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Projecting the impact of climate change on the transmission of Ross River virus: methodological challenges and research needs

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Abstract

Ross River virus (RRV) is the most common vector-borne disease in Australia. It is vitally important to make appropriate projections on the future spread of RRV under various climate change (CC) scenarios because such information is essential for policy–makers to identify vulnerable communities and to better manage RRV epidemics. However, there are many methodological challenges in projecting the impact of CC on the transmission of RRV disease. This study critically examined the methodological issues and proposed possible solutions. A literature search was conducted between January and October 2012, using the electronic databases MEDLINE, Web of Science and PubMed. 19 relevant papers were identified. These studies demonstrate that key challenges for projecting future climate change on RRV disease include: 1. a complex ecology (e.g., many mosquito vectors, immunity, heterogeneous in both time and space); 2. Unclear interactions between social and environmental factors; 3. Uncertainty in CC modelling and socioeconomic development scenarios. Future risk assessments of CC will ultimately need to better understand the ecology of RRV disease and to integrate CC scenarios with local socioeconomic and environmental factors, in order to develop effective adaptation strategies to prevent or reduce RRV transmission.

Key words: Climate change, Ross River virus, projection, temperature, rainfall

Introduction

Ross River virus (RRV) is the causal pathogen of the most widely spread mosquito-borne disease (MBD) in Australia. Thousands of clinical cases are reported to the Australian Department of Health and Ageing each year. In 2011, RRV infections accounted for 60.3% (5,139) of all reported MBD notifications [1]. Although outbreaks, epidemics, small case clusters, and incidental cases have been reported from all Australian states and territories each year (Figure 1), the most notifications were from Queensland (QLD), tropical Western Australia and the Northern Territory [1]. For example, from 1993 to 2012, the notifications from QLD accounted for an average of 49% of the total cases, ranging from 78% in 1994 to 42% in 2012. Between 1993 and 2012 the average incidence for QLD was 57/100,000, compared with the national average of 22/100,000 (compiled from communicable diseases data http://www9.health.gov.au/ cda/Source/CDA-index.cfm) [1].

[Figure 1 here]

RRV outbreaks have increased throughout the country, notably in urban settlements and tourist destinations [2-6]. Over the past decade, Queensland Health has noted an increase in disease incidence throughout the state, including expansion into areas where the disease was previously absent, possibly related to an increase in travel [7]. The annual costs of symptom management and productivity losses are estimated at A$3-6 million, although this sum does not account for public health surveillance, control and response activities or full diagnostic and medical costs [3, 8]. The cost of healthcare resources and productivity loss have been estimated at A$1,000 - 2,500 per person between 1996 and 2002 [3, 9, 10], while it was more recently estimated to be over A$1000 per person (varied from A$1,018 to 1,180) [11, 12] and the aggregated cost was $4.3 to 4.9 million in 2007 [12]. Outbreaks of RRV impact considerably on tourism and industry, as well as on local communities [5, 13].

The epidemiology of RRV is complex because transmission cycles are driven by various mosquito species and vertebrate hosts within a variety of disparate geoclimatic regions [14-16]. More than 30 mosquito species have been implicated as vectors of RRV [16, 17]. Significant vectors include, *Aedes vigilax* and *Aedes camptorhynchus* with larval habitats in intertidal coastal wetlands, other *Aedes* species breed in freshwater and are found in many inland areas, and *Culex annulirostris*, which is found in vegetated semi-permanent and permanent fresh water, is common in tropical and temperate areas. Marsupials (e.g., kangaroos, wallabies) and other animals (e.g., dogs, cats, horses, possums) are implicated as intermediate vertebrate hosts for this disease. The incubation period may be as short as 3 days or as long as 21 days (usually 7–9 days on average) [18].

Mosquitoes are cold–blooded (ectothermic) and thus are especially sensitive to climatic changes [19]. Ross River virus is likely to be affected by climate change because weather influences the survival and reproduction rates of mosquitoes. This in turn influences distribution, abundance, intensity and temporal patterns of mosquito activity (particularly biting rates) throughout the year; as well as rates of development, survival and reproduction of pathogens within mosquitoes [20]. These results suggest that RRV may become increasingly widespread in the future due to global warming [21].

