Garnaut Climate Change Review

Climate change impacts on the burden of Ross River virus disease

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June 2008

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1 Key messages

Ross River virus disease is the most prevalent mosquito-borne disease in Australia, with an average of 4400 cases reported each year. A conservative estimate of the economic costs of the disease is $1000–1200 per person for medical expenses and loss of income. Additional publicly borne costs are incurred by state and local governments to cover vector control, education campaigns and research. In 2004 Queensland spent an estimated $10 million protecting the public from Ross River virus infection.

Climate sets the conditions that dominate the lifecycle of the many mosquitoes and hosts that support the virus. Temperature, rainfall, humidity and tides impact substantially on virus replication, mosquito breeding and survival, and immunity levels of host animals. Climate change this century will increase average and extreme temperatures, change rainfall (patterns and amount), and increase sea levels—all relevant to the proliferation of the virus.

The Ross River virus has a reasonably complex transmission cycle. The level of viral activity and subsequent human disease varies widely between tropical, temperate and semi-arid regions, as well as between inland and coastal areas. The impacts of changing climate on the burden of Ross River virus disease are difficult to predict at the broad-scale and need to be researched at the regional-level.

The following are probable trends:

- Low temperatures limit mosquito breeding in parts of the country. Increasing average temperatures may support Ross River virus activity in new places, or for more months of the year.
- There may be less annual virus activity in areas that become very hot and dry and in irrigated regions where water will be substantially restricted (i.e. the Murray Darling Basin).
- The pattern of outbreaks will change in some regions as droughts increase and are punctuated by heavier rainfalls and floods. Explosive outbreaks followed by periods of inactivity are more likely than at present.
- Epidemic regions that are currently on the border of endemic regions may move towards an endemic pattern of disease in future.
- Coastal wetlands will be inundated by tides more frequently as sea levels rise, a condition that is likely to favour saltwater mosquito breeding.
- Future human population growth means the absolute number of people at risk of being infected by Ross River virus will increase each year. The predicted increase in urban sprawl may also place more people in contact with the natural cycle of the virus.

The impacts of climate change on the pattern of Ross River virus disease are likely to be slow to observe at first, and then to become increasingly noticeable as temperature and rainfall differences are amplified, relative to the present. In the mid- to longer term, the environment will become more volatile and less predictable. This requires information sharing and vigilance to reduce the risk of large outbreaks of infectious diseases in future.

Uncertainty about the specific impacts of climate change on infectious disease transmission at the regional level, and the manner in which the social environment will mediate these impacts, means that policy responses at the three levels of government are required. At the federal level, the best support for regional adaptation will be a funding and policy environment that is sympathetic to promoting coordination between jurisdictions, and research.

Sustained and preparatory mosquito control programs are more effective at avoiding cases of disease than reactive, ad-hoc ones. Early warning of a high-risk season for Ross River virus disease is highly desirable. Ongoing research will be needed to better understand the basic mechanisms of transmission, region by region, and to keep pace with the effects of changing climate on disease patterns. Maintaining existing collections of local mosquitoes, and expanding these into regions that are vulnerable to future increases in Ross River virus activity, is a basic prevention technique.

There is a risk that wider approaches taken to adapt to climate change may unintentionally increase future risks of Ross River virus disease by promoting breeding habitats for mosquitoes. Coordination between the health, urban planning and environment departments is needed to explore how climate change adaptations (such as water storage and management, housing developments, protection of native wildlife) can be adjusted to minimise an increase in Ross River virus activity.

Many of the issues raised in this paper are analagous to those for other infectious pathogens affected by climate. Rates of mosquito-borne infections such as Murray Valley encephalitis and Barmah Forest as well as food-borne infections such as *Campylobacter*, *Salmonella*, and *E. coli* will also be affected by climate changes.

2 Introduction

The aim of this paper is to discuss the impact of climate change on the pattern of Ross River virus disease, the most prevalent vector-borne disease in Australia.

2.1 Ross River virus disease

Ross River virus causes a non-fatal polyarthritis, with arthritic symptoms that range from mild (people typically recover in about two weeks), to severe and debilitating (a very small proportion are affected for months or years). There is no cure, and treatment is confined to relieving pain. People of any age can be infected, although it is mostly people between 20 and 60 who report symptoms.

