Rainfall and vector mosquito numbers as risk indicators for mosquito-borne disease in Central Australia

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Abstract

There have been 5 confirmed cases of Murray Valley encephalitis virus (MVE) infection in the Alice Springs region during the high rainfall years of 1999/00 and 2000/01, compared with one case in the preceding 9 years. There also appeared to be an increased prevalence of Ross River virus (RR) infection in the Alice Springs and Tennant Creek regions associated with high rainfall. This paper presents an analysis of summer rainfall from 1990/91 to 2000/01, numbers of seroconversion of sentinel chickens to MVE, and RR cases in both regions. In Alice Springs where summer rainfall (December to February) and average vector numbers in the December to March period are closely correlated, the analysis also included mosquito vector numbers and MVE cases. Summer rainfall over 100 mm was significantly associated with sentinel chicken seroconversions to MVE. From December to March there was also a significant association of average vector numbers (≥ 300) with seroconversions in sentinel chickens following high summer rainfall. MVE appears enzootic in the Tennant Creek region and epizootic in the Alice Springs region. In Alice Springs during December to March, there was a significant association of RR cases with rainfall over 100 mm and with average vector numbers over 300. There was also a significant correlation of summer rainfall with RR cases in Tennant Creek. Summer rainfall is a new and good early indicator of high risk for both MVE and RR disease in the Alice Springs locality and RR in the Tennant Creek locality. Although similar relationships between rainfall and vector abundance, and disease incidence probably exist in other areas of central Australia, rainfall and vector abundance thresholds will probably vary according to local climatic and environmental conditions. *Commun Dis Intell* 2003;27:110-116.

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Introduction

Murray Valley encephalitis virus (MVE) is a mosquito-borne arbovirus primarily carried by the common banded mosquito *Culex annulirostris*.[1,2] The human disease caused by this flavivirus can result in severe symptoms and has a 25 per cent mortality rate.[3,4] The virus is considered enzootic in the Kimberley region of Western Australia, the Top End of the Northern Territory, and possibly in north Queensland.[5] The virus is responsible for infrequent severe epidemics in eastern Australia, with the latest occurring in 1974.[5] The Alice Springs and Tennant Creek regions in the Northern Territory (Figure)[6] are thought to be epizootic for MVE following widespread and heavy wet season rainfall.[7] The natural host of MVE is thought to involve wild waterbirds, particularly herons and egrets.[2] The mosquito vector *Cx. annulirostris* is found throughout the Northern Territory and reaches very high numbers two to three weeks after heavy rainfall and widespread flooding in arid areas.[7]

There were 18 confirmed cases of MVE disease in the Northern Territory in 6 separate years between 1974 and 1993.[7] Most cases since 1993 have occurred in the Alice Springs region. Recent cases in Central

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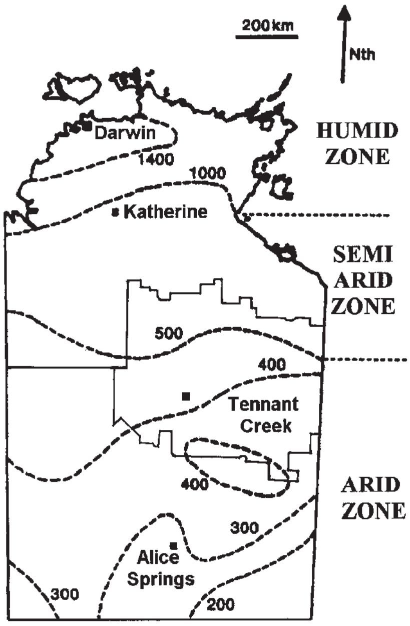
Figure. Northern Territory mean annual rainfall isohyets (mm) and the approximate limits of climatic zones



Adapted from McDonald and Alpine.[6]

Australia were from February to April during 2000 and 2001.[8] It has been suggested that the increase in cases in the Alice Springs region might be associated with high summer rainfall and subsequent high vector numbers.[8]

Regular adult mosquito monitoring has been established in Alice Springs and Tennant Creek to guide vector control and to provide an indication of increased potential for arbovirus disease in these regions.[5] Sentinel chicken flocks were established in 1995 in Tennant Creek and in late 1996 in Alice Springs to monitor MVE activity by testing for general and specific flavivirus seroconversion. Media alerts and media warnings are issued by the Department of Health and Community Services in response to increased vector numbers and to new seroconversions to MVE in sentinel chickens.[5]