There is no vaccination or specific treatment for RRV infection. The most effective way to prevent infection is to protect the person from mosquito bites. As climate conditions can directly and indirectly affect mosquito density and mosquito habitats, there is growing concern regarding the future risks of arbovirus diseases arising from climate change [6, 22, 23]. Therefore, it is vitally important to make appropriate projections on the future spread of

RRV under various climate change scenarios in order for policy–makers to identify vulnerable communities and better manage RRV epidemics and mosquito vectors.

This paper brings together and critically reviews the current methodological challenges and research needs for projecting the potential impacts of climate change on RRV-, which may have wide applications in the development of effective risk management programs for RRV and other MBDs nationally and internationally.

Methods

A literature search was conducted and updated between January and October 2012, using the electronic databases MEDLINE, Web of Science and PubMed. The key words and Medical Subject Headings (MeSH) terms used were: “climate”, “climate change”, “climate variability”, “global warming”, “greenhouse effect” AND “Ross River virus”, AND “project*”, “forecasting”, “future” or “scenario*”. References and citations of the articles identified were inspected to ensure that the relevant articles were included in the detailed review.

Two inclusion criteria were used to select articles. First, only quantitative, empirical studies published in peer–reviewed English journals were selected. Second, a paper had to contain information on the possible impact of CC on RRV disease.

Results

General

We identified forty-two papers from searches of the selected electronic bibliographic databases. After reviewing the titles and abstracts of these papers, we retrieved twenty-six articles for the detailed examination. Finally, nineteen studies met the eligibility criteria and were included in the review. Figure 2 shows a flowchart of this process and the reasons for exclusion of articles at each stage.

[Figure 2 here]

Among the relevant papers identified, only two studies projected how changes in rainfall patterns will affect RRV disease in Australia by 2100 using “dry season” and “wet season” scenarios RRV [12, 24]. The results presented in both studies were similar. Changes to transmission patterns are thought to be regionally-specific. The annual pattern will probably change from epidemic to endemic in temperate regions that border sub-tropical endemic regions. Longer months of RRV activity may occur in cooler temperate regions such as southern Tasmania, higher altitude New South Wales and Victoria. Dramatic decreases in rain in southwest Western Australia may reduce RRV in this location. However, long drought periods may provide suitable conditions for building numbers of susceptible kangaroo hosts, which suggests a stronger pattern of large outbreaks of RRV disease interspersed by years of inactivity in certain temperate and semi-arid regions [12]. In coastal areas, salt water vector breeding will be enhanced by increased tidal inundation due to sea level rise and population growth will increase the number of people at risk of infection. Because of the increased scarcity and cost of water leading to reduced irrigation, the irrigation areas of southwest New South Wales and northern Victoria will cease to be a significant location of RRV activity [12].

Seventeen other studies developed the predictive early warning models and assessed the relative risks of climate, mosquito and other socio-economic factors on RRV, based on retrospective data which explored the model validation, inclusive variables and regional variations (Table 1). In general, the studies cover all Australian climates, except equatorial and desert (Figure 3). The body of research covered a range of areas including QLD [5, 13, 22, 25-32], Victoria [33], Western Australia [4, 34], South Australia [35, 36], Tasmania [6] and the Top End of the Northern Territory [37].

[Figure 3 here]

These studies appear to confirm that several environmental variables, including rainfall, temperature, humidity, and high tide (or even river height as demonstrated in the article by Williams et al. [36]) are correlated with mosquito abundance and subsequent activity of RRV. Several of these studies demonstrate that the environmental variables related to RRV disease incidence often differ between regions, thus making it difficult to generalise findings from one regional model to another [2, 27, 31, 33, 36]. A lagged effect of climate drivers on RRV transmission has also been identified in these studies. Lags have been employed to account for virus/mosquito lifecycle, incubation period in the human host, and presentation to a medical practitioner [38]. Combining mosquito population data with locally available and easily accessible climate data, has been shown to enhance the ability of local models to predict RRV disease outbreaks [33, 37]. Other socio-ecological factors were also important contributors in studying climate-RRV relation [2, 23, 33].

