes resulting from human activities and separate from natural climate variations have already begun (Githeko et al. 2000; Patz et al. 1996). This is due to large-scale pollution of the lower atmosphere with greenhouse gases, of which carbon dioxide related to both fossil fuel use and deforestation is the major contributor (Patz et al. 1996). There is now general agreement that anthropogenic greenhouse gas emissions are significantly accelerating current global trends in warming. It was estimated that by 2100 the average temperature increase would be 2.0°C with a range of 1.0°C to 3.5°C (Githeko et al. 2000). However, the most recent estimates which include carbon-cycle feedbacks in the modelling now predict an average rise of 5.5°C by 2100 (Cox et al. 2000). It is also estimated that sea levels may rise by approximately 0.5m by the year 2100 (Patz et al. 1996). The earlier more conservative estimated rises in temperature and sea level represent five-fold and three-fold faster rates respectively than those which have occurred over the last 100 years. Of concern is that in addition to the direct effects of global warming it is predicted that ENSO events such as severe storms and weather conditions causing floods and droughts may become more frequent with global warming (Kovats 2000; Nicholls 1993; Patz et al. 1996).

In addition to the direct effect of increased temperature and rainfall on vector-borne diseases, climate variability and natural disasters can result in extensive human migration, damage to health system infrastructure and crop failure with resulting malnutrition and economic instability. There is therefore the potential for catastrophic multifactorial health impacts from global warming when combined with population pressures and environmental destruction such as deforestation and desertification.

## Specific Diseases in Australia

For Australia, it was predicted that by 2030 temperatures will rise by 0.3-1.4°C, and there may be an overall decrease in rainfall, although this has not been evident in recent analyses (Githeko et al. 2000). The most recent CSIRO prediction is for a 0.4-2.0°C rise over most of Australia by 2030 (CSIRO 2001). Furthermore, although rainfall may decrease in southern Australia the overall rainfall in the tropical north may well increase and in particular be associated with heavier monsoonal rainfall (Nicholls 1993). A study from the Top End of the Northern Territory showed a slight overall increase in annual total rainfall over the last 50 years with an increase in the strength of the Australian summer monsoon during that period (Butterworth & Arthur 1993).

### *Malaria*

Malaria was an important cause of morbidity and mortality during early European settlement of northern Australia (Currie 1993). The decline of malaria in the north resulted from a combination of case treatment, surveillance and drug eradication programs, together with vector mosquito control measures around population centres. The last indigenous case of malaria in Australia (not imported or from an introduced case) was from Roper River, Northern Territory in 1962. However, the continuing presence of certain Anopheles mosquito species makes tropical Australia north of latitude 19°S (north of a line connecting Broome and Townsville) considered to be receptive for malaria reintroduction (Currie 2000). There has been no malaria transmission in the Northern Territory since 1962, but in north Queensland there have been occasional local cycles of transmission called “introduced malaria”, which involved local mosquitoes being infected from an imported case (Brookes et al. 1997). A case of “airport malaria” was reported from Cairns in 1996 and was presumed to be caused by importation of an infected mosquito (Jenkin et al. 1997).

With the close geographical and cultural links to Papua New Guinea, the Torres Strait Islands are particularly vulnerable to introduced malaria and the potential for reestablishment of indigenous disease. Deaths from *Plasmodium falciparum* malaria occurred in the Torres Strait Islands in 1990 and 1992, and in 2000 a brief local transmission cycle was implicated in a reported case of introduced *P. falciparum* malaria (Harley et al. 2001). Since the events of late 1999 leading to independence for East Timor, there has been a substantial increase in numbers of malaria cases imported to Darwin and the Northern Territory, with several severe cases and one fatality (Blum & Stephens 2001). Potential future population migrations from malaria endemic areas to receptive northern Australia make ongoing malaria control measures essential. These include entomological surveillance with larval and adult mosquito control where indicated; longer term physical control measures to prevent vector mosquito breeding sites around urban areas; supervised therapy and follow up of cases to confirm parasite clearance; and active case detection in selected situations for high-risk groups, such as boat people and refugees from highly endemic areas.