Ross River virus (RR) is an alphavirus that causes a debilitating and sometimes chronic polyarthritis disease in humans.[2] The normal vertebrate hosts of RR are native macropods, such as kangaroos and wallabies.[2] *Culex annulirostris* is the major vector in inland areas of Australia, although *Ochlerotatus normanensis* is also a possible vector.[9,10] Epidemic activity of RR in inland areas of temperate Australia is usually associated with summer and autumn rain.[2]

RR disease was not considered common in Central Australia prior to 1991 when improved records were started.[9] Confirmation of local transmission was reported during an outbreak in 1995.[10] It has been suggested that a recent apparent increase of RR disease in Central Australia is related to increased rainfall and the subsequent high number of vector mosquitoes.[11]

A recent outbreak of MVE and RR disease in Central Australia has revived the interest in predicting seasons of increased arbovirus disease potential so that timely warnings can be made to residents in at-risk regions.

This paper describes the association of rainfall, vector numbers, seroconversion to MVE in sentinel chickens, and cases of MVE and RR disease, for use as predictors of outbreaks of mosquito-borne disease in the Alice Springs and Tennant Creek regions of the Northern Territory.

Methods

Rainfall data for Alice Springs and Tennant Creek were obtained from the Bureau of Meteorology records.[12] The daily rainfall totals for each month were combined into a total for December to February combined (summer) and an annual total.

Adult mosquito numbers in Alice Springs were monitored on one night per week by battery operated carbon dioxide baited EVS traps[13] at four regular monitoring sites. The traps were set and retrieved by the Environmental Health Officers of the Alice Springs Town Council. The trap sites included two sites at either end of Ilparpa Swamp, the closest boundary being 2 km south of the southern outskirts of the urban area. One was set in a semi-rural area approximately 500 m east of the eastern swamp boundary, and one within an urban area approximately 3 km north of the swamp. The trap sites were chosen to monitor the dispersal of mosquitoes from the swamp into the semi-rural and urban areas.

The traps were set before sunset and retrieved after sunrise. The mosquitoes were sent to the Medical Entomology Branch in Darwin for identification. All mosquitoes were identified and counted for trap collections that contained up to 200 mosquitoes. For trap collections over 200 mosquitoes, sub-samples of around 100 were identified and counted, and the total estimated by weight. For *Cx. annulirostris* the mean number of mosquitoes per trap night from the four sites was calculated for the periods December to February, December to March, and annually (Table 1). The December to March category was chosen to include the lag in adult vector mosquito numbers resulting from rain in February. Mosquito trap results from Tennant Creek were not available for continuous years.

The sentinel chicken flocks usually contained 10 birds, and were established in semi-urban areas in Alice Springs and Tennant Creek. Veterinary officers of the Department of Business, Industry and Resource Development bled the chickens each month. Blood samples were sent to the Arbovirus Surveillance and Research Laboratory at the University of Western

Australia for both general and specific testing using an epitope-blocking enzyme immunoassay for flavivirus antibody.[5] When the majority of the chickens in a flock seroconverted during the arbovirus season (December to August), the entire flock was replaced. Otherwise it was replaced at the end of each season. The number of new seroconversions to MVE each month were totalled for each financial year.

The MVE cases were the number of annually notified laboratory-confirmed cases for the Alice Springs or Tennant Creek region recorded by the Centre for Disease Control in Darwin.

The RR cases were the number of annually notified laboratory-confirmed cases from Alice Springs or Tennant Creek recorded by the Centre for Disease Control in Darwin.

The rainfall, vector numbers, sentinel chicken seroconversions, MVE cases, and RR cases were tabulated for each year for which they were available (Table 1, Table 4). Correlation analyses were used to determine whether there was a significant linear association between rainfall or vector numbers, and the number of disease cases and seroconversions. In addition, cut-offs for division into a categorical variable were determined to represent differences between years of high and low rainfall and vector numbers. For analysis $p < 0.05$ was considered significant. Analysis was performed using Intercooled STATA version 7.0 (Stata Corporation Texas).

Results

Alice Springs

The mean annual rainfall for Alice Springs was 273.7 mm (Figure).[6,12] The results of rainfall, mosquito vector numbers, sentinel chicken seroconversions, MVE cases, and RR cases for Alice Springs for the last 11 years are displayed in Table 1.