There were generally three steps in the published research to assess the pre-existing association between RRV and climate. First, the model was developed using various independent variables with RRV as the dependent variable. Various models were used in the included articles. The two main ones were Seasonal Auto-Regressive Integrated Moving Average used in six of the studies, various regression models used in seven studies and four others (Intergovernmental Panel on Climate Change (IPCC) scenarios, change mapping, mixed models, Generalised linear model. (See Table 1). Some studies used more than one model to compare the results [25, 29]. Second, model fit was checked. Finally, the model was verified by predictive variables matched with the actual observations. The criteria for choosing a model included the Bayesian Information Criterion [37], Akaike Information Criterion (AIC) [28], Change in AIC (ΔAIC) [37], goodness-of-fit test [5, 27, 29, 33, 34], and Deviance Information Criterion [26, 30].

The impact of important climate variables on RRV transmission

Rainfall has almost universally been included in models of RRV infection around Australia [38]. As shown in a Brisbane study, 85% of the variation in RRV incidence was accounted for by rainfall [2]. In Broome, 117 mm of monthly rainfall was associated with a 95% likelihood of an outbreak of RRV disease, with 85% specificity and 87% sensitivity [4]. For a lag period of 0–4 months, Tong and Hu found no significant correlation between rainfall and RRV incidence in Gladstone [31]. A significant positive correlation was evident during a 1-month lag in Darwin [37] and South Australia [35], a 2-month lag in Brisbane [28, 31], Townsville [5] and Cairns [13] and the whole Queensland [31], a 3-month lag in Mackay [31] and Tasmania [6], and a 4-month lag in Bundaberg [31]. Some studies showed a significant correlation between rainfall and vectors, during a 1-month lag in Brisbane [32] and Darwin [37] for *Culex annulirostris* and *Aedex vigilax* vectors, as well as 2- and 4-month lag times in Townsville and Toowoomba for *Aedex vigilax* [25], and a 2-month lag in Darwin for *Aedex notoscriptus* [37].

Other climatic indicators seemed to play a role on the transmission of RRV disease but the effect was region-specific. Minimum temperature was positively associated with RRV during a 1-month lag in South Australia [35], 2-month lag in Townsville [5] and QLD [31] and 3-month lag in Darwin [37]. A positive relationship was found between maximum temperature and RRV infection in Townsville [5] and QLD [25, 31) and Tasmania [6]. The Southern Oscillation Index (SOI) had a positive association during a 2-month lag in South Australia [35] and Brisbane [2]. Humidity was negatively related to the number of cases in the previous month in South Australia (35), 2-month in Townsville [5] and with a 5-month lag in Cairns [13].

High tide was implicated as an important precursor of outbreaks of RRV in several studies. The negative relationship between tide and RRV cases at 0 and 1 month in Tasmania is novel to the study by Werner et al. [6]. A positive relationship between maximum tide and RRV infections in the current month was found in Darwin [37] and Townsville [5]. Absolute tide height was positively related to RRV in Bunbury [34].

Climate data alone was moderately sensitive (e.g., 64%) in predicting epidemics and the addition of mosquito surveillance data increased the sensitivity of the early warning model to 90% in Western Australia [33, 34]. The best model was found to include climate indicators and mosquito species, which explained more deviance than climate-only or vector-only models [37]. A study in Brisbane found that 95% of variation in RRV incidence was accounted for by mosquito density [29]. While not demonstrating causative relationships, several mosquito species were significantly associated with increased virus activity. In the Renmark-Paringa Local Government Area, *Coquillettidia linealis*, known to be an efficient vector of RRV, was found to be a significant factor. Conversely, time-lagged *Cx. globocoxitus* abundance was also found to be a significant predictor of activity, despite not being considered a competent vector of RRV [36].

Climate is not the only factor affecting RRV incidence. Other socio-ecological factors were also important contributors in studying climate-RRV relationships [22, 23, 33]. For example, there was a positive relationship between RRV incidence and the proportion of people with lower levels of education and with vegetation density. There was a negative relationship between RRV incidence and the proportion of labour workers that a decrease was found for an increase of the percentage of the labor workers [22]. However, non-climatic factors are seldom included in much of the research cited, possibly due to data availability.

No models to date have incorporated data on vertebrate hosts or information on human population movements from non-endemic areas to endemic areas [38].