Cycles of climate variation and potential global warming both have important implications for malaria. Malaria epidemics have occurred in South America after heavy rain and flooding associated with El Niño (Kovats 2000). However while malaria epidemics are more likely during and following an El Niño event in the Punjab and Sri Lanka, in the Punjab these epidemics are associated with above-normal rainfall while in Sri Lanka they are associated with below-normal rainfall (Githeko et al. 2000). The Sri Lankan situation is attributed to increased mosquito breeding in stagnant pools of water in the drier conditions. It has been predicted that the most dramatic impact on malaria with global warming will be in regions near the altitude or latitude limits of the disease, where there is unstable transmission and a large non-immune population (Githeko et al. 2000; Loevinsohn 1994; Patz et al. 1996).

Climate modeling for the Australian situation has suggested that global warming will enlarge the potential range of the main malaria vector in Australia, *Anopheles farauti*. With a model incorporating a 1.5°C increase in temperature and a 10% increase in summer rainfall in southern Australia by the year 2030, it was estimated that *A. farauti* could extend along the Queensland coast as far south as Gladstone, which is 800km south of the present limit of *A. farauti* (Bryan, Foley & Sutherst 1996).

### Dengue

Since the 1880s dengue and its main mosquito vector *Aedes aegypti* have periodically invaded north Australia. Initial epidemics spread south as far as northern New South Wales. As *A. aegypti* breeds in water receptacles, it is thought that the replacement of open rainwater tanks with reticulated water has substantially contributed to the dramatic decline of *A. aegypti* which resulted in eradication of dengue in 1955 (Currie 1993). However, in the 1980s there was a resurgence of dengue in north Queensland, with seven outbreaks documented between 1990 and 1998 (Hanna et al. 1998). *A. aegypti* remains present in north Queensland and dengue continues to be introduced, with extensive surveillance and public health measures required, such as the Dengue Fever Management Plan for imported dengue cases and when local transmission occurs (Hanna et al. 2001). *A. aegypti* and therefore dengue remain eradicated from the Northern Territory and Western Australia, but imported mosquitoes and/or larvae are occasionally detected, most recently in boats arriving from East Timor. In addition, since late 1999 there has been a substantial increase in the numbers of dengue cases arriving in Darwin, mostly from East Timor. Continued surveillance is therefore essential to prevent reestablishment of dengue in the Top End of the Northern Territory.

Increased rainfall can affect *A. aegypti* density in some locations and high rates of dengue and dengue haemorrhagic fever in 1998 in parts of Asia were attributed to weather conditions related to El Niño (Kovats 2000). Epidemics of dengue in some South Pacific islands have been linked to La Niña events, which were associated with more rainfall and a higher temperature than normal (Kovats 2000). However, in Indonesia dengue fever epidemics have occurred in drought conditions following El Niño (Kovats 2000). This may in part reflect the importance in urban settings of *A. aegypti* breeding in peri-domestic receptacles.

The increases in dengue in many tropical regions over the last 20 years have been attributed to a combination of urbanisation, population migration, absence of closed water systems and inadequate mosquito control (Kovats 2000; Patz et al. 1996). In addition, there has been a clear association of increased rates of dengue during warmer years. With slightly higher temperatures the extrinsic incubation period of the virus in the mosquito decreases, resulting in a higher proportion of mosquitoes becoming infectious at a given time (Patz et al. 1996). It has also been shown that at high temperatures *A. aegypti* bite more frequently. Therefore global warming is likely to result in both an increased distribution of dengue to higher latitudes and altitudes as well as an increased incidence in endemic areas.

### Murray Valley Encephalitis

The Murray Valley encephalitis (MVE) virus is a mosquito-borne flavivirus of the West-Nile Japanese encephalitis antigenic complex. MVE virus usually causes asymptomatic infection, but for those with encephalitis the mortality from the destructive neurological disease is 20% (Currie 2000). MVE is endemic in the Kimberley region of Western Australia and the adjacent Northern Territory. MVE virus has caused epidemics of encephalitis in southeastern Australia, particularly in the Murray Darling River system. The last epidemic was in 1974, which involved 58 cases, with 13 deaths (Mackenzie 1999). The virus survives in zoonotic transmission cycles involving various vertebrate reservoir hosts of which wild birds and in particular wading water birds such as the Nankeen (Rufous) night heron are believed to be most important. The main mosquito vector is Culex annulirostris. The infrequent epidemics in temperate south-eastern Australia occur between January and May, usually following several seasons of high rainfall and flooding with large increases in vector populations (Mackenzie 1999; Spencer et al. 2001). This flooding is generally associated with La Niña events (Nicholls 1993). Cases of MVE also occur occasionally in Queensland and in Papua New Guinea (Spencer et al. 2001). MVE has been rare in Central Australia but after exceptionally heavy rainfall accompanied by flooding in early 2000 there was a cluster of cases confirmed in the region (Brown 2000).

