Climate Variations and the Transmission of Ross River Virus Infection in Coastal and Inland Region of Queensland: An Analysis from Townsville and Toowoomba

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To determine the different impact of climate variability on the transmission of Ross River (RR) virus infection between coastal and inland regions of Queensland, historic data analysis was conducted in Townsville and Toowoomba over the period 1985-96. The results show that temperatures, rainfall and high tides are possible contributors to the transmission of RR virus infection in the coastal region of Queensland, with a lagged effect of zero to four months, while temperatures were the main potential risk factor for the transmission of RR virus infections in inland regions of Queensland. These different climatic risk factors in coastal and inland regions seem to have their influence through the different distributions of the vectors of the diseases in the two regions. This study suggests that the transmission of RR virus infection is related to climate variations and attention should be paid to this, given global warming and its consequent impacts.

Key words: *Ross River Virus; Climate Change; Queensland; GLS Regression Analysis*

Arboviral diseases, including Ross River (RR) virus infection, are among the most sensitive of all diseases to climate change (Lindsay & Mackenzie 1996). Various studies have shown that the transmission of RR virus infection is related to weather and climate (Lindsay & Mackenzie 1996; Tong et al. 2001). Temperatures, rainfall, relative humidity, and high tides can affect the development of mosquitoes, the vector of the disease, and hence the transmission of the RR virus infection.

RR virus infection, or epidemic polyarthritis, is a mosquito-borne disease caused by an alphavirus, Ross River virus. It is a debilitating and frequently persistent disease characterised by arthritis, fever, rash, and fatigue (Mackenzie, Lindsay & Coelen 1994; Curran et al. 1997). RR virus infection is the highest incidence vector-borne disease in the Australasian region, with thousands of cases occurring annually in Australia (Mackenzie, Lindsay & Coelen 1994). For example, the national notified incidence in 1996 was 42.7/100,000 and a total of 53,347 laboratory-confirmed cases were reported to the Commonwealth Department of Health over the period 1991-2000. Queensland had more than 60% of all the cases (Commonwealth Department of Health and Ageing 2001; Curran et al. 1997).

The virus has been isolated from 38 species of mosquitoes in Australia (Mackenzie, Lindsay & Coelen 1994). The disease has different mosquito vectors in different regions. On the northern coasts of Australia, it is *Aedes vigilax*. On the south and southwest coasts of Australia, *Aedes camptorhynchus* is thought to be the main vector. Both species of mosquitoes are dependent on tides. *Culex annulirostris*, which breeds in vegetated semi-permanent and permanent fresh water, is the major vector in the inland tropics and temperate inland regions of New South Wales and Queensland that are subject to flooding or irrigation during summer (Lindsay, Mackenzie & Condon 1993). *Aedes notoscriptus* may be important in semi-rural and urban areas. These freshwater mosquitoes are closely associated with human habitations (Dale & Morris 1996). There are three possible drivers of RR virus infections: rainfall and its effect on salt-marsh-breeding mosquito population dynamics, rainfall and its effect on fresh water-breeding mosquito population dynamics, and tidal inundation of saltmarsh and its effect on mosquito population. All of these, together with other potential risk factors, could lead to the transmission of the disease.

We have reported that there was a spatial shifting for RR virus infections in Queensland over the period 1985-96, which could be due to the impact of climate variations (Tong et al. 2001). We also found that temperatures, rainfall and high tides are possible contributors to the transmission of RR virus infection in the coastal region of Queensland (Bi & Parton 2002). However, the differences in climatic factors affecting the transmission of the disease between coastal and inland regions remain unclear. Therefore, in the present study a historic data analysis was conducted for Townsville and Toowoomba, a coastal and an inland town in Queensland, respectively, using data covering the period 1985-96.

Materials and Methods

Study sites and populations

Situated in the tropics of North Queensland, Townsville is located approximately 1,380 kilometres north of Brisbane, and 350 kilometres south of Cairns. With a population exceeding 130,000 in 1996, it is the largest population centre in northern Queensland. With incidence per 100,000 being the main variable of interest, all annual residents of Townsville over the period 1985-96 were treated as the study population (as the denominator). Locally notified RR virus infections during this period were treated as the numerator.

Toowoomba from the Darling Downs and Granite Belt was chosen to represent the inland region of Queensland in this study, given its population and incidence of the disease. As Australia's second largest inland city after Canberra, Toowoomba is located 700 metres above sea level at the eastern edge of the Great Dividing Range. With a population of nearly 90,000 in 1996, the city sits at the gateway to the inland western region from the coastal corridor of Queensland.

Data collection

The Queensland Department of Health provided notified cases of RR virus infection. Population data for Townsville and Toowoomba were provided by the Australian Bureau of Statistics. Climate data were retrieved from the Australian Bureau of Meteorology.