Discussion

Climate change will likely increase the risk of RRV transmission

The fourth assessment report of the IPCCreported that global mean surface temperature will likely rise by between 1.1 °C and 6.4 °C by 2100, with best estimates of between 1.8 °C and 4.0 °C. During this century, global average surface temperature increases are likely to exceed the safe threshold of 2.0 °C above the preindustrial average temperature [39]. In Australia, if emissions are low, warming of between 1 ºC and 2.5 ºC is likely to occur by around 2070, with a best estimate of 1.8 ºC. Under a high emission scenario, the best estimate for warming is 3.4 ºC, with a range of 2.2 ºC to 5 ºC [40]. It also predicts that decreases in annual average rainfall are likely to occur in southern Australia, droughts are likely to become more frequent and sea levels will continue to rise [40]. These changes will increase the level of climate change related risks for the rest of the century and create significant challenges in terms of RRV infection and endemicity [21, 23].

Rainfall is considered the most important climatic factor driving RRV prevalence due to mosquitoes' reliance on water to complete their life-cycle [5, 6, 28]. At higher temperatures but before reaching the upper threshold, the proliferation and reproduction rates increased, transmission season was extended, and ecological balances and climate–related migration of vectors, reservoir hosts, or human populations changed [41]. Tidal inundation of salt marshes is a major source of water for breeding of the important arbovirus vectors *Aedex vigilax* and *Aedex camptorhynchus*. Adult females of both species lay their eggs on soil, mud substrate and the plants around the margins of their larval habitats. The eggs hatch when high tides subsequently inundate the sites. Large populations of adult mosquitoes can emerge as soon as eight days after a series of spring tides [5].

Because RRV is transmitted by various mosquito species in different situations, the epidemiology of the disease varies between and within regions. The different risk factors identified in the different regions possibly reflect the underlying climatic environments, and/or different vector populations and habitats [27]. In the temperate south, epidemic activity is usually associated with summer and autumn rainfall in inland areas or rain and/or tidal inundation of coastal marshes during the warmer seasons, when the vectors are most active. In the tropical north, distinct seasonal activity associated with the highest spring tides and the wet season is apparent, and in some regions there may be year-round activity [15]. Many cases of infections occur in coastal regions which have intertidal salt marsh and mangrove habitats harbouring large populations of the mosquitoes that can carry the virus. However, cases are also reported in inland areas of Australia, in response to rainfall and salinity. In northern and central Queensland, RRV is active throughout the year, in other states, disease presence follows spring and summer rains.

Projection is a useful tool for policy-making

RRV is one of the few infectious diseases that can be predicted by climate-based early warning systems [34]. Early warning of weather conditions conducive to outbreaks of RRV disease is possible at the regional level, with a high degree of accuracy [33]. It is important to make appropriate projections on the future spread of RRV under various climate change scenarios because such information is essential for policy–makers to identify vulnerable communities and to better manage RRV epidemics [12, 42]. Using climatic indices along with forecasting models can alert authorities to possible changes in the risk level, either immediately or in the near future [43]. The ability to predict an outbreak months or years in advance based upon climatic indicators may make it possible to implement early intervention initiatives or aggressive vector control programs [44].

Current challenges

There have been several key methodological challenges in projecting the impact of climate change on RRV transmission from the projection research of climate change-MBDs. These include: 1) Data selected are heavily dependent on availability and technique limitation. For example, climate data in an Local Government Area is generally sourced from the station with the most complete data or the longest recording history [27, 28]. 2) Analytical scales (e.g., monthly) may be too coarse to assess the immediate effects of climate variation on RRV disease, however the incidences of RRV may be too low to assess if weekly or daily indices were used [28]. 3) Numbers of the IPCC emission scenarios were applied and various baseline time periods were chosen in previous projection of CC on other MBDs. No standard method is recommended. 4) In order to project future climate factors within specific regions, downscaling techniques and regional models need to be applied to project future regional climate change. However, regional climate models are very complex and there are no consistent procedures. 5) Both biological and statistical models were used to describe the climate–MBDs relationship and the modelling technique is not yet standard. In addition, there are limitations to these models in that potential changes to the immune status of the human population, and in the ecology of vertebrate virus reservoirs, have not been taken into account [36]. 6) Finally, uncertainties exist in scenario-based climate change risk assessment. Future greenhouse gas emissions, population growth, socio-economic status, urbanisation, land use change phenomena, migration and disease control programs will affect future risks of RRV outbreaks.