It is thought likely that the virus is sporadically re-introduced into southern locations by birds from the north of Australia following periods of extreme rainfall and flooding. It has been proposed that environmental and ecological changes as a result of damming the Ord River to establish the irrigation area within the Kimberley region of northern Western Australia have been responsible for an increase in MVE virus activity and endemicity (Mackenzie 1999). In addition, predicted increases in temperature and intensity and frequency of tropical storms and extreme weather events associated with global warming may result in an extension of the current MVE virus endemic area and more frequent epidemics in central and southern Australia.

### Japanese Encephalitis

Japanese encephalitis (JE) virus is a mosquito-borne flavivirus similar to MVE virus. The first outbreak of JE in Australia occurred in the Torres Strait in 1995 (Hanna et al. 1996). Two of the three cases were fatal. The cases occurred on Badu Island but seroepidemiological studies of sentinel pigs showed evidence of widespread infection within the Torres Strait Islands. As viral isolates were virtually identical, it was thought that the outbreak originated from a single source (Mackenzie 1999; Van Den Hurk et al. 2001). One human case of JE was reported from the Mitchell River area in south-west Cape York from March 1998 (Hanna et al. 1999). Extensive serological studies showed no evidence of other human infections in Cape York communities but domestic pigs seroconverted to JE virus in several regions. Sentinel pigs in the Torres Strait have shown JE virus activity during most wet seasons subsequent to 1995. However, sentinel pigs on Cape York have remained negative since 1998, suggesting only the single incursion of JE virus into the Australian mainland to date (Mackenzie 1999).

It has now been shown that JE virus is also established in Papua New Guinea and in particular in the Western Province (Mackenzie 1999). JE virus isolates from Papua New Guinea, the Torres Strait Islands and the Australian mainland have all been nearly identical (Van Den Hurk et al. 2001). This has led to speculation that the introduction of JE virus to Australia is through infected mosquitoes transported down from Papua New Guinea by winds associated with monsoonal weather systems (Mackenzie 1999; Van Den Hurk et al. 2001). However, further studies are necessary to definitively elucidate the mechanisms of incursion of JE virus into Australia and the roles of potential vertebrate hosts such as domestic and feral pigs and birds and the relative importance of the various potential vector mosquito species. JE has recently been confirmed also from East Timor (Hueston et al. 2001).

There is also a relationship between JE and weather patterns. Epidemics have occurred in India following heavy rainfall (La Niña effect) (Nicholls 1993). Increased temperatures and increased extremes of weather involving Papua New Guinea and northern Australia have the potential to increase the likelihood of further JE incursions into Australia. In addition, environmental factors may be important in cycles of JE virus transmission. In particular the increasing numbers of feral pigs across northern Australia have the potential to act as amplifying hosts for the virus. Authorities have estimated the numbers of feral pigs to now be in the millions in both the Top End of the Northern Territory and in Cape York, with substantial populations near many remote Aboriginal communities (Savannah Links 1999).

### Melioidosis

*Burkholderia pseudomallei* is a soil and water saprophytic bacterium which infects humans and animals to cause melioidosis. Melioidosis is the most common cause of fatal community-acquired bacteraemic pneumonia in the tropical Top End of the Northern Territory (Currie et al. 2000a). Melioidosis is also important in north Queensland, including the Torres Strait Islands and in the Kimberley (Currie et al. 2000b). Two small outbreaks have been documented in remote Aboriginal communities associated with contamination of the water supply (Currie et al. 2001; Inglis et al. 2000). Other cases in Australia have also occurred following heavy rains and flooding in areas not normally considered endemic for melioidosis. These have included cases in the Brisbane River Valley at Ipswich (27.5°S) (Munckhof et al. 2001) and Tennant Creek (19.5°S) (Hassell et al. 2001).

Melioidosis is closely linked with rainfall. In the Top End of the Northern Territory 85% of cases occur during the six months of the monsoonal wet season (November through April) (Currie et al. 2000a).