Data analysis

Data analysis was conducted using the Statistical Package for the Social Sciences (SPSS) (SPSS 2001). The monthly incidence of RR virus infections in each town was treated as the dependent variable, and climatic variables such as monthly mean maximum and minimum temperatures, relative humidity, monthly total amount of precipitation and monthly mean high tide as independent variables. Spearman's correlation analyses were conducted between monthly climatic variables and the incidence of the disease. For consideration of lagged effect, the analyses were conducted between the incidence of the disease and climatic variables in the current month, and previous one, two, three and four months. Since there might be auto-correlations among both dependent and independent variables, AutoRegressive Integrated Moving Average (ARIMA) and Generalised Least Square (GLS) regression analyses were performed to control for this. A model was developed after the effect of auto-correlation had been removed by the ARIMA procedures, and the GLS regression analysis was conducted to assess the independent effects of each climatic variable thereby inferring unique variance aspects (Box & Jenkins 1976).

Results

The monthly mean values of dependent and independent variables at the study sites

Table 1 describes the mean, standard deviation, and the minimum and maximum values of the monthly incidence of RR virus infection and climatic variables in Townsville and Toowoomba over the study period. It shows that the monthly mean incidence of the disease was 11.75/100,000 in Townsville, a coastal town. This was much higher than 3.72/100,000 in Toowoomba, an inland town. The information about the climatic variables in these towns also shows differences in temperatures, rainfall and high tides, in which Townsville has higher temperature and more rainfall.

Table 1: Monthly incidence of RR virus infection and climatic variables in Townsville and Toowoomba, Australia, 1985-96*

	Mean	Std. Deviation	Minimum	Maximum
Incidence	11.75^	2.69^^	0.00	119.46
(1/100,000)	3.72^	1.82^^	0.00	22.67
MaxT °C	28.96	2.22	23.60	34.30
	22.50	3.36	14.50	30.50
MinT °C	19.90	2.37	12.40	25.70
	11.90	2.95	4.80	18.80
3pmRH (%)	55.80	6.47	41.00	74.00
	51.20	9.84	25.00	76.00
9amRH (%)	64.80	6.20	52.00	85.00
	72.30	8.08	46.00	89.00
High Tide (cm)	278.7	9.40	258.50	309.20
	#	#	#	#
Rainfall (mm)	19.95^	5.89^^	0.10	865.40
	11.22^	3.02^^	0.10	421.20
SOI**	-3.10	9.94	-25.40	21.00

** Upper line: the data in Townsville; lower line: the data in Toowoomba; ^ the geometric means of incidence of the disease and rainfall; ^^geometric standard deviation; # data inapplicable because Toowoomba is not a coastal town*

*** Southern Oscillation Index*

Correlation between the monthly incidence of RR virus infection and climatic variables at the two study sites, 1985-96

Table 2 shows that, with the exception of the SOI, there were significant correlations between the monthly incidence of RR virus infection and climatic variables, both in Townsville and Toowoomba. The lagged effect lasts from zero to two months in Townsville and zero to four months in Toowoomba. It seems that at both locations the correlation between monthly mean minimum temperature and the incidence of the disease was marginally stronger than that between monthly mean maximum temperatures and the incidence of the disease.

Table 2: Correlation between monthly incidences of RR virus infection and climatic variables in Townsville and Toowoomba, 1985-96

	Townsville		Toowoomba	
	Coefficient	*P*	Coefficient	*P*
MaxT (°C)	0.432 (2)	0.000	0.482 (4)	0.000
MinT (°C)	0.454 (2)	0.000	0.496 (3)	0.000
Rainfall (mm)	0.387 (2)	0.000	0.327 (4)	0.000
SOI	-0.156 0.102		0.089	0.150
3pmRH (%)	0.342 (1)	0.000	0.306 (1)	0.000
9amRH (%)	0.292 (1)	0.000	0.329 (1)	0.000
HT (cm)	0.410	0.000	#	

The number in the bracket is the amount of lagged months; # data inapplicable

Inter-correlations among climatic variables in the two locations were also examined (Table 3). This shows that there were strong correlations between monthly mean minimum and maximum temperatures, and between 3.0pm relative humidity and 9.0am relative humidity, both in Townsville and Toowoomba. In the assessment of the relationship between climate variability and the transmission of RR virus infection using regression analysis, these correlations indicated where attention needed to be given to potential problems of multicollinearity. Therefore, they were put into different regression models as shown in Tables 4 and 5.