Recommendations for future research directions

An assessment of the future risk of RRV transmission associated with climate change will ultimately need to integrate global and regional climate–based analysis with local socio-economic and environmental factors, in order to guide comprehensive and sustainable strategies to control and prevent RRV transmission. We would like to make the following recommendations for future research directions:

First, the availability of climate data at a sub-regional level (e.g., Statistical Local Area or Local Government Area) over a long-term period will assist better understanding of the distribution of RRV transmission across the country. Accordingly, the climate data at various stations at a sub-regional level should be incorporated in the models to project the distribution of the disease in both time and space.

Second, improved understanding of the RRV ecology, and the direct and indirect effects of climate variability on the RRV cycles is required to establish the baseline relationship between climatic factors and RRV transmission.

Third, a local model (e.g., Local Government Area/Statistical Local Area level) for projecting future climate change–related RRV risk needs to be developed. This is an area which is relevant not only for developing adaptation strategies to the direct climate change effects on RRV but also for planning interventions to reduce the indirect effects of factors such as land use and ecological degradation. In particular, the development of combining process–based models (capturing the ecology of the RRV transmission system) with a statistical approach is needed.

Fourth, uncertainty analysis should be included within the model. The problem with non–climatic drivers of RRV transmission is that most of their impacts have not been quantified and thus, minimising these uncertainties would dramatically improve the outcomes of future projections of climate change impacts on RRV.

Finally, for any predictive models to become part of effective warning systems, they must provide reliable forecasts with clear parameters for triggering response activities. The specificity of the models for particular regions means that they are limited in geographic applicability. Such models are most effective when developed for specific regions [36].

Conclusion

Future risk assessments of climate change will ultimately need to better understand the ecology of RRV disease and to integrate climate change scenarios with local socioeconomic and environmental factors, in order to develop effective adaptation strategies to control and prevent RRV transmission. Current methods of projecting the impact of climate on RRV transmission are still at an early stage and needs further developments.

Abbreviations:

AIC: Akaike Information Criterion; CC: climate change; IPCC: Intergovernmental Panel on Climate Change; MeSH: Medical Subject Headings; MBD: mosquito-borne disease; QLD: Queensland; RRV: Ross River virus; SOI: The Southern Oscillation Index.

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Table 1 The characteristics of the included studies.

Study	Time period	Setting	Climatic factors	Model	Considered other factors	Findings
Indirect projection						
Werner et al. 2012 [6]	1993-2009	Southeastern Tasmania	Monthly mean maximum temperature, monthly rainfall and monthly mean maximum tide	Negative binomial regression model	Mosquito larvae data	RRV cases are projected to increase 23.2% in temperature and 9.9% in rainfall over the long-term average per unit increase.
Mclver et al. 2010 [4]	JAN. 2000-MAY 2007	Broome, the west Kimberley region of Western Australia	Monthly minimum and maximum temperatures, monthly rainfall, humidity and monthly maximum tide height	Seasonal auto-regressive integrated moving average (SARIMA) model	–	A threshold level of 117mm monthly rainfall would predict an outbreak of RRV disease with 85% specificity and 87% sensitivity.
Hu et al. 2010 [30]	1999-2001	Queensland	Monthly maximum temperature and rainfall	Bayesian spatiotemporal conditional autoregressive model	Socio-Economic Index for Areas, population	The average increase in monthly RRV incidence was 2.4% and 2.0% for a 1 °C increase in monthly maximum temperature and a 10mm increase in rainfall, respectively.
Williams et al. 2009 [36]	1999-2006	The River Murray Valley of South Australia	Seasonal rainfall relative to the historic mean (i.e. seasonal rainfall/historic mean). Seasonal minimum and maximum temperatures	Stepwise multiple regression	Mosquito community data	Although rainfall, river height and mosquito abundance are significant factors in determining RR virus activity, there are regional differences in this relationship.
Jacups et al. 2008 [37]	1 JAN. 1991-30 JUN. 2006	Darwin	Monthly mean, minimum and maximum temperatures, monthly rainfall and monthly sea level	Generalised linear model	Mosquito trap averages	The best global model included rainfall, minimum temperature and tree mosquito species, which explained 63.5% deviance and predicted disease accurately.
Hu et al. 2007 [22]	2001	Brisbane	Monthly Southern Oscillation Index (SOI) data	Multiple negative binomial regression models	Overseas visitors, indigenous population, labor workers, educational level family income, and vegetation	The spatial pattern of RRV disease in Brisbane seemed to be determined by a combination of local ecologic, socioeconomic, and environmental factors.
Woodruff et al. 2006 [34]	JUL. 1991-JUN. 1999	Southwest Western Australia	Monthly minimum and maximum temperatures, monthly rainfall and rain days, and monthly mean tide height	Multivariate logistic regression models	Monthly mosquito trap numbers	Climate data on their own were moderately sensitive (64%) for predicting epidemics and addition of mosquito surveillance data increased the sensitivity to 90%.

