RESEARCH REPORT

Climate variability and Ross River virus transmission

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Objectives: (1) To examine the feasibility to link climate data with monthly incidence of Ross River virus (RRv). (2) To assess the impact of climate variability on the RRv transmission.

Design: An ecological time series analysis was performed on the data collected between 1985 to 1996 in Queensland, Australia.

Methods: Information on the notified RRv cases was obtained from the Queensland Department of Health. Climate and population data were supplied by the Australian Bureau of Meteorology and the Australian Bureau of Statistics, respectively. Spearman's rank correlation analyses were performed to examine the relation between climate variability and the monthly incidence of notified RRv infections. The autoregressive integrated moving average (ARIMA) model was used to perform a time series analysis. As maximum and minimum temperatures were highly correlated with each other (r_s=0.75), two separate models were developed.

Results: For the eight major cities in Queensland, the climate-RRv correlation coefficients were in the range of 0.12 to 0.52 for maximum and minimum temperatures, −0.10 to 0.46 for rainfall, and 0.11 to 0.52 for relative humidity and high tide. For the whole State, rainfall (partial regression coefficient: 0.017 (95% confidence intervals 0.009 to 0.025) in Model I and 0.018 (0.010 to 0.026) in Model II), and high tidal level (0.030 (0.006 to 0.054) in Model I and 0.029 (0.005 to 0.053) in Model II) seemed to have played significant parts in the transmission of RRv in Queensland. Maximum temperature was also marginally significantly associated with the incidence of RRv infection.

Conclusion: Rainfall, temperature, and tidal levels may be important environmental determinants in the transmission cycles of RRv disease.

It has become increasingly clear that global climate change will alter—indeed, may now be altering—the pattern of climate variability, although the projected trends within specific geographical regions remain uncertain.[1,2] There are unresolved questions about, first, how climate change may affect the transmission of vector borne diseases, and, second, to what extent the empirical evidence of short-term climate variation and disease transmission can be applied to the estimation of future impacts of climate change.

Arboviral infections are a global health problem accounting for significant morbidity and mortality in human populations.[3] Ross River virus (RRv) infection is one of the most common arboviral diseases in Australia and some island nations.[3–5] For example, a total of 53 347 laboratory confirmed cases of RRv infection was reported in Australia during the past decade (1991–2000).[6]

RRv infection, also known as epidemic polyarthritis, is a debilitating and frequently persistent disease characterised by arthritis, fever, rash, muscle and joint pain, and fatigue.[5,7] The economic impact of this disease is thought to be costing a minimum of tens of millions of dollars annually in direct and indirect health costs in Australia.[4,8,9]

The effects of RRv disease were first recognised in 1928, although the virus and its association with the disease were not identified until the early 1960s.[10] RRv—an alphavirus—was first isolated from *Aedes vigilax* mosquitoes collected around Ross River in northern Queensland, Australia, in 1959. However, it was not until the single largest reported outbreak in the South Pacific islands in 1979–80 that the virus was isolated from the serum of a patient suffering from epidemic polyarthritis.[11] More than 50 000 people were affected in that epidemic event. In Australia, it was not until 1985 that RRv was isolated from a patient with epidemic polyarthritis.[12]

Queensland, located in north eastern Australia, is the State where most cases of RRv infection have been reported. For example, in 1996, there were 7823 notifications of RRv infection reported in Australia (notification rate: 42.7 per 100 000), and 63.1% of the cases were from Queensland.[7] There is evidence showing that the geographical distribution of the RRv infection within Australia has been expanding[13,14] and RRv activity seems to have increased in the past decade, although the causes remain largely unknown.[7,8] Our pilot work suggests that climate variation may be associated with RRv activity.[15] This study examined the potential impact of climate variability on the transmission of RRv infection across Queensland, Australia.

SUBJECTS AND METHODS

Queensland is the second largest State with the largest habitable area in Australia.[16] Lying generally between 10° and 29° south of the equator, it ranges from the temperate and densely populated south east to the tropical, sparsely populated Cape York Peninsula in the north (fig 1). Its population was 3 512 356 on 30 June 1999.