Infection with Ross River virus disease are reported in all states and territories. Notifications from 1992–2007 totalled 69,908 (an average of 4400 per year).[1] The national annual incidence rate has been up to 47 per 100 000 in 1996, and state and regional rates have been as high as 203 and 670 per 100 000 respectively.[2]

The natural cycle of Ross River virus is between a mosquito (the vector) and a non-human animal (the host). The virus occasionally 'spills over' into the human population when a high level is circulating in the environment. This contrasts with dengue fever, another mosquito-borne disease of concern in Australia. Dengue is transmitted by mosquitoes from one human to another without the need for an intermediary host. The natural hosts of Ross River virus are thought to be macropods (kangaroos and wallabies), although fruit bats, horses and humans can sometimes be involved in transmission.[3] Brushtail possums are the likely main host in tropical urban areas.[4] Ross River virus has been isolated from over 30 mosquito species in Australia, including freshwater and saltwater species that inhabit varied climatic regions—from tropical to temperate and arid, coastal and inland.

3 Issues and context

3.1 Climate and environment

Climatic conditions set the basic spatial and temporal limits for the transmission of many infectious diseases—via the survival and replication of pathogens, the season of activity of vectors, the geographic range of hosts, and the behaviours of susceptible human populations. Within these general climatic constraints, short-term fluctuations in weather affect the timing and intensity of outbreaks. Within each climate zone other ecological, social and economic factors also influence the occurrence and prevalence of infectious diseases.

The transmission of Ross River virus—compared to malaria or dengue—is relatively complex. The many different mosquito species and hosts involved result in widely varying transmission dynamics across Australia.[5] These considerably increase the challenge of modelling future changes in rates of this disease. Research has demonstrated that no one set of climate variables can adequately predict outbreaks of disease across an entire state,[6] let alone the whole country. Modelling of the climate-disease relationship at the local and regional level, however, has proven reasonably successful.[6–10]

Rainfall is crucial for the aquatic stages of the mosquito life cycle, and studies typically show that cases of disease rise with rainfall. In Queensland for example, annual rainfall increases towards the north, and Ross River virus rates also generally increase with distance north.[11] An investigation of Ross River virus outbreaks and climate from 1886 to 1998 found that very large outbreaks were most often associated with above average rainfall.[12] However, heavy rainfalls aren't always followed by outbreaks of disease. The timing of rainfall during a year (its seasonality) is critical for supporting mosquito breeding in temperate inland areas,[9] and substantial rainfall in one year may influence the number of cases in the next (through the role of kangaroo breeding and virus immunity levels).[10] Higher than normal sea levels that inundate the habitat of saltwater breeding mosquitoes can produce large numbers of mosquitoes and result in outbreaks of disease.

Warmer temperatures generally enhance the transmission of mosquito-borne infections. Viruses reproduce much more quickly as temperatures increase. High temperatures reduce the time it takes for mosquito larvae to grow to adulthood, meaning that there are more infectious generations within a time period. However, mosquitoes are susceptible to losing body water and dying if warmer temperature are not also accompanied by a rise in humidity.

In the tropics Ross River virus outbreaks occur with the highest spring tides and during the wet season.[5] In these areas the disease is considered to be endemic (cases occur in most months of each year). In temperate and semi-arid zones the disease has an epidemic pattern. Outbreaks are associated with summer and autumn rainfall in inland areas, or rain and tidal inundation of wetlands in coastal areas during the warm season when mosquitoes are most active. The number of cases in epidemic regions fluctuates widely between years—reflecting changes in weather and host immunity.

3.2 Social context

The pattern of Ross River virus disease in Australia is also influenced by the availability and effectiveness of public health response (i.e. mosquito control and prevention). For individuals, vulnerability to Ross River virus infection relates to where a person lives as well as their age, immunity level, behaviour (recreational activities, outside work) and level of protection (using repellent, wearing protective clothing, staying indoors at peak biting periods). At the community level the location of settlements near mosquito habitat (such as irrigated agriculture, wetlands, estuaries, water treatment works), wildlife and bushland will generally increase the risk of infection.

3.3 Economic costs

The true cost of a case of Ross River virus disease includes both individual costs as well as publicly borne costs such as control and education activities. An individual's medical costs, diagnostic costs and loss of work output have been estimated to vary from $1018 to $1180 per case,[3,13,14] assuming that each person consults a general practitioner twice and half of the people affected take one week off work. This does not include the costs of medication or reduced work output beyond one week. At aggregate, this equates to a cost of $4.3 to $4.9 million borne by individuals in Australia in 2007 (4179 cases).