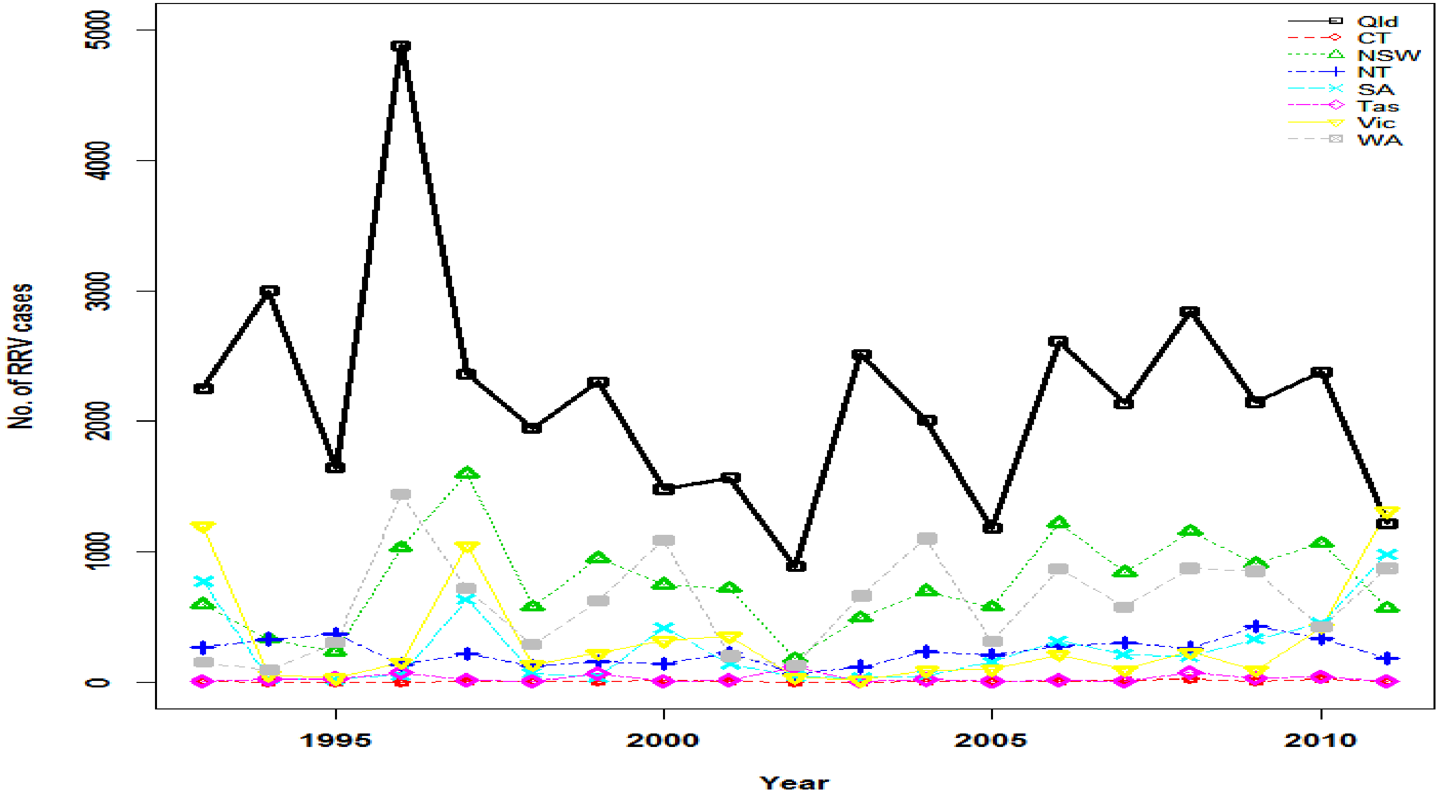
Table 1 The characteristics of the included studies (Continued).

