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Climate variability and Ross River virus transmission in Townsville Region, Australia, 1985–1996

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Summary

BACKGROUND How climate variability affects the transmission of infectious diseases at a regional level remains unclear. We assess the impact of climate variation on the Ross River virus (RRv) transmission in the Townsville region, Queensland, north-east Australia.

METHODS We obtained population-based information on monthly variations in RRv cases, climatic factors, sea level, and population growth between 1985 and 1996. Cross-correlations were computed for a series of associations between climate variables (rainfall, maximum temperature, minimum temperature, relative humidity and high tide) and the monthly incidence of RRv disease over a range of time lags. We assessed the impact of climate variability on RRv transmission using the seasonal auto-regressive integrated moving average (SARIMA) model.

RESULTS There were significant correlations of the monthly incidence of RRv to rainfall, maximum temperature, minimum temperature and relative humidity, all at a lag of 2 months, and high tide in the current month. The results of SARIMA models show that monthly average rainfall ($\beta = 0.0007$, $P = 0.01$) and high tide ($\beta = 0.0089$, $P = 0.04$) were significantly associated with RRv transmission and maximum temperature was also marginally significantly associated with monthly incidence of RRv ($\beta = 0.0412$, $P = 0.07$), although relative humidity did not seem to have played an important role in the Townsville region.

CONCLUSIONS Rainfall, high tide and maximum temperature were likely to be key determinants of RRv transmission in the Townsville region.

keywords climate change, cross-correlation function, Ross River virus, seasonal auto-regressive integrated moving average, time series

Introduction

Ross River virus (RRv) disease is endemic in all states of Australia (Russell 1998). RRv causes a debilitating disease characterized by arthritis, rash, and constitutional symptoms such as fever, fatigue and myalgia (Curran *et al.* 1997). The natural vertebrate hosts for this arboviral disease include marsupial animals (e.g. kangaroos and wallabies, etc.) and possibly other animals (e.g. dogs, cats and possums). RRv usually incubates for 7–9 days. Incubation may be as long as 21 days or as short as 3 days (Harley *et al.* 2001). Vectors that transmit this disease comprise *Aedes/Ochlerotatus* (17 species), *Culex* (five species), *Anopheles* (two species), *Coquillettidia* (two species), *Mansonia* (one species), *Triperoides* mosquitoes (one species) and others (Russell 1998). The disease caused by RRv was first recognized in New South Wales in the late 1920s (Nimmol 1928), although the virus and its association with disease were not identified until the early 1960s (Nimmol 1928; Shope & Anderson 1960). RRv, an alphavirus was first isolated by Doherty and colleagues from *Ochlerotatus vigilax* mosquitoes collected near the Ross River at Townsville region in northern Queensland in 1959 (Doherty *et al.* 1963). The single largest reported outbreak occurred in the South Pacific islands in 1979–1980, during which more than 50 000 people were affected (Aaskov *et al.* 1981).

The RRv disease is the most prevalent vector-borne disease in Australia. For example, over the last 11 years (1992–2002), 48 242 laboratory confirmed cases of RRv infection were reported (Australian Department of Health and Aged Care 2003). Several studies have examined the relationship between climate variation and vector-borne diseases (McMichael *et al.* 1996; Tong *et al.* 1998; Hales *et al.* 2002), and models have been developed to assess the potential impact of future climatic change on the transmission of arboviral diseases (McMichael *et al.* 1996). Since the early 1970s, time series methods, in particular

ARIMA and seasonal auto-regressive integrated moving average (SARIMA) models, which have the ability to cope with stochastic dependence of consecutive data, have become well-established in commerce and industry (Helfenstein 1991, 1996). In ARIMA and SARIMA models, an important concept is that of stationarity, which implies that the probability structure of the series does not change with time. Many epidemiological time series data are not stationary and they often exhibit trends. However, experience in economics and more recently in epidemiology has shown that the time series of differences (i.e. each value in the series is replaced by the difference between that value and the preceding value) is often stationary (Helfenstein 1991). Box and Jenkins have extended the concepts to cope with time series that contain seasonal variations. In particular, a time series with seasonal non-stationarity may be transformed to stationary data by taking seasonal differences into account (Bowie & Prothero 1981; Helfenstein 1991).