The public costs incurred by state and local governments are less well documented. These include expenditure on mosquito control, education campaigns, and research. The available information about these costs comes from Queensland, where local governments spent more than $10 million implementing mosquito control in 2004.[11] The majority of this expenditure occurred in the more densely populated local government areas of the southern coastal strip. In southeast QLD during the period 1993–2004, for each actual notification of Ross River virus disease an estimated two notifications were avoided. This equates to 2200 notifications avoided each year through effective mosquito control.[11]

Comparing the cost of mosquito control with the costs saved from avoiding disease shows that, on average, nearly forty per cent of mosquito control expenses in southeast QLD are recouped.[11] In years where environmental conditions are right to support a large outbreak of Ross River virus disease, effective mosquito control can forestall an epidemic. The monetary value of avoided cases of disease in such situations exceeds the costs of mosquito control. In 1996 Brisbane City Council avoided an estimated 3945 Ross River virus cases through mosquito control. This equated to a saving of $4.2 million (with a cost-benefit ratio of 1:1.54). In contrast, in years when rainfall is low or below average and Ross River virus rates are low, the cost of maintaining mosquito control programs can exceed the cost of avoided cases of disease. As surveillance programs improve across the country (Queensland has already commenced a surveillance program for the early detection of suitable mosquito conditions) and regional-level research on Ross River virus transmission progresses, it is probable that the knowledge of what constitutes high and low risk years in each region will improve and the cost-benefit gap can close further.

The indirect economic impact of Ross River virus disease on tourism is difficult to gauge. At present there is no evidence to test the idea that people’s choice of a holiday destination in Australia is influenced by the risk of acquiring an infectious disease. Given the many factors involved in choosing where to holiday, the presence of Ross River virus in an area (a non-fatal disease) is unlikely to rank high in the list, especially as outbreaks rarely receive national media attention. However if a region (be that Australia, Queensland, or Brisbane) were to become associated with outbreaks of several infectious diseases, some potentially fatal such as dengue or Japanese encephalitis, this could possibly have an influence on tourism.

4 Impacts of climate change

4.1 Level of uncertainty

Although the ecology of Ross River virus has been substantially studied over the past 40 years, there are still significant gaps in our understanding of the influence of base-line climate on transmission at the regional level. Australia-wide models of the impact of climate change on dengue and malaria have been developed,[15,16] but the large differences in Ross River virus activity and rates of disease between regions means modelling has not been successful at the state or whole country level.

The seasonal activity of the three major mosquito vectors is relatively well known, and the potential for them to be influenced by temperature changes can be predicted in the simplest sense.[5] However, global warming also changes rainfall (patterns and amount) and sea levels as well as temperature. Predicting the impact of these on the distribution and abundance of mosquito species, and on Ross River virus cycles that involve vertebrate hosts also affected by climatic factors, is not simple. Given this uncertainty, what is it possible to say about the future impact of climate change on this disease?

4.2 Trends

General principles derived from observations by entomologists, and the accumulated knowledge of epidemiological studies, suggest the following are probable:

- The Ross River virus has multiple hosts and mosquito vectors, each with advantages and limitations regarding the likelihood of survival. This suggests the virus is well-placed to adapt to variations in both extreme and gradual climate change.

- Some areas could expect an increase in Ross River virus activity. The average rise in temperatures is likely to be generally favourable for mosquito development, level of infectivity and virus reproduction. The average level of evaporation is predicted to increase over all of Australia,[17] which suggests that humidity may not always increase with temperatures. This may limit virus activity during very hot summers.

- In places where low temperature, low rainfall or lack of mosquito habitat currently limit the transmission of virus, climate change may edge local conditions into becoming suitable, thereby supporting transmission in new places, for more months of the year, or at greater levels than previously experienced. For example, parts of the country where the annual pattern of Ross River virus disease is epidemic may change in future to being endemic. This would be most probable in temperate regions that border sub-tropical endemic regions.[18] It is also probable that cooler temperate regions (e.g. southern Tasmania, higher altitude NSW and Victoria) may experience longer months of Ross River virus activity a year.

- Predicting changes in future rainfall—including the total amount, annual timing, duration, etc—is difficult. In general though, climate change is expected to cause decreases in rainfall over most of southern and sub-tropical Australia. In southwest Western Australia rain has reduced dramatically since around the middle of the 1970s, and global climate models consistently project increased drying in this region. Slight increases are projected in Tasmania, central NT and northern NSW (see **Figures 1** and **2**).[17] Drier conditions are less conducive to mosquito breeding and Ross River virus activity may reduce during these periods. Rainfall is also projected to become more intense and variable. The number of extreme droughts per 100 years and the average duration of droughts are likely to increase by a factor of 2 and 6 respectively.[19] Long drought periods between intense rainfalls are suitable for building the number of susceptible kangaroo hosts. This suggests a stronger pattern of large outbreaks of Ross River virus disease interspersed by years of inactivity in certain temperate and semi-arid regions. Very heavy rainfalls may wash away mosquito larvae or dormant eggs and interrupt the transmission of virus from mosquitoes that breed in still water.

- Tide height is an important feature in the initiation of Ross River virus disease epidemics in coastal areas. The projections for increases in mean sea level due to climate change are relevant.