Study	**Time period**	**Setting**	**Climatic factors**	**Model**	**Considered other factors**	**Findings**
Hu et al. 2006 [29]	1 NOV.1998-31 DEC. 2001	Brisbane	Monthly rainfall	Polynomial distributed lagtime-series regression and SARIMA	Population size, monthly mosquito density	85% and 95% of the variance in the RRV transmission was accounted for by rainfall and mosquito density, respectively. Only mosquito density at lags of 0 and 1 months was significantly associated with the transmission or RRV disease.
Tong et al. 2005 [32]	1998-2001	Brisbane	Monthly rainfall, SOI, high tides	Poisson time series regression models	Monthly mosquito number	The increases in the high tide, rainfall, mosquito density, the density of *Culex annulirostris* and *Ochlerotatus vigilax* , each at a lag of 1 month, were statistically significantly associated with the rise of monthly RRV incidence.
Gatton et al. 2005 [27]	1991–2001	Queensland	Daily average minimum and maximum temperatures, the number of days with temperatures >35°C, total rainfall, and number of days	Logistic regression	-	Heterogeneity predisposing outbreaks supports the notion that there are different RRV epidemics throughout Australia but also suggests that generic parameters for the prediction and control of outbreaks are of limited use at a local level.
Darren, et al. 2005 [26]	1984-2001	Queensland	Aggregated climate zones	Mixture model	_	A lower number of components preferred for data from the zone which appeared to show a more distinctive pattern.
Hu et al. 2004 [28]	1985-2001	Brisbane	Monthly mean, minimum and maximum temperatures, total precipitation, mean relative humidity and high tidal levels	SARIMA	_	Monthly precipitation was significantly associated with RRV transmission.
Tong et al. 2004 [5]	1985-1996	Townsville		SARIMA	_	Rainfall, high tide and maximum temperature were likely to be key determinants of RRV transmission in the Townsville region.

Table 1 The characteristics of the included studies (Continued).

Study	**Time period**	**Setting**	**Climatic factors**	**Model**	**Considered other factors**	**Findings**
Bi and Parton 2003 [25]	1985-1996	Townsville and Toowoomba	Monthly mean minimum temperature, high tides, rainfall, relative humidity, SOI, maximum temperature	Autoregressive integrated moving average (ARIMA) and Generalised Least Square (GLS) Regression analyses	_	Temperature, rainfall and high tides are possible contributors to the transmission of RRV 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 RRV in inland regions of Queensland.
Woodruff et al. 2002 [33]	1991-1999	Southeastern, Australia	Monthly rainfall totals ,Number of rain days , Average temp Average maximum temp Absolute maximum temp. Average minimum temp Absolute minimum temp averages of min temperature Average relative humidity Monthly SOI Southern	multivariable logistic regression model	Irrigation and mosquito control measures	Weather conditions at relatively coarse temporal and spatial resolutions can be used to predict RRV disease epidemics with sufficient accuracy and lag time for public health planning.
Tong and Hu 2002 [31]	1985–1996	Queensland	Monthly rainfall, maximum temperature, minimum temperature, and relative humidity	Time series Poisson regression models		The incidence of RRV disease was significantly associated with rainfall, maximum temperature, minimum temperature, relative humidity, and high tide in the coastline region, and with rainfall and relative humidity in the inland region.
Tong and Hu 2001 [13]	1985–1994	Cairns	Monthly minimum and maximum temperatures, rainfall, relative humidity and high tidal levels	ARIMA	Population	The relative humidity at a lag of 5 months and the rainfall at a lag of 2 months appeared to play significant roles in the transmission of RRV disease.
Direct projection						
Woodruff et al. 2008 [12]	2030 2060 2090	Australia	Rainfall	IPCC scenario analysis	_	Decreases in rainfall over most of southern and sub-tropical Australia. In southwest Western Australia rain has reduced dramatically and slight increases are projected in Tasmania, central NT and northern NSW.
Bambrick et al. 2011 [24]	2100	Australia	Rainfall	Map projected changes	_	Changes to transmission patterns will be regionally-specific.

Fig 1. Number of notifications of Ross River virus infection, received from State and Territory health authorities, 1993- 2012.