Time series analyses have been increasingly used in epidemiological research (Bowie & Prothero 1981; Helfenstein 1986, 1991, 1996; Catalano & Serxner 1987; Allard 1998; Checkley *et al.* 2000; Nobre *et al.* 2001; Abeku *et al.* 2002; Borghi *et al.* 2002; Clancy *et al.* 2002; Dominici *et al.* 2002; Hajat & Haines 2002; Pope *et al.* 2002). In this paper, we used a time series model to examine the association between climate variation and RRv transmission in the Townsville region, Australia.

Methods

Townsville region is situated in the tropics of north Queensland and located approximately 1380 km north of Brisbane (the state's capital) (Fig. 1). Townsville region, comprising Townsville and Thuringowa with a population exceeding 130 000 in 2001, is the largest regional centre in Queensland (Australian Bureau of Statistics 2002), in which RRv transmission has been highly active over recent years.

The computerized data set on monthly notified RRv cases in Queensland for the period of 1985–1996 and information on notification (including place and time of onset) were obtained from the Queensland Department of Health. The data on RRv cases had been collected for the National Notifiable Diseases Surveillance System, which is conducted under the auspices of the Communicable Diseases Network Australia, New Zealand. The quality of routinely collected RRv data, assuming constancy over time, is generally regarded as valid information for a large-scale assessment of the impact of climatic variations (McMichael *et al.* 1996). Climate, sea level and population data were obtained from the Australian Bureau of Meteorology, Queensland Transport Department, and the Australian Bureau of Statistics, respectively. Climate data consisted of monthly average maximum and minimum temperature, monthly average rainfall, relative humidity at 9 AM and 3 PM and high tides.

To examine whether climate variation was associated with the RRv transmission, cross-correlations were used to compute a series of correlations between climate variables and the incidence of RRv disease over a range of time lags (a time lag was defined as the time span between a climatic observation and the incidence of RRv) (Chatfield 1975). The SARIMA model was used to estimate the independent contribution of each climate variable in this study as it was assumed that there was a dose–response relationship between the dependent variable and independent variables. Three steps were undertaken in the modelling of the relationship between climate variation and the RRv transmission in Townsville region. First, SARIMA models were developed using the monthly incidence of RRv as dependent variable and the monthly averages of climate variables and high tides as independent variables after seasonal difference was smoothed to make a drifting series stationary. Secondly, the goodness-of-fit of the models was checked for adequacy, using both time series (i.e. auto-correlation functions of residuals which are defined as the differences between the actual values and the forecasted values) and classical tools (i.e. to check the normality of residuals) (Tabachnick & Fidell 2001). Finally, the model developed was verified by dividing the data file into two data sets: the data between January 1985 and December 1994 were used to construct a SARIMA model and those

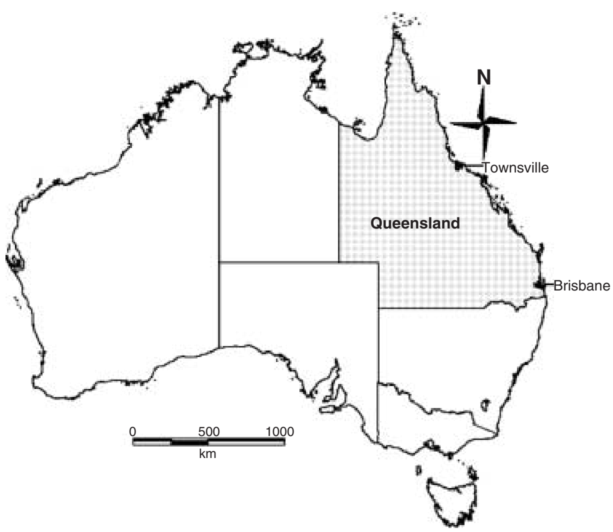

Figure 1 Location of Townsville region, Queensland, Australia.