Heavier rainfall is associated with more cases and in particular extreme weather events have resulted in clusters of cases within the endemic region. For example, subsequent to the Katherine floods on Australia Day, 26 January 1998, there were 11 cases of melioidosis with one death. Following Cyclone Thelma, a category 5 severe tropical cyclone that struck the Tiwi Islands on December 7, 1998, there were seven cases of melioidosis from the Islands, with one death. Prior to this melioidosis had been extremely uncommon on the Tiwi Islands, possibly because of the predominance of sandy soil layers rather than the clay seen across much of the mainland Top End. In addition to high rainfall predicting melioidosis cases, environmental factors are also important. Disturbance of surface soil with engineering works has been associated with animal and human case clusters in Australia (Currie et al. 2000b; Inglis et al. 2000). It is thought that these disturbances result in an increasing presence of *B. pseudomallei* at the surface, resulting in an increased likelihood of percutaneous inoculation or possibly inhalation of the bacteria. Agricultural practices have also been implicated in changes in the microbial ecology of the soil environment in certain regions. In particular it is postulated that widespread rice farming in Thailand may be implicated in a greater presence of *B. pseudomallei* in the soil and surface water (Dance 2000). In parts of northeastern Thailand melioidosis is the most important cause of community-acquired septicaemia (Chaowagul et al. 1989). Recent molecular genetic studies of the microbial ecology of soils from virgin forest and cleared areas of the Big Island in Hawaii showed a dramatic change of soil organisms within the cleared location towards *Burkholderia pseudomallei* and related species (Nusslein & Tiedje 1999). The use of pesticides and herbicides may also be relevant to the presence of *B. pseudomallei*. Elucidating the association of *B. pseudomallei* with specific vegetation and its interaction with the rhizosphere and with other soil microflora has important implications for the epidemiology of melioidosis.

It is therefore likely that potential global warming and more severe weather conditions, in particular more heavy rain and flooding, will extend the current melioidosis endemic locations. In addition, various environmental factors such as disturbances of surface soils and alterations in soil microbial ecology may result in an increase in melioidosis.

### *Leptospirosis*

Leptospirosis is a zoonotic disease of worldwide distribution. *Leptospira* hosts include rodents, livestock, marsupials and dogs. Animals may have asymptomatic infection and harbour the spirochaete for months in their kidneys, with urinary excretion resulting in environmental contamination (Centers for Disease Control and Prevention 2001). Heavy rainfall and high temperatures increase the survival of the organism in the environment. Transmission to humans usually follows contact of skin (especially abraded skin) with contaminated water or wet soil or vegetation. Ingestion of contaminated water is also a mode of transmission. Leptospirosis is therefore an occupational hazard for those working on the land or with animals as well as being a recreational hazard to bathers, campers and most recently those involved with sporting events such as white water rafting and the recent Eco-Challenge-Sabah 2000 in Borneo, Malaysia (Centers for Disease Control and Prevention 2001).

In South America most cases occur during the rainy season (Lomar, Diament, & Torres 2000). Over the last few years leptospirosis has been increasingly diagnosed in north Queensland and the Top End of the Northern Territory (Krause 2001; Smythe et al. 2000). This is in part attributed to increasing numbers of people with recreational exposure and contrasts with the long known association of leptospirosis with sugar cane cutters exposed to rat urine. It is also possible that the *Leptospira* organisms are becoming more widespread, associated with changes in the environment with increased numbers of animal reservoirs and possibly also associated with changes in rainfall patterns. As well as increasing numbers of cases in northern Australia there has been an increase in severity of cases in both north Queensland and the Northern Territory, with patients requiring intensive care management for multiple organ damage and fatalities from severe pulmonary haemorrhage (Simpson et al. 1998).

### Scrub Typhus

Scrub typhus is caused by the bacterium *Orientia tsutsugamushi*, which is transmitted to humans by the bite of a larval trombiculid mite. The mite is an ectoparasite of small mammals such as rodents and native marsupials. The bacterium is maintained in the environment through a rodent-mite cycle. Scrub typhus has long been recognised as endemic in coastal Far North Queensland as well as in Asia, Southeast Asia and some Pacific islands (McBride et al. 1999). The geographic distribution of scrub typhus vectors and disease are characteristically patchy and in north Queensland most of the circumscribed foci (mite islands) have been rainforest areas of high humidity and annual rainfall exceeding 1500mm (Currie, O'Connor & Dwyer 1993). Scrub typhus cases in humans have occurred when virgin rainforest (formerly called “scrub” in Queensland) was cleared for human settlement or activities. In Asia scrub typhus has had a monsoonal relationship.