The computerised datasets on the notified RRv cases in Queensland for the period of 1985 to 1996 and their key sociodemographic information were obtained from the Queensland Department of Health. The data on RRv were routinely collected for the National Notifiable Diseases Surveillance System, which is conducted under the auspices of the Communicable Diseases Network Australia New Zealand. Climate and population data were obtained from the Australian Bureau of Meteorology and the Australian Bureau of Statistics, respectively. Tidal data were obtained from the Queensland Department of Transport. High tidal level was regarded as a "climate" variable in this study because of its relevance to climate change.

Spearman's rank correlation analyses were performed to examine the relation between climate variability and the monthly incidence rates of notified RRv infections in eight major cities where there had been the majority of cases.

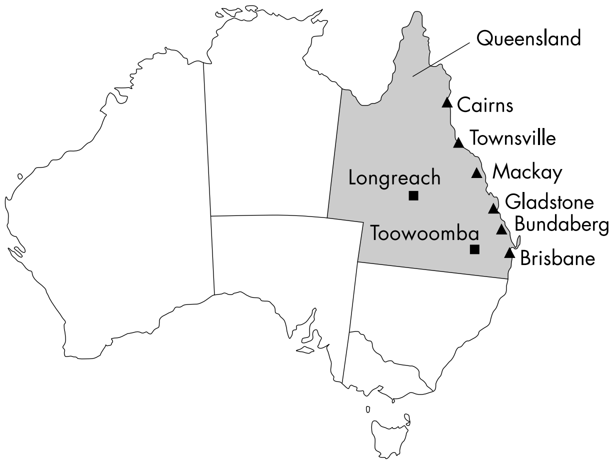

Figure 1 A map of Queensland, Australia.

Table 1 Autocorrelation coefficients and Q statistics for the Ross River virus input series, Queensland, Australia, 1985–1996

Input series (lag)	Autocorrelation coefficient	Q statistic	p Value
1	–0.00	0.01	0.91
2	0.03	0.82	0.66
3	0.00	0.82	0.84
4	–0.03	1.49	0.83
5	0.03	2.58	0.76
6	–0.02	3.15	0.79
7	0.03	4.28	0.75
8	–0.04	5.66	0.68
9	0.00	5.66	0.77
10	0.02	5.92	0.82
11	–0.06	9.92	0.54
12	0.01	9.96	0.62
13	0.05	12.36	0.50
14	0.02	12.60	0.56
15	0.01	12.73	0.62
16	0.04	14.03	0.60

Autoregressive integrated moving average (ARIMA) models were fitted to the time series of RRv. The Ljung-Box *Q* statistic was used to assess autocorrelation of residuals in the input series.[17] The autocorrelation coefficients and *Q* statistic for each lag are shown in table 1. The autocorrelation function and partial autocorrelation function of the residual series were plotted, and they appeared to be randomly distributed with none of scattered correlations which exceeded the 95% confidence limits (the data available on request). Furthermore, the *Q* statistic for the input series was not statistically significant at any lag. This is consistent with the assumption of an ARIMA model that the autocorrelation of residuals is around zero. In the construction of the model, seasonality, and the time when the case was notified were adjusted for. Two regression models were developed with the inclusion of maximum and minimum temperature separately because of the strong correlation between them (r_s=0.75).

RESULTS

Figure 2 shows the incidence rates of the RRv infection in Queensland between 1985 and 1996 and in Australia between 1991 and 1996 (the nationwide data are only available from 1991). The incidence rates of the RRv infection in Queensland were generally higher than those in Australia.

The results of correlation analyses show that most climate variables were statistically significantly associated with the incidence rates of RRv, particularly for the cities along the coastline (table 2). For the eight major cities in Queensland, the correlation coefficients were in the range of 0.12 to 0.52 for maximum and minimum temperatures, –0.10 to 0.46 for rainfall, and 0.11 to 0.52 for relative humidity and high tide. However, the associations between climate variation and RRv infections seemed generally stronger in coastal cities than those in inland cities—for example, Longreach (r_s ranged from 0.11 to 0.22).

ARIMA analyses of the whole State data indicate that rainfall (partial regression coefficient: 0.017 (95% confidence intervals 0.009 to 0.025) in Model I and 0.018 (0.010 to 0.026) in Model II), and high tidal level (0.030 (0.006 to 0.054) in Model I and 0.029 (0.005 to 0.053) in Model II) seemed to have played significant parts in the transmission of RRv in these areas (table 3). Maximum temperature was also marginally significantly associated with the incidence of RRv infection (partial regression coefficient: 0.592 (95% CI –0.046 to 1.230). The Ljung-Box *Q* statistic shows that there was no significant autocorrelation in the residuals of the regression models.