Table 3: Inter-correlations among climatic variables in Townsville and Toowoomba, 1985-96^

	MaxT	MinT	3pmRH	9amRH	Rain	HT	SOI
MaxT	1.00						
	1.00						
MinT	0.93	1.00					
	0.92	1.00					
3pmRH	0.41	0.65	1.00				
	-0.20	0.17	1.00				
9amRH	0.14	0.36	0.79	1.00			
	-0.16	0.19	0.92	1.00			
Rain	0.29	0.44	0.67	0.60	1.00		
	0.25	0.45	0.52	0.43	1.00	1.00	
HT	0.39	0.42	0.48	0.32	0.38	1.00	
SOI	-0.10	0.06	0.35	0.30	0.19	0.11	1.00
	-0.04	-0.002	0.18	0.13	0.21	#	1.00

^ The upper line is the results of Townsville and lower one is the results of Toowoomba; # data inapplicable

Regression analyses between the monthly incidence of RR virus infection and climatic variables, 1985-96

The results for Townsville (Table 4) show that monthly mean minimum temperature, high tide and rainfall or the monthly mean maximum temperature and high tides were significant climatic variables associated with the transmission of RR virus. It seems that the monthly mean minimum temperature plays a more important role than the monthly mean maximum temperature because Model 1 has higher R^2 values than Model 2, indicating larger extent of variance explained. These results tend to confirm previous observations that particular temperatures and rainfall are necessary for the developments of the mosquitoes and the virus within the mosquitoes (Lindsay, Mackenzie & Condon, 1993; Tong et al. 2001). Further, *Aedes vigilax* the main species in northern Queensland is sensitive to high tides.

The regression analysis for Toowoomba (Table 5) shows that temperatures affect the occurrence of RR virus infection in the city. As for Townsville, it seemed that the role of mean minimum temperatures is possibly more important than that of mean maximum temperatures.

Table 4: Climatic variables and monthly incidence disease in Townsville, 1985-96

Explanatory variables	B	*P* value
Model 1		
MinTP2 (°C)	0.0618	0.011
HT (cm)	0.0098	0.046
RainP2 (mm)	0.0006	0.036
Constant	-8.708	0.000
	R^2=0.37	
Model 2		
MaxTP2 (°C)	0.0388	0.018
HT (cm)	0.0095	0.047
RainP2 (mm)	0.0005	0.121
Constant	-7.6118	0.000
	R^2=0.32	

Table 5: Climatic variables and monthly incidence disease in Toowoomba, 1985-96

Explanatory variables	B	*P* value
Model 1		
MinTP3 (°C)	0.0395	0.020
9amRHP1 (%)	0.0091	0.114
Constant	-5.9560	0.000
	R^2=0.32	
Model 2		
MaxTP4 (°C)	0.0310	0.039
9amRHP1 (%)	0.0099	0.085
Constant	-6.2415	0.000
	R^2=0.30	

Discussion

RR virus infection is fairly common in Australia. In southeast Australia, cases occur primarily between January and April; in south coastal Victoria and southwest Australia, they are between October and December (Kay & Aaskov 1988; Mackenzie, Lindsay & Coelen, 1994; Mackenzie et al. 1998). The distinctive seasonal pattern is related to the life cycle and habitat of the vector. Climate variability might impact on the incidence, temporal and spatial distributions of the disease via its influence on the vectors.

Rainfall is important in the transmission of RR virus infection. Mosquitoes have aquatic larval and pupal stages and therefore require water for breeding. Sufficient amounts of precipitation will assist in maintaining the mosquito's breeding habitats further into the summer months, which is particularly important for fresh water breeding mosquitoes. Outbreaks of RR virus infection in Western Australia are predominantly rainfall associated; a feature of the outbreaks in the arid north and interior of the state is the short interval between the occurrence of heavy rains and notification of the first human case (Lindsay, Mackenzie & Condon 1993).

Timing of rainfall is as important as the amount. Major outbreaks of RR virus infections in southwestern Australia, for example, usually follow heavy late spring or summer rain, but not heavy winter rain. The outbreaks in the arid Pilbara region of Western Australia usually follow heavy autumn and winter rain (Lindsay & Mackenzie 1996). The pattern of rainfall is also important in the transmission of RR virus infection. Too much rain at once might flush dormant mosquito eggs away from breeding sites. More frequent, lighter rains might replenish existing breeding sites and maintain higher levels of humidity, which assists in dispersal and survival of adult mosquitoes. Also above average winter and spring rains are thought to increase the survival rate of juvenile western grey kangaroos (Lindsay & Mackenzie 1996; McMichael 1996).

Temperature has a dramatic effect on the length and efficiency of the extrinsic incubation period (EIP) of RR virus in its vectors. Mosquitoes exposed to higher temperatures after ingestion of RR virus become "infective" more rapidly than mosquitoes of the same species exposed to lower temperatures (Lindsay & Mackenzie 1996). Transmission of RR virus may therefore be enhanced under warmer conditions because more mosquitoes become infectious within their often-short life span. Temperatures, especially minimum temperatures, may also play an important role in maintaining the survival of mosquito larvae in winter and have a significant impact on the development of adult mosquitoes. But too high temperatures in summer might speed the death of adult mosquitoes (Lindsay & Mackenzie 1996). Also, the high temperatures might force people to stay in their houses and thus reduce their contact with mosquitoes.