Since 1990, nine cases of scrub typhus have been diagnosed in people visiting Litchfield Park, an area of rainforest 140km south of Darwin in the Northern Territory (Currie, O'Connor & Dwyer 1993). This region was opened to the public as Litchfield National Park in 1986 and cases have only become evident since the area became accessible to tourists. A genetic analysis of the Litchfield strain of *O. tsutsugamushi* shows it to be substantially different from strains from the East Coast of Australia and from overseas (Odorico et al. 1998). It is therefore likely that *O. tsutsugamushi* has been present in the mites and native mammals of northern Australia for millennia. There may well be other circumscribed foci of vectors, endemic rodents and *O. tsutsugamushi* in the discrete rainforest habitats across northern Australia where humans have to date rarely intruded (Currie, O'Connor & Dwyer 1993). These may become evident as tourism to the “outback” increases. It is also possible that changes in weather patterns with increasing rainfall in some regions will result in *O. tsutsugamushi* being introduced into new locations. In contrast, it has been noted that tick-borne diseases often favour temperate climates with cooler temperatures because of higher tick mortality at higher temperatures (Githeko et al. 2000). Therefore, Australian Tick Typhus, which is caused by *Rickettsia australis*, may have a diminished northern range with global warming, although higher humidity would favour tick survival.

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### References

Blum, P. G. & Stephens, D. 2001, ‘Severe falciparum malaria in five soldiers from East Timor: a case series and literature review’, *Anaesthesia and Intensive Care*, vol. 29, pp. 426-34.

Bouma, M. J., Kovats, R. S., Goubet, S. A., Cox, J. S. & Haines, A. 1997, ‘Global assessment of El Nino’s disaster burden’, *Lancet*, vol. 350, pp. 1435-8.

Brookes, D. L., Ritchie, S. A., van den Hurk, A. F., Fielding, J. R., & Loewenthal, M. R. 1997, 'Plasmodium vivax malaria acquired in far north Queensland', *Medical Journal of Australia*, vol. 166, pp. 82-3.

Brown, A. 2000, 'An outbreak of Australian encephalitis due to Murray Valley Encephalitis Virus and Kunjin Virus in Central Australia, March 2000.' *The Northern Territory Disease Control Bulletin*, vol. 7, pp. 1-4.

Bryan, J. H., Foley, D. H. & Sutherst, R. W. 1996, 'Malaria transmission and climate change in Australia', *Medical Journal of Australia*, vol. 164, pp. 345-7.

Butterworth, I. & Arthur, J. 1993, 'Rainfall trends over the Northern Territory Top End', *Bureau of Meteorology, Darwin*, vol. 2, pp. 111-6.

Centers for Disease Control and Prevention 2001, 'Update: Outbreak of acute febrile illness among athletes participating in Eco-Challenge-Sabah 2000, Borneo, Malaysia, 2000', *Morbidity and Mortality Weekly Report*, vol. 50, pp. 21-4.

Chaowagul, W., White, N. J., Dance, D. A., Wattanagoon, Y., Naigowit, P., Davis, T. M., Looareesuwan, S. & Pitakwatchara, N. 1989, 'Melioidosis: A major cause of community-acquired septicemia in northeastern Thailand', *Journal of Infectious Disease*, vol. 159, pp. 890-9.

Colwell, R. R. 1996, 'Global climate and infectious disease: the cholera paradigm', *Science*, vol. 274, pp. 2025-31.

Cox, P. M., Betts, R. A., Jones, C. D., Spall, S. A., & Totterdell, I. J. 2000, 'Acceleration of global warming due to carbon-cycle feedbacks in a coupled climate model', *Nature*, vol. 408, pp. 184-7.

CSIRO 2001, 'Climate change projections for Australia', pp. 1-8, http://www.dar.csiro.au/publications/projections2001.pdf: CSIRO.

Currie, B. 1993, 'Medicine in tropical Australia', *Medical Journal of Australia*, vol. 158, pp. 609-15.

Currie, B. 2000, 'Infectious diseases of Tropical Australia', *Medicine Today*, vol. 1, pp. 71-81.

Currie, B., O'Connor, L. & Dwyer, B. 1993, 'A new focus of scrub typhus in tropical Australia', *American Journal of Tropical Medicine and Hygiene*, vol. 49, pp. 425-9.