DISCUSSION

The results of this study indicate that climate variability may have played a significant part in the transmission cycles of RRv. However, the relative importance of these climatic factors (for example, temperature, rainfall, relative humidity, and sea level) in the RRv transmission varied with geographical area. It appeared that climate variation exhibited greater impact on the transmission of RRv in the cities along the coastline than inland cities (for example, Longreach). This may primarily be related to the geographical distribution of different species of mosquitos and dominant strains of virus in different areas as discussed below. Overall, rainfall, temperature, and sea level appeared to be the most important environmental variables in the RRv transmission cycles in Queensland, Australia.

Changes in climate and the environment may influence the abundance and distribution of vectors and intermediate hosts.[18 19] Precipitation is an important factor in the transmission of RRv. All mosquitoes have aquatic larval and pupae stages and therefore require water for breeding.[18 19] Precipitation determines the presence or absence of breeding sites.[18]

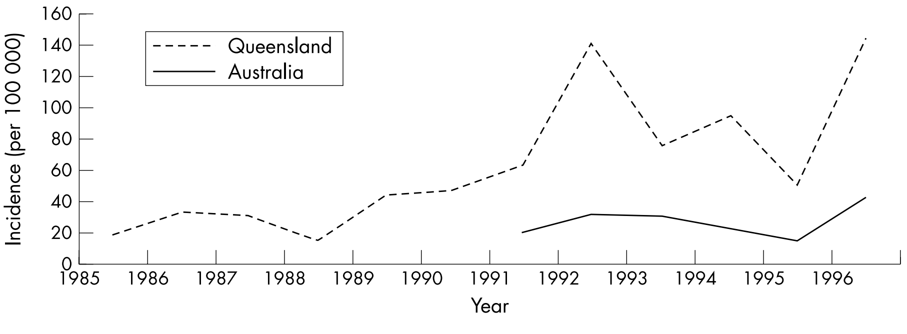

Figure 2 The incidence rates of notified RRv infections in Queensland and Australia.

Table 2 Spearman's correlation coefficient (95% confidence intervals) between climate variables and incidence of Ross River virus in Queensland*

City	MaxT	MinT	Rainfall	RH9am	RH3pm	HT
Cairns	L2=0.52 (0.39 to 0.63)†	L3=0.24 (0.08 to 0.39)	L1=0.46 (0.32 to 0.58)	L0=0.42 (0.28 to 0.55)	L1=0.43 (0.28 to 0.55)	L0=0.52 (0.39 to 0.63)
Townsville	L3=0.32 (0.17 to 0.46)	L2=0.37 (0.22 to 0.51)	L2=0.36 (0.21 to 0.49)	L2=0.24 (0.08 to 0.39)	L2=0.31 (0.16 to 0.45)	L0=0.44 (0.30 to 0.56)
Mackay	L3=0.40 (0.25 to 0.53)	L2=0.43 (0.29 to 0.56)	L2=0.29 (0.13 to 0.43)	L0=0.17 (0.01 to 0.32)	L4=0.33 (0.18 to 0.47)	L2=0.34 (0.18 to 0.48)
Gladstone	L2=0.23 (0.07 to 0.38)	L2=0.30 (0.15 to 0.44)	L1=–0.097 (–0.26 to 0.07)	L0=0.16 (0.00 to 0.32)	L0=0.21 (0.05 to 0.36)	L0=0.20 (0.04 to 0.35)
Bundaberg	L4=0.35 (0.20 to 0.48)	L3=0.40 (0.26 to 0.53)	L2=0.26 (0.10 to 0.41)	L2=0.41 (0.26 to 0.54)	L2=0.41 (0.27 to 0.54)	L2=0.36 (0.21 to 0.50)
Brisbane	L3=0.44 (0.30 to 0.56)	L3=0.40 (0.25 to 0.53)	L2=0.30 (0.15 to 0.44)	L0=0.33 (0.18 to 0.47)	L2=0.38 (0.23 to 0.51)	L0=0.32 (0.16 to 0.46)
Toowoomba	L3=0.43 (0.29 to 0.56)	L3=0.43 (0.28 to 0.55)	L3=0.30 (0.14 to 0.44)	L3=0.10 (–0.07 to 0.26)	L1=0.21 (0.05 to 0.38)	‡
Longreach	L2=0.12 (0.04 to 0.28)	L1=0.12 (0.04 to 0.28)	L1=0.22 (0.06 to 0.37)	L1=0.17 (0.00 to 0.32)	L1=0.11 (0.06 to 0.27)	‡
Total	L3=0.25 (0.20 to 0.31)	L3=0.32 (0.27 to 0.37)	L2=0.26 (0.20 to 0.31)	L1=0.36 (0.30 to 0.40)	L2=0.41 (0.36 to 0.45)	L0=0.16 (0.10 to 0.21)