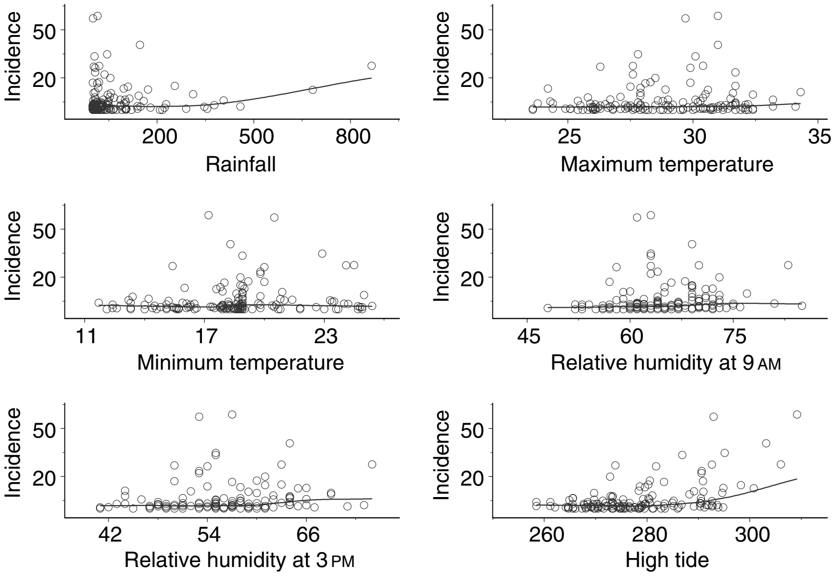

Figure 2 The relationships between monthly incidence of Ross River virus and climate variables in Townsville region between 1985 and 1996.

data between January 1995 and December 1996 were then used to verify that particular model.

Results

Figure 2 shows the associations between monthly incidence rates of RRv infection and rainfall, maximum temperature, minimum temperature, relative humidity and high tide in the Townsville region between 1985 and 1996. Climate variability (e.g. rainfall, maximum temperature, minimum temperature, relative humidity) was positively associated with the RRv, as also was high tide.

The results of the cross-correlations show that climate variables (including tidal level) were significantly associated with the incidence of RRv. The significant associations were found for rainfall ($r = 0.43$, $P < 0.05$), maximum temperature ($r = 0.16$, $P < 0.05$), minimum temperature ($r = 0.23$, $P < 0.05$), and relative humidity ($r = 0.24$, $P < 0.05$) at a lag of 2 months, and high tide ($r = 0.31$, $P < 0.05$) in the current month in Townsville region (Table 1). The results of SARIMA models show that the incidence of RRv disease was significantly associated with rainfall ($\beta = 0.0007$, $P = 0.01$), and high tide ($\beta = 0.0089$, $P = 0.04$). Maximum temperature was also marginally significantly associated with monthly incidence of RRv ($\beta = 0.0412$, $P = 0.07$) in the Townsville region after adjustment for other covariates (Table 2).

Figure 3 shows that there was no significant autocorrelation between residuals at different lag times in the SARIMA model. The graphic analysis of residuals shows that the residuals in the model appeared to fluctuate randomly around zero with no obvious trend in variation as the predicted incidence values increased. Thus, no violation of assumptions was apparent.

The SARIMA models were also verified using the data over the period of January 1995 to December 1996 after

Table 1 Cross-correlation coefficients between climate variables and incidence of Ross River virus (RRv) in Townsville region, Australia*

Lag (months)	MaxT	MinT	Rainfall	Rh9am	HT
0	0.070	0.050	−0.174†	−0.219†	0.306†
1	−0.023	0.106	0.076	0.129	0.224†
2	0.161†	0.227†	0.427†	0.244†	0.134
3	0.071	−0.093	0.033	0.088	−0.015
4	0.126	0.035	−0.033	−0.016	−0.159†

* MaxT, maximum temperature; MinT, minimum temperature; Rh9am, relative humidity at 9 AM; HT, high tide.
† Significant at the 0.05 level (two-tailed).

Table 2 Regression coefficients of climate variables on the monthly incidence of Ross River virus (RRv) disease in Townsville region, Queensland*

Variable	β	SE	*P*-value
Intercept	−3.4874	1.2534	0.01
Rainfall	0.0007	0.0001	0.01
High tide	0.0089	0.0044	0.04
Maximum temperature	0.0412	0.0222	0.07
Relative humidity	0.0040	0.0063	0.52

* Minimum temperature was not significantly associated with RRv transmission when it was used to replace maximum temperature in a separate model ($P = 0.20$).