Over 90% of cases of RR virus infection in southwestern Australia occur between November and March, the warmest months of the year. This may, in part, be due to a faster development of the mosquito and a much shorter EIP of RR virus in *Aedes camptorhynchus* at warmer temperatures. However, the outbreaks of RR virus infection in arid regions of Western Australia rarely occur during the hottest months of the year. Combined with temperatures, it was found that heavy autumn and winter rains are far more likely to result in outbreaks of RR virus infection than summer rains (Lindsay & Mackenzie 1996). This is probably because temperatures in summer in Western Australia are too high and reduce the growth and development of the mosquitoes. High temperatures also affect the reproduction of the vertebrate host.

The study at Port Hedland and Exmouth on the arid Pilbara coast of Western Australia showed that most RR virus infections occurred during the months of highest relative humidity in both towns. This might reflect the timing of rainfall at the two towns to some extent. However, the fact that rain sometimes falls at other, less humid times of the year indicates that humidity should be considered as another possible contributing factor to outbreaks of arboviral diseases, particularly in normally arid regions (Lindsay & Mackenzie 1996).

Tidal inundation of salt marshes is a major source of water for breeding of the important arbovirus vectors *Aedes vigilax* and *Aedes camptorhynchus*. Adult females of both species lay their eggs on soil, mud substrate and at the base of plants around the margins of their breeding sites. Large populations of adult mosquitoes can emerge as little as eight days after a series of spring tides, depending on temperature. A rise in sea level might lead to more frequent and widespread inundation of coastal saltmarshes in the region, as a consequence extending the breeding grounds of these two species of mosquito. This, in turn, could give rise to a much larger summer population of mosquitoes and consequent exposure of large numbers of urban dwellers on the eastern seaboard to infection. This is particularly important to the transmission of RR virus infections in the coastal region, especially the northern coastal district of Queensland, including Townsville, because the main mosquito species there is *Aedes vigilax* (Lindsay, Mackenzie & Condon 1993; Russell 1995). Perhaps a principal cause of the outbreak of RR virus infections in 1988-1989 in Western Australia was the rise in sea level and an accompanying increase in high tides. It was found that for the last eight months of 1988 and the first four months of 1989, the mean sea level was 5.5 cm above the long-term mean. Thus, large areas of saltmarsh that are normally dry during the summer months were regularly inundated with water through the summer of 1988-1989. This provided ideal breeding sites for *Aedes camptorhynchus* during late spring and summer and *Aedes vigilax* in summer. Of particular importance was the fact that the regular inundation of the breeding sites enabled *Aedes camptorhynchus* to persist through the summer of 1988-1989 (Lindsay, Mackenzie & Condon 1993).

Conclusion

This study in Queensland showed that there was an association between climate variability and the transmission of RR virus infection in Townsville, a coastal region in northern Queensland, with 30% to 37% of variance explained and significant though low power of association. The rise in temperatures (minimum and maximum), precipitation and sea levels might have an important impact on the epidemic potential in northern Queensland in future. This is because these climatic variations will act on *Aedes vigilax*, the main vector in this area and thus on the transmission of the disease. This could take two months, which is consistent with the two month lagged effect from this study. If global warming results in a significant sea level rise, an increase in temperatures and more irregular rainfall as predicted by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) (CSIRO 1996), the distribution of breeding sites for saltwater mosquitoes will also change locally along low lying parts of the Queensland coast leading to an expansion of the epidemic focus and a higher potential for epidemics.

In Toowoomba, an inland region of Queensland, the results showed that there were correlations between various climatic variables and the monthly incidence of RR virus infections. However, in the regression analysis, only temperatures (minimum and maximum temperatures) were significantly associated with the transmission of RR virus infection. However, the reason why "precipitation" was not significant in the transmission of the disease remained unclear. Obviously, arboviral transmission in an area is complicated and involves many parameters, such as vertebrate host identity and availability, vector identity, breeding conditions and sites, vegetation/herbage for vector protection during sunlight hours; as well as weather conditions, and physical requirements (tides, saltmarsh, rivers, lakes, or dams). In this study in Toowoomba, only weather conditions were taken into account in the analysis, therefore, multi-disciplinary study is needed in future to have a better understanding of RR virus transmission in this area.

Besides other biological and physical parameters mentioned above, the various distributions of different vectors between coastal and inland regions of Queensland and their various sensitivities to climate effects could be one of the main reasons for the higher incidence in the coastal region than in the inland region. These need to be addressed in further studies. However, results from this study should be applicable to other districts in Australia and even in the Australasian region generally, and be helpful to policy makers in developing preventive strategies.

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