Currie, B. J., Fisher, D. A., Howard, D. M., Burrow, J. N., Lo, D., Selva-Nayagam, S., Anstey, N. M., Huffam, S. E., Snelling, P. L., Marks, P. J., Stephens, D. P., Lum, G. D., Jacups, S. P. & Krause, V.L. 2000a, 'Endemic melioidosis in tropical northern Australia: A 10-year prospective study and review of the literature', *Clinical Infectious Diseases*, vol. 31, pp. 981-6.

Currie, B. J., Fisher, D. A., Howard, D. M., Burrow, J. N., Selvanayagam, S., Snelling, P. L., Anstey, N. M. & Mayo, M. J. 2000b, 'The epidemiology of melioidosis in Australia and Papua New Guinea.' *Acta Tropica*, vol. 74, pp. 121-7.

Currie, B. J., Mayo, M., Anstey, N. M., Donohoe, P., Haase, A. & Kemp, D. J. 2001, 'A cluster of melioidosis cases from an endemic region is clonal and is linked to the water supply using molecular typing of Burkholderia pseudomallei isolates', *American Journal of Tropical Medicine and Hygiene*, vol. 65,177-9.

Dance, D. A. 2000, 'Ecology of Burkholderia pseudomallei and the interactions between environmental *Burkholderia* spp. and human-animal hosts', *Acta Tropica*, vol. 74,159-68.

Githeko, A.K., Lindsay, S.W., Confalonieri, U.E., & Patz, J.A. 2000, 'Climate change and vector-borne diseases: A regional analysis', Bulletin of the World Health Organization, vol. 78, pp. 1136-47.

Hanna, J. N., Ritchie, S., Phillips, D., Serafin, I., Hills, S., van den Hurk, A., Pyke, A., McBride, W., Amadio, A. & Spark, R. 2001, 'An epidemic of dengue 3 in far north Queensland, 1997-1999', *Medical Journal of Australia*, vol. 174,pp. 178-82.

Hanna, J. N., Ritchie, S. A., Merritt, A. D., van den Hurk, A. F., Phillips, D. A., Serafin, I. L., Norton, R. E., McBride, W. J., Gleeson, F. V., & Poidinger, M. 1998, 'Two contiguous outbreaks of dengue type 2 in north Queensland', *Medical Journal of Australia*, vol. 168, pp. 221-5.

Hanna, J. N., Ritchie, S. A., Phillips, D. A., Lee, J. M., Hills, S. L., van den Hurk, A. F., Pyke, A. T., Johansen, C. A. & Mackenzie, J. S. 1999, 'Japanese encephalitis in north Queensland, Australia, 1998', *Medical Journal of Australia*, vol. 170, pp. 533-6.

Hanna, J. N., Ritchie, S. A., Phillips, D. A., Shield, J., Bailey, M. C., Mackenzie, J. S., Poidinger, M., McCall, B. J. & Mills, P. J. 1996, 'An outbreak of Japanese encephalitis in the Torres Strait, Australia, 1995', *Medical Journal of Australia*, vol. 165, pp. 256-60.

Harley, D., Garstone, G., Montgomery, B. & Ritchie, S. 2001, 'Locally-acquired Plasmodium falciparum malaria in Darnley Island in the Torres Strait', *Clinical Infectious Diseases*, vol. 25, pp. 151-3.

Hassell, M., Pearson, M., Burrow, J. & Anstey, N. 2001, 'Melioidosis can occur in Central Australia after heavy rainfall', *NT Disease Control Bulletin*, vol. 8, p. 1.

Hueston, L., Lobo, S., Andjaparidze, A., Corte Real, A., Slote, A., Kacvinska, A., Cartwright, M., Tulloch, J., Mendes, J., Kelly, K., Condon, R., Lynch, C. & Brown, L. 2001, 'Japanese Encephalitis in East Timor ( abstract)', *Microbiology Australia*, vol. 22, A94.

Inglis, T. J., Garrow, S. C., Henderson, M., Clair, A., Sampson, J., O'Reilly, L. & Cameron, B. 2000, '*Burkholderia pseudomallei* traced to water treatment plant in Australia', *Emerging Infectious Diseases*, vol. 6, pp. 56-9.