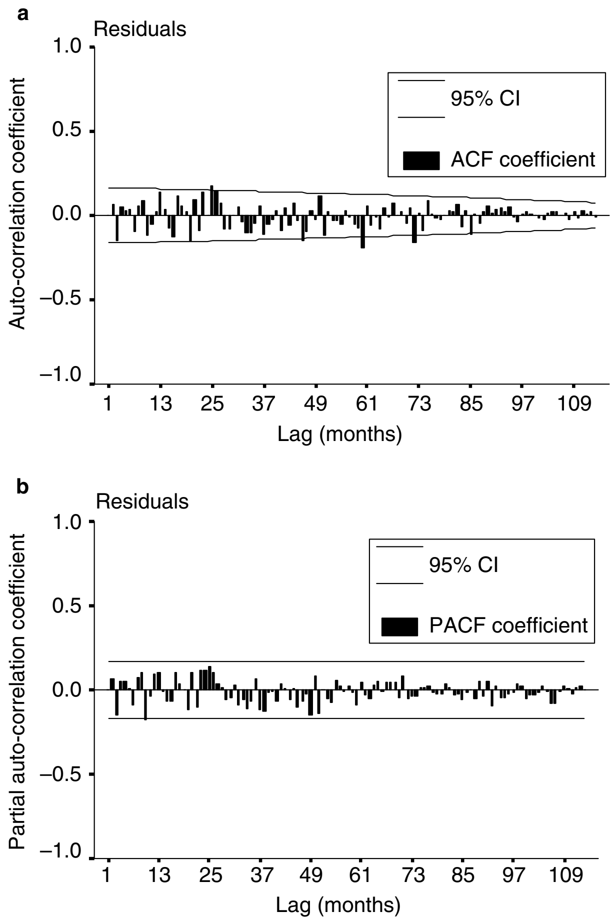

Figure 3 Auto-correlation (a) and partial auto-correlation (b) of residuals (ACF, auto-correlation function; PACF, partial auto-correlation function).

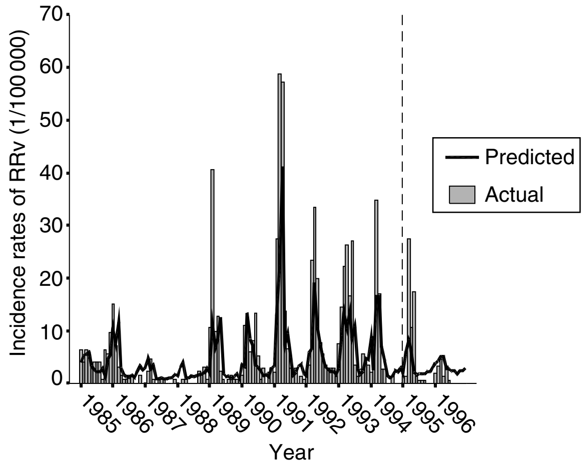

Figure 4 The validated seasonal auto-regressive integrated moving average (SARIMA) model of climate variation in Townsville region (validation period: January 1995–December 1996, i.e. to the right of the vertical dotted line).

the models had been constructed with the data compiled between January 1985 and December 1994. Figure 4 indicates that the predicted values and the actual incidence rates of RRv matched well.

Discussion

Although global climate change may pose a significant threat to the control and prevention of infectious disease, little empirical research has been conducted in this field. Some recent studies suggest that climate variation is associated with changes in the occurrence of various vector-borne and waterborne diseases (Lindsay & Mackenzie 1996; Tong *et al.* 1998; Curriero *et al.* 2001; Tong & Hu 2002; Woodruff *et al.* 2002). We found that rainfall and high tides are among the major determinants in the transmission of RRv infection in Townsville region, Australia.

The incidence of RRv infection fluctuates with the seasons and is usually associated with warmer and more humid weather. In general, epidemic activity is more often observed in temperate areas with heavy rainfall or flooding, whereas in tropical Australia transmission occurs throughout the year (Mackenzie *et al.* 1998). Nevertheless, distinct epidemics do occur in northern Australia, especially associated with heavy monsoonal rainfalls.