There were 4 years which had an annual rainfall of over 300 mm; 1994/95, 1996/97, 1999/00 and 2000/01 (Table 1). These were the only years where the average numbers of *Cx. annulirostris* per trap per night were over 116 for the whole year, over 198 for December to February and over 327 for December to March. These years, with the exception of 2000/01, also reported a relatively high number of cases of RR (14 cases or over).

During the years when sentinel chickens were in place, there were seroconversions to MVE in all 4 years and, except for 1994/95, cases of MVE were also reported in these years (Table 1). MVE cases were restricted to the Alice Springs locality, except in 1990/91 and 1999/00 (90/91 in Tanami and 99/00 in Willowra, Docker River and Hermannsburg), when 4 cases occurred in small communities in the wider Alice Springs region.

With one exception (2000/01) the years which recorded a rainfall of more than 100 mm during the summer months (December to February), also reported high numbers of RR cases (14 cases or more). Except for 1994/95, seroconversions to MVE in sentinel chickens and cases of MVE were also recorded in these years. The average vector numbers

Table 1. Cases of Murray Valley encephalitis virus and Ross River virus, vector numbers, rainfall, and Murray Valley encephalitis seroconversions in sentinel chickens, Alice Springs, 1990/91 to 2000/01, by financial year

	Financial year										
	1990/91	1991/92	1992/93	1993/94	1994/95	1995/96	1996/97	1997/98	1998/99	1999/00	2000/01
Cx. annulirostris Dec-Feb	23	1	85	7	369	0	199	1	137	496	1,188
Cx. annulirostris Dec-Mar	100	7	64	11	407	2	328	2	109	888	1,046
Cx. annulirostris (annual)	99	29	30	23	130	4	117	6	76	315	431
Summer rainfall (Dec-Feb) (mm)	111.0	25.0	78.4	83.8	170.4	43.0	286.2	48.0	48.8	343.6	285.4
Annual rainfall (mm)	162.8	127.6	264.8	233.6	301.0	115.6	369.4	254.8	216.0	663.2	523.4
New seroconversions to MVE							7	0	0	5	8
Cases of MVE infection	1	0	0	0	0	0	1*	0	0	3	2
Cases of RR infection	14	2	9	1	25	0	26	5	1	14	4

* Presumptive case[14]

per trap per night for these years were an annual count of over 98 for all years, over 198 for December to February except for 1990/91, and over 327 for December to March except for 1990/91.

Alice Springs statistics

The data on rainfall, vector numbers, sentinel chicken seroconversions, MVE cases and RR cases for Alice Springs were all normally distributed. Mosquito vector numbers from December to February were significantly correlated with summer rainfall for the same months (r=0.72, p=0.012) (Tables 2 and 3). December to March vector mosquito numbers were significantly correlated with summer rainfall (r=0.89, p=0.0003). MVE seroconversions significantly correlated with summer rainfall as a continuous variable (r=0.89, p=0.0003) and were significantly associated with summer rainfall of 100 mm or higher (p=0.017). MVE seroconversions were significantly associated with December to March mosquito numbers of 300 or higher per trap per night (p=0.017), but not with mosquito numbers during December to February.

RR cases were significantly associated with summer rainfall of 100 mm or higher (p=0.026). They were also significantly associated with December to March mosquito numbers of 300 or higher per trap per night (p=0.022). However, there was no significant association of RR cases with December to February mosquito numbers.

Tennant Creek

The mean annual rainfall for Tennant Creek Airport was 451.5 mm (Figure). The results of sentinel chicken seroconversions, rainfall, and RR cases for Tennant Creek are shown in Table 4.

There were 5 years which had an annual rainfall of over 500 mm; namely 1990/91, 1992/93, 1996/97, 1999/00 and 2000/01 (Table 4). Four of these years had relatively high numbers of RR cases (23 cases or over), with the highest number of cases in the year of highest annual rainfall (2000/01). All of the years when sentinel chickens were in place had seroconversions to MVE, except for 1995/96 and 1997/98, which were years of relatively low annual rainfall (Table 4).

All years which reported a high number of RR cases (more than 10), had a summer rainfall of over 400 mm. The exception was 1999/00, when there were 6 cases of RR reported. However, sentinel chicken seroconversion occurred in 2 years when summer rainfall was not over 400 mm (Table 4).