Jenkin, G. A., Ritchie, S. A., Hanna, J. N. & Brown, G. V. 1997, 'Airport malaria in Cairns', *Medical Journal of Australia*, vol. 166, pp. 307-8.

Kovats, R. S. 2000, 'El Nino and human health', *Bulletin of the World Health Organization*, vol. 78, pp. 1127-35.

Krause, V. 2001, 'Leptospirosis update', NT Disease Control Bulletin, vol. 8, p. 8.

Loevinsohn, M. E. 1994, 'Climatic warming and increased malaria incidence in Rwanda', *Lancet*, vol. 343, pp. 714-8.

Lomar, A. V., Diament, D. & Torres, J. R. 2000, 'Leptospirosis in Latin America', *Infectious Disease Clinics of North America*, vol. 14, pp. vii-viii, 23-39.

Mackenzie, J. S. 1999, 'Emerging viral diseases: An Australian perspective', *Emerging Infectious Diseases*, vol. 5, pp. 1-8.

McBride, W. J., Taylor, C. T., Pryor, J. A. & Simpson, J. D. 1999, 'Scrub typhus in north Queensland', *Medical Journal of Australia*, vol. 170, pp. 318-20.

McCarthy, M. 2001, 'Dust clouds implicated in spread of infection', *Lancet*, vol. 358, p. 478.

Munckhof, W. J., Mayo, M. J., Scott, I. & Currie, B. J. 2001, 'Fatal human melioidosis acquired in a subtropical Australian city', *American Journal of Tropical Medicine and Hygiene*, vol. 65, pp. 325-8.

Nicholls, N. 1993, 'El nino-southern oscillation and vector-borne disease', *Lancet*, vol. 342, pp. 1284-5.

Nusslein, K. & Tiedje, J. M. 1999, 'Soil bacterial community shift correlated with change from forest to pasture vegetation in a tropical soil', *Applied Environmental Microbiology*, vol. 65, pp. 3622-6.

Odorico, D. M., Graves, S. R., Currie, B., Catmull, J., Nack, Z., Ellis, S., Wang, L. & Miller, D. J. 1998, 'New Orientia tsutsugamushi strain from scrub typhus in Australia', *Emerging Infectious Diseases*, vol. 4, pp. 641-4.

Patz, J. A., Epstein, P. R., Burke, T. A. & Balbus, J. M. 1996, 'Global climate change and emerging infectious diseases', *Journal of the American Medical Association*, vol. 275, pp. 217-23.

Rogers, D. J. & Packer, M. J. 1993, 'Vector-borne diseases, models, and global change', *Lancet*, vol. 342, pp. 1282-4.

Savannah Links 1999, 'Pigs in the Savannas: Disease threat', Savannah Links, located at http://savanna.ntu.edu.au/publications/savanna_links8/cover.html, 1-2.

Simpson, F. G., Green, K. A., Haug, G. J., & Brookes, D. L. 1998, 'Leptospirosis associated with severe pulmonary haemorrhage in Far North Queensland', *Medical Journal of Australia*, vol. 169, pp. 151-3.

Smythe, L., Dohnt, M., Symonds, M., Barnett, L., Moore, M., Brookes, D. & Vallanjon, M. 2000, 'Review of leptospirosis notifications in Queensland and Australia: January 1998-June 1999', *Communicable Diseases Intelligence*, vol. 24, pp. 153-7.

Spencer, J., Azoulas, J., Broome, A., Buick, T., Daniels, P., Doggett, S., Hapgood, G., Jarrett, P., Lindsay, M., Lloyd, G., Mackenzie, J., Merianos, A., Moran, R., Ritchie, S., Russell, R., Smith, D., Stenhouse, F. & Whelan, P. 2001, 'Murray Valley encephalitis virus surveillance and control initiatives in Australia', *Communicable Diseases Intelligence*, vol. 25, pp. 33-47.

Tong, S. 2000, 'The potential impact of global environmental change on population health', *Australian and New Zealand Journal of Medicine*, vol. 30, pp. 618-25.

Van Den Hurk, A. F., Johansen, C. A., Zborowski, P., Phillips, D. A., Pyke, A. T., Mackenzie, J. S. & Ritchie, S. A. 2001, 'Flaviviruses isolated from mosquitoes collected during the first recorded outbreak of Japanese encephalitis virus on Cape York Peninsula, Australia', *American Journal of Tropical Medicine and Hygiene*, vol. 64, pp. 125-30.

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