*MaxT, maximum temperature; MinT, minimum temperature; RH9am, relative humidity at 9am; RH3am, relative humidity at 3pm; HT, High tide; ‡ data unavailable; Lx, the lagged months. †95% confidence intervals.

Table 3 Adjusted relations between the monthly incidence rates of notified Ross River virus and climatic variables*

	Model I		Model II	
Climate variable	β	95% CI	β	95% CI
Temperature (°C)	0.59	–0.05 to 1.23	0.16	–0.36 to 0.69
Rainfall (mm)	0.02	0.01 to 0.03	0.02	0.01 to 0.03
High tide (cm)	0.03	0.01 to 0.05	0.03	0.01 to 0.05
Relative humidity (%)	0.06	–0.11 to 0.22	0.07	–0.09 to 0.24

*Maximum and minimum temperature at a lag of three months were included in Model I and Model II, respectively. Rainfall at a lag of two months, tidal level in the current month and relative humidity at a lag of two months were used in the models. A lag of time is defined as the time span between two observations. The variables adjusted for included autoregressive variable, moving average factor, seasonality, and the year when the case was notified.

Rainfall events and subsequent floods can lead to outbreaks of arboviral disease, largely by enabling breeding of vector mosquitoes.[19] In general, epidemic activity of arbovirus is more often observed in temperate areas with intermittent heavy rainfall, flooding or high tides, whereas in tropical Australia transmission occurs throughout the year.[20] Nevertheless, distinct epidemics do occur in northern Australia, especially associated with heavy monsoonal rainfalls. Over the past decade, major outbreaks caused by heavy rainfall and/or high tides have been reported from several States in Australia.[8 20 21] The timing of rainfall is as important as the amount of rain. For example, major outbreaks of RRv disease in south western Australia usually follow heavy late spring or summer rains, but not heavy winter rains.[21] In contrast, outbreaks in the arid Pilbara region of Western Australia usually follow heavy autumn and winter rains, not summer rains.[19] These observations may be explained by interactive effects of temperature and rainfall on the viruses and their vectors. The pattern of rainfall may also play a part. Extremely heavy precipitation may flush dormant mosquito larvae away from breeding sites, or kill them directly.[18] More frequent, lighter rains may replenish existing breeding sites and maintain higher levels of humidity, which assists in dispersal and survival of adult mosquitoes.[18 19] In this study, we found that precipitation is one of the most important determinants in the RRv transmission cycles. This may reflect the environmental conditions of tropical/subtropical regions.

Warmer temperatures may allow vectors to survive winters that normally would have limited their populations and to reach maturity much faster than at lower temperatures.[19] For example, within the temperature range that permits a mosquito species to breed, larvae reared at high temperatures develop much faster than those reared at lower temperatures.[18] Furthermore, environmental temperature has a marked effect on length and efficiency of the extrinsic incubation periods (EIPs) of arboviruses in their vectors.[18 19] The EIP is inversely related to the temperature of incubation, within the temperature ranges that allow virus replication to occur—that is, mosquitos exposed to higher temperatures after ingestion of virus become "infectious" more rapidly than mosquitos of the same species exposed to lower temperatures.[19] Transmission of an arbovirus may therefore be increased under warmer conditions because more vector mosquitoes become infectious within their life span. In this study, we found that a change in maximum rather than minimum temperature was associated with the transmission of RRv. This may be because Queensland has tropical and subtropical climate, and most of the physiological functions of vectors in this area are subject to optimal maximum rather than minimum temperatures.