Table 2. Correlation of rainfall, vector and Murray Valley encephalitis virus variables, Alice Springs, December to February 1990/91 to 2000/01

Variable 1	Variable 2	r value	p value
Summer rainfall*	Average vector numbers Dec-Feb*	0.72	0.012
Summer rainfall*	Average vector numbers Dec-Mar*	0.89	0.0003
Summer rainfall*	MVE seroconversions*	0.89	0.0003
Summer rainfall 100 mm*	MVE seroconversions*		0.017
Average vector numbers Dec-Feb	MVE seroconversions		ns
Average vector numbers Dec-Mar 300*	MVE seroconversions*		0.017
Average vector numbers Dec-Mar	MVE cases		ns

* Significant correlation 0.05 level

ns Not significant

Table 3. Correlation of Ross River virus, rainfall and vector numbers, Alice Springs, December to February 1990/91 to 2000/01

Variable 1	Variable 2	r value	p value
Summer rainfall	RR cases	0.58	0.059
Summer rainfall 100 mm*	RR cases*		0.026
Average vector numbers Dec-Feb	RR cases		ns
Average vector numbers Dec-Mar 300*	RR cases*		0.022

* Significant correlation 0.05 level

ns Not significant

Table 4. Cases of Ross River virus, rainfall, and Murray Valley encephalitis virus seroconversions in sentinel chickens, Tennant Creek, 1990/91 to 2000/01, by financial year

	Financial year										
	1990/91	1991/92	1992/93	1993/94	1994/95	1995/96	1996/97	1997/98	1998/99	1999/00	2000/01
Summer rainfall (mm)	448.4	99.0	582.6	338.2	199.8	101.2	615.4	259.2	223.6	450.8	517.8
Annual rainfall (mm)	503.4	189.2	663.0	401.0	304.8	351.4	632.0	320.0	356.6	751.6	947.0
RR cases	27	3	30	0	3	2	23	1	6	6	64
New seroconversions to MVE	-	-	-	-	7	0	7	0	10	8	12

Tennant Creek statistics

There was a significant correlation of summer rainfall with RR cases (p=0.022), with a highly significant association of rainfall over 400 mm with notification of more than 5 RR cases (p=0.003) (Table 5). There was no significant correlation of summer rainfall with MVE seroconversions as either continuous or categorical data.

Discussion

Alice Springs

The highly significant correlation of vector numbers in December to March with summer rainfall indicates that high summer rainfall is a good parameter to predict high numbers of *Cx. annulirostris* in the Alice Springs locality. The weaker correlation between vector numbers in December to February and summer rain is probably due to the delay in a rise in adult vector numbers after rain in January or February.

High levels of summer rainfall are generally widespread in Central Australia and are usually associated with monsoonal influences from the north and north-west.[12] High summer rain (over 100 mm) in Alice Springs is an indicator of rain in other localities in the region, causing localised flooding or pooling that creates breeding habitats for *Cx. annulirostris*. Heavy and widespread summer rain in the arid area would be an indicator of the extent of increased MVE risk.

The highly significant correlation between MVE seroconversions in sentinel chickens and summer rainfall, both as a continuous variable or a categorical variable when rainfall exceeds 100 mm, indicates that summer rainfall is a very good indicator of MVE transmission in the Alice Springs locality. To our knowledge, this is the first published quantitative measure of rainfall and MVE transmission in a locality.[15]

Seroconversions in sentinel chickens in the Alice Springs locality occurred each year when MVE cases in humans occurred in the region. Seroconversions are thus an indicator of risk of MVE in the region and probably in adjacent areas of other states after widespread summer rain.

Two years of below average rainfall and no seroconversion of sentinel chickens in Alice Springs were followed by a year of sentinel seroconversions and MVE cases. The Forbes hypothesis states that an increased risk of MVE disease in south-east Australia follows two years of above average rainfall of catchments in Northern Territory, Queensland, New South Wales and Victoria. It is clear that there is no similar requirement for two consecutive years of above average rainfall in Central Australia for MVE transmission. This suggests either MVE is endemic in Central Australia or there is a rapid spread of either infected birds or mosquitoes from enzootic regions to the north or north-west.