Clearly, precipitation is one of the important elements for the breeding and development of mosquitoes (Hennessy & Whetton 1997). All mosquitoes have aquatic larval and pupal stages and therefore require water for breeding (Lindsay & Mackenzie 1996; McMichael *et al.* 1996). Considerable evidence has accrued to show that heavy rainfall and flooding can lead to increased mosquito breeding and outbreaks of arboviral disease in Australia (McMichael *et al.* 1996; Liehne 1998). Examples are readily available for RRv outbreaks in various parts of Australia (Liehne 1998). Our study corroborated previous observations and indicated that rainfall is one of the key predictors of RRv transmission. However, climate models predict that, under likely scenarios of climate change, little rainfall change will occur in the Townsville area, with a range of annual rainfall change of −4 to +4% by 2030 and −12 to +12% by 2070 (Whetton 2001). Therefore, there may be no increase of RRv cases resulting from rainfall change in that region. However, the possible future impact of rainfall on the transmission of RRv disease should be estimated cautiously, as many socio-ecological factors can also influence the balance of

RRv transmission cycles. Future climate changes in adjoining regions of Australia may affect the transmissibility of RRv in those areas.

High tides and rise in sea level have been implicated as important precursors of outbreaks of RRv (McManus *et al.* 1992; Lindsay *et al.* 1993; Weinstein 1997). Tidal inundation of salt marshes is a major source of water for breeding of the important arbovirus vectors *O. vigilax* and *O. camptorhynchus*. Adult females of both species lay their eggs on soil, mud substrate and the plants around the margins of there breeding sites. The eggs hatch when high tides subsequently inundate sites. Large populations of adult mosquitoes can emerge in as soon as 8 days after a series of spring tides (Lindsay & Mackenzie 1996). There is good evidence that a rise in sea level may contribute to a major outbreak of RRv. Our results corroborate the previous findings, indicating that sea level is an important factor in the transmission of RRv in Townsville region.

Temperature changes affect RRv transmission and epidemic potential by altering the vectors' reproduction or biting rate; by shifting a vectors' geographic range or distribution; by altering the extrinsic incubation periods (EIPs) of the pathogen; and by increasing or decreasing vector–pathogen–host interaction and thereby affecting host susceptibility (McManus *et al.* 1992). In this study, temperature was only marginally associated with the incidence of RRv. This may be because the Townsville region is located in the tropical zone and the monthly maximum temperature is usually high (more than 20 °C). Hence, temperature does not play the same important role, as do rainfall and sea level. Additionally, in a recent study, it was found that rearing temperature seemed unimportant to vector competence for mosquito species *O. vigilax* found in Townsville (Kay & Jennings 2002). Our epidemiological finding appeared to provide compelling support to the laboratory data.

Relative humidity influences longevity, mating, dispersal, feeding behaviour and oviposition of mosquitoes (McMichael *et al.* 1996). 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 from vector breeding sites. Clearly, humidity is another factor contributing to outbreaks of RRv disease, particularly in normally arid regions (Lindsay & Mackenzie 1996). In this study, however, relative humidity did not appear to have played a major role in the RRv transmission, possibly because the Townsville region is on the coast and usually not dry.

The RRv disease epidemics are commonly driven by environmental conditions such as heavy rainfall, flooding and tidal inundation of marshes (and probably levels of host immunity as well) (Lindsay & Mackenzie 1996; Harley *et al.* 2001). The fact that RRv outbreaks often occur suddenly after such events has led researchers to investigate the mechanism of RRv transmission more closely. For example, Lindsay *et al.* (1993a) have indicated that there is a strong evidence that the virus can persist in the environment during adverse conditions (dry season) by vertical transmission in desiccation-resistant mosquito (*Aedes/Ochlerotatus*) eggs. They isolated the virus from male mosquitoes prior to an outbreak implying that vertical transmission is a likely explanation for the sudden recurrence of virus activity after heavy rainfall. The incubation period in humans ranges from 5 to 21 days but is usually 7–9 days (Harley *et al.* 2001), which also helps rapid transmission once the outbreak starts.

Research outcomes from this study may be used to assist public health decision making and environmental health risk management. Early warning based on forecasts could assist in improving vector control, community intervention and personal protection. A practical model for estimating the probability of epidemic occurrence in relation to socio-ecological change can help decision makers to determine where and when RRv disease is likely to occur, so that response can be made promptly and limited resources can be mobilized and allocated more effectively and efficiently.

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