High tides and a rise in sea level have been implicated as important precursors of outbreaks of RRv.[21–23] Tidal inundation of saltmarshes is a major source of water for breeding of the important arbovirus vectors *Ae vigilas* and *Ae camptorhynchus*. Adult females of both species lay their eggs on soil, mud substrate, and the bases of plants around the margins of their breeding sites. The eggs hatch when high tides subsequently inundate the sites. Large populations of adult mosquitoes can emerge as quickly as eight days after a series of spring tides.[19] There is good evidence that a rise in sea level may contribute to a major outbreak of RRv. For example, in an outbreak of RRv infection in south western Australia during the summer of 1988–89, a rise in sea level of 5.5 cm (above the long term mean), exacerbated by a pattern of strong north and south westerly winds, led to more frequent and widespread inundation of coastal salt marshes in the region than is normally recorded. This subsequently increased the populations of *Ae vigilas* and *Ae camptorhynchus* mosquitoes and as a result, an outbreak of RRv infection occurred.[20] The results of this study corroborate the previous findings, indicating that sea level is an important factor in the transmission of RRv in the coastal region.

Relative humidity influences longevity, mating, dispersal, feeding behaviour, and oviposition of mosquitoes.[18] At high humidity, mosquitoes generally survive for longer and disperse further. Therefore, they have a greater chance of feeding on an infecting animal and surviving to transmit a virus to humans or other animals. Relative humidity also directly affects evaporation rates form vector breeding sites. Clearly, humidity is another contributing factor to outbreaks of RRv disease, particularly in normally arid regions.[19] In this study, however, the regression coefficient of relative humidity was not significant in the regression equation. It might be because that most of the cities studied are not located in the dry and arid regions.

Limitations of this study must also be acknowledged. Firstly, the ecology of RRv is complex.[24] Many factors, such as virus, vector, host, or environmental variations, are involved in the transmission cycles of RRv. Temperature, humidity, virus strain, mosquito population densities and survival, human behaviour, population immunity, and housing characteristics, all contribute to and interact in the RRv transmission cycles.[25–27] However, the availability of most of these data is limited. Secondly, the quality of notification data might vary over time. It is difficult to quantify the potential impact of any such variation in data quality. Such impact is unlikely to be large in the assessment of the climate impact on monthly incidence rates of notified RRv infection, because any temporal change in the awareness of this disease in health professionals and general public was likely to be minimal on a monthly scale.

The results of this study indicate that climate variability may have contributed to the RRv transmission in Queensland. According to the meteorological record, Australian annual mean maximum temperatures have risen 0.5°C and mean minimum temperatures have risen 0.9°C since the start of this century and Australian annual mean rainfall has increased by about 1% since 1890.[28] By the year 2070, climate change is expected to increase Australia's mean temperature by 1.0–6.0°C over most of Australia.[29] Recent evidence indicates that acceleration of global warming may occur this century.[30] If climate scenarios predicted by current models do eventuate, it seems likely that the transmission of RRv will increase because of several of the climate related variables discussed above, given that other ecological conditions remain unchanged. Therefore, it is important to investigate the nature and extent of the disease response to climate change and public health intervention strategies for the control and prevention of this disease.

Outbreaks of arbovirus have a considerable impact on tourism, industry, and residents of affected areas. The public health responses to the threat of increased virus activity must include further research into the ecology of the virus, its known and potential vectors and hosts, the impact of environmental change, and the interactions of these factors.[4 5 18 19 24] An effective and well coordinated surveillance and monitoring system is essential because it will provide not only forewarning of outbreaks of disease but also valuable information on which to base public health decision making. Computer models need to be developed on the basis of in depth research to predict possible epidemic activity under different environmental conditions, and as a means of predicting future consequences of environmental change.[31 32] The findings from this study might assist in the development of a predictive early warning system. For example, we found that the nature and extent of the effect of climate variability on the transmission of RRv disease vary with geographical area. It suggests that each city or climate region may need to develop a predictive early warning system using the local data. It is anticipated that global warming and global sea level rise is likely to have significant impacts on the transmission of RRv and other vector borne diseases, and therefore, more public health resources need to be directed into this area.

Key points

- The nature and magnitude of the relation between climate variation and vector borne diseases remain unclear.
- The associations between climate variability and the transmission of RRv seemed to vary with geographical area.
- Rainfall, temperature, and high tide are significant predictors of RRv transmission.
- The impact of climate variation on the transmission of RRv needs to be viewed in the context of social and ecological change.

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