The lack of seroconversion to MVE in sentinel chickens in the Alice Springs locality for 2 consecutive years (1997 to 1999) (Table 1) may indicate a lack of endemicity of MVE in that region. The periodic seroconversion in Alice Springs associated with north-west monsoon weather, and the simultaneous

Table 5. Tennant Creek statistics, December to February 1990/91 to 2000/01

Variable 1	Variable 2	p value
Summer rainfall*	RR cases*	0.022
Summer rainfall ≥ 400 mm*	RR cases 5*	0.003
Summer rainfall	MVE seroconversions	ns
Summer rainfall ≥ 400 mm	MVE seroconversions	ns

* Significant correlation at 0.05 level

Ns Not significant

seroconversion in Alice Springs and Tennant Creek during the 3 years, 1996/97,1999/00 and 2000/01, suggests the periodic introduction of MVE to the Alice Springs region. This introduction is most probably from the north or north-west by infected wind-blown mosquitoes or wind-assisted dispersal of infected birds. The north-south dispersal of MVE through Central Australia may have been an additional mechanism for the introduction of MVE to south and eastern Australia in the widespread outbreak in 1974.[2]

Sentinel chickens have been used as indicators of MVE activity in Western Australia and the Northern Territory in the past and have been useful predictors of disease.[5,16] However, there are delays in receiving data from sentinel chicken programs. The results presented here indicate that high summer rainfall is a good indicator of risk of MVE disease in the Alice Springs locality and probably the region as a whole. The use of accumulated rainfall is independent of sentinel chicken results and therefore offers an earlier indicator of probable MVE activity.

The highly significant correlation with December to March average vector numbers of 300 mosquitoes or higher and MVE seroconversions in sentinel chickens gives a good threshold indicator of vector numbers for expected MVE activity in the Alice Springs area. This is the only published quantitative measure of vector numbers for increased risk of MVE transmission of which we are aware.

High average vector numbers in the above order of magnitude in the December to March period in other localities in the arid zone, in association with widespread heavy summer rain, would be a further indication of increased risk of MVE in that locality.

Summer rainfall over 100 mm is also a good predictor of increased RR risk. However, the relatively low number of cases of RR in 2000/01 did not correlate with high rain and high numbers of cases (Table 1). It is possible that people in Alice Springs protected themselves more from mosquitoes in that year after the considerable publicity following cases of MVE in the town.

An average vector number of over 300 mosquitoes per trap per night for December to March is a vector threshold for RR transmission to humans in the Alice Springs locality. While there have been a number of published qualitative indicators of rainfall and vector numbers with RR transmission, the above indicator is among the few published quantitative indicators for RR transmission.[17,18,19]

The lack of a significant correlation of RR cases with December to February vector numbers could be an indication that the RR virus-mosquito-host cycle takes a longer time to develop before conditions are favourable for transmission to humans. The lack of correlation of RR cases with December to February vector numbers also indicates that the rapid appearance of floodwaters *Ochlerotatus* mosquitoes, which occur very soon after heavy rain, are not the prime vectors of RR to humans in Alice Springs.

Rainfall alone is a significant indicator of probable MVE or RR activity. When the threshold of summer rainfall is exceeded in any part of the region, media warnings urging self-protection against mosquito bites, and enhanced vector control measures should be commenced.

Tennant Creek

RR transmission follows high summer rainfall in the Tennant Creek locality, and probably the whole of the Tennant Creek region. Summer rainfall over 400 mm is a good indicator for enhanced RR transmission in the Tennant Creek locality.

Although there is inconsistent mosquito monitoring data for Tennant Creek, those results available for specific years do indicate high numbers of *Cx. annulirostris* and *Ochlerotatus normanensis* following summer rainfall (Peter Whelan, unpublished data). Either *Cx. annulirostris* or *Oc. normanensis* could be the vectors of RR in the Tennant Creek locality and the region as a whole. However, relatively high numbers of *Cx. annulirostris* tend to remain longer after heavy rain and localised flooding (Peter Whelan, unpublished data), indicating that *Cx. annulirostris* is probably the major vector of RR in this region.

The lack of correlation of summer rainfall with MVE seroconversion of sentinel chickens in Tennant Creek indicates that seroconversions are independent of high rainfall. There were seroconversions in sentinel chickens in most years and with summer rainfall totals as low as 199.8 mm. This suggests the probable endemicity of MVE in the Tennant Creek locality and the Tennant Creek region.

While the frequent annual seroconversion of sentinel chickens suggests that MVE may be enzootic in the Tennant Creek locality, more information is required on both vector numbers and sentinel chickens to make valid conclusions on the endemicity of MVE in the locality and the region. It is possible that the Tennant Creek region is not enzootic for MVE and that the north-west monsoon winds blow MVE infected mosquitoes or assists infected bird dispersal from the north-west of Western Australia or the Top End of the Northern Territory into the region in most years. This speculation regarding the north-south dissemination of infected wind blown mosquitoes is supported by the occasional recovery of the coastal salt marsh mosquito *Ochlerotatus vigilax* in both Tennant Creek and Alice Springs during January and February in some years (Peter Whelan, unpublished data).