CT: Capital territory; NSW: New South Wales; NT: northern territory; QLD: Queensland; SA: South Australia; Tas: Vic: Victoria; WA: West Australia.

Source: Australian Department of Health and Ageing. National Notifiable Diseases Surveillance System: http://www9.health.gov.au/cda/source/Rpt_4.cfm

Fig 2. Procedure of literature search.

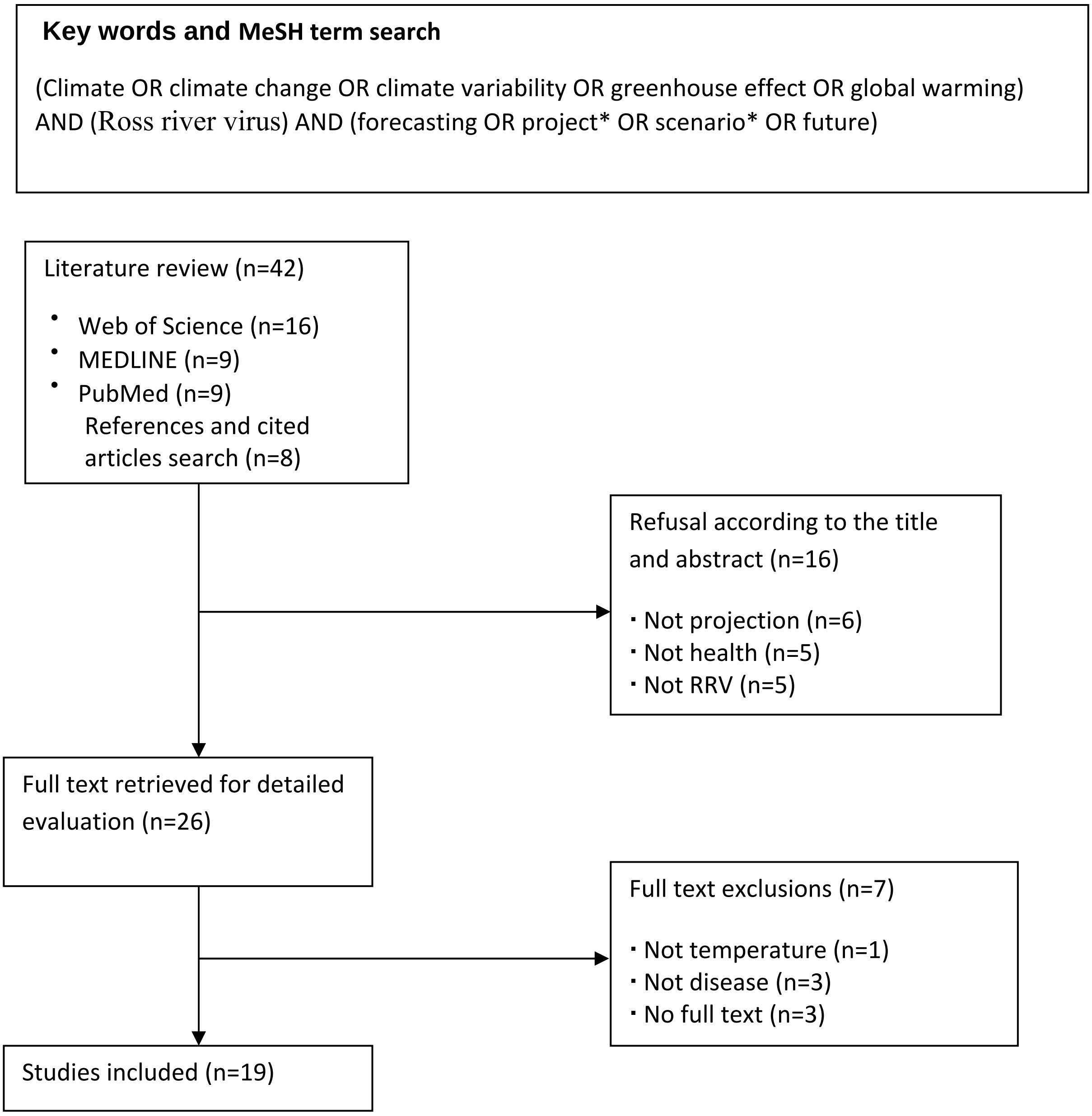


Fig 3. The climates of the included study areas.