It is evident however, that MVE risk is high in the Tennant Creek locality and Tennant Creek region following summer rain. Over 200 mm of accumulated rain in summer appears to be a working indicator for an initial warning for both MVE and RR, with enhanced warnings issued after 400 mm of rain.

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References

1. Russell RC. Vectors vs. humans in Australia — who is on top down under? An update on vector-borne disease and research on vectors in Australia. *J Vector Ecol* 1998;23:1–46.
2. Russell RC, Dwyer D. Arboviruses associated with human disease in Australia. *Microbes and Infection* 2000;2:1693–1704.
3. Burrow JNC, Whelan PI, Kilburn CJ, Fisher DA, Currie BJ, Smith DW. Australian encephalitis in the Northern Territory: clinical and epidemiological features, 1987–1996. *Aust N Z J Med* 1998;28:590–596.
4. Mackenzie JS, Smith DW, Broom AK, Bucens MR. Australian encephalitis in Western Australia, 1987–1996. *Med J Aust* 1993;158:591–595.
5. Spencer JD, Azoulas J, Broom AK, Buick TD, Currie B, Daniels PW *et al*. Murray Valley encephalitis virus surveillance and control initiatives in Australia. *Commun Dis Intell* 2001;25:33–47.
6. McDonald NS, McAlpine J. Floods and droughts: the northern climate. In: Haynes CD, Ridpath MG, Williams MAJ, eds. *Monsoonal Australia: Landscape, Ecology and Man in the Northern Lowlands.* AA Balkema, Rotterdam, Netherlands; 1991:41–62.
7. Whelan P, Burrow J. Australian encephalitis in the Northern Territory. *Northern Territory Communicable Diseases Bulletin* 1994;2:21–23.
8. Brown A, Bolisetty S, Whelan P, Smith DW, Wheaton GR. Reappearance of Murray Valley encephalitis virus and Kunjin virus in Central Australia after an absence of 26 years. *Commun Dis Intell* 2002;26:39–44.
9. Tai KS, Whelan P, Patel M, Currie B. An outbreak of epidemic polyarthritis (Ross River virus disease) in the Northern Territory during the 1990–91 wet season. *Med J Aust* 1993;158:522–525.
10. Whelan P, Krause V, Horsburgh K, Sutherland G, Rossiter J. Confirmed case of Ross River virus infection acquired in Alice Springs March 1995. *Northern Territory Communicable Diseases Bulletin* 1995;2:9–11.
11. Northern Territory Department of Health and Community Services. Medical Entomology Branch annual report 2000–2001.
12. Bureau of Meteorology Monthly Weather Review; Northern Territory.
13. Rohe DL and Fall RP. A miniature battery powered CO^2 baited light trap for mosquito borne encephalitis surveillance. *Bull Soc Vector Ecol* 1979;4:24–27.
14. Merritt A, Philips DA, Carney I, Whelan PI. A presumptive case of fatal Murray Valley encephalitis acquired in Alice Springs. *Commun Dis Intell* 1998;22:103–104.
15. Forbes JA. Murray Valley encephalitis 1974 — also the epidemic variance since 1914 and predisposing rainfall patterns. Australasian Medical Publishing Co. Glebe.1978;20.
16. Broom A, Sturrock K, Van Heuzen B, Lindsay M, Smith D. Seroconversions in sentinel chickens provide an early warning of Murray Valley encephalitis virus activity in Western Australia. *Arbovirus Research in Australia* 2001;8:43–47.
17. Whelan P, Merianos A, Hayes G, Krause V. Ross River transmission in Darwin, Northern Territory, Australia. *Arbovirus Research In Australia* 1997;7: 337–345.
18. Ryan PA, K-A. Do, Kay BH. Spatial and temporal analysis of Ross River virus disease patterns at Maroochy Shire, Australia: Association between human morbidity and mosquito (Diptera:Culicidae) abundance. *J Med Entomol* 1999;26:515–521.
19. Tong S, Hu W. Different responses of Ross River virus to climate variability between coastline and inland cities in Queensland, Australia. *Occup Environ Med* 2002;59:739–744.