Estimates are for a rise of 18 to 59 cm by 2100.[20] This suggests that tidal inundations of wetlands will occur more frequently than at present, which would be generally positive for saltwater mosquito breeding in many coastal areas. *Aedes* populations in dry inland areas may be adversely affected by a projected change from winter rainfall to uniform rainfall. An increase in rainfall during summer may enhance the availability of mosquito habitat that, combined with higher average temperatures, could lead to a longer season of abundance and greater transmission.[21] This may affect, among other things, a change in the main season when outbreaks usually occur.

- There is a high level of Ross River virus activity in most of rural south-eastern Australia, with concentrations around the irrigation areas of southwest NSW (e.g. Griffith) and northern Victoria (e.g. Mildura). The recent long drought has provoked changes in water cost and reduced the availability of water for commercial irrigation. This may mean these regions cease to be a locus of Ross River virus activity in future, especially if conditions inland become drier.[5]

4.3 Human and environment interactions

Population growth and human settlement patterns. The Australian population is expected to grow from 20 million to between 23 and 31 million by 2050.[22] By the end of the century the upper estimate is 38 million, although the mid-range estimate is for population to stabilise at around 26 million. Whichever estimate is correct, there will be an increase in the absolute number of people at risk of infection from Ross River virus each year: up to 55% more people by 2050, and up to 90% more by 2100.

Contact with bushland. The shift from rural to city living has accelerated in Australia in recent decades, as elsewhere in the world. Currently 89% of the Australian population live in urban areas.[23] This is expected to rise to 94% by 2050. Even as population density in all the larger cities has increased, the greatest population growth continues to be in outer suburbs—in greenfield developments around city fringes.[24] This pattern of urban expansion into bushland and coastal areas suggests humans will continue to be caught in the midst of the natural cycling of Ross River virus between mosquitoes and marsupial hosts.

Water resources and management. Outbreaks of Ross River virus disease usually occur when there are increases in mosquito populations in places where there is more mosquito habitat than elsewhere, or at times when the habitat is more favourable than usual.[5] This is sometimes associated with local water-storage developments, wetlands of various types, and the movement of people into closer contact with these habitats and their mosquitoes. The extended drought over the past decade has left most capital cities and rural towns considering the need to increase water storage capacity. The inclusion of water storage tanks at new domestic dwellings is now promoted in most cities and has been mandated in some. Inadequate maintenance of water tanks (e.g. not replacing gauze filters as they rust) has already been identified as a specific risk for freshwater mosquito proliferation in SE Queensland.[25] This has implications for mosquito control, as spraying in that region has traditionally focused principally on saltwater mosquitoes. Other responses to climate change and decreasing biodiversity, such as the conservation and remediation of natural wetlands, could also change the pattern of Ross River virus activity in an area.[26] This need not necessarily mean an increase in virus activity, as it depends on changes in the amount of water, fish life and plant life. Development proposals for constructed wetlands for water management or treatment within communities should be required to address the possibility of these facilities supporting mosquito life, and the options for reducing this risk (such as introducing fish).

5 Adapting to the impacts of climate change

5.1 Current Ross River virus management

Most infectious diseases, and all mosquito-borne diseases in Australia (including Ross River virus disease), do not have a vaccine to prevent infection. The principal disease management activities are publicly funded and involve: (i) surveillance (of mosquitoes and human cases), (ii) mosquito control (using chemical, biological and physical methods, such as water management), (iii) development control (to discourage human settlements near mosquito sites) and (iv) community education (notifying the public of high risk periods and of personal protection measures).[27]

Ross River virus management is a joint responsibility of Health Departments and Local Government authorities in all states and territories, with different jurisdictions adopting different models to apportion costs and responsibility for surveillance, control and prevention activities.

5.2 Future adaptation

Advance warning of outbreaks

Early warning of the likelihood of 'high-risk' or 'low-risk' seasons of Ross River virus disease can focus mosquito control and public education to those years when the risk of a large number of cases is greatest. To develop an accurate advance warning mechanism, regions need: (i) to monitor and follow-up human cases, (ii) ongoing mosquito trapping in active areas, (iii) an understanding of the relationship between climate and outbreaks of disease in that locality, (iv) knowledge of the role of local mosquitoes and animals in the transmission of Ross River virus, and (v) weather observations.

Sustained and preparatory mosquito control is the most effective technique for reducing Ross River virus disease outbreaks.[11] In Queensland, the state with the highest number of Ross River virus cases each year, notifications of disease are consistently lower in local government areas that use routine surveillance and mosquito control to pre-empt a build up of mosquitoes. Reactive, ad-hoc mosquito control programs (such as those initiated in response to heavy rainfall or community complaints of mosquitoes) are not effective at reducing the number of Ross River virus cases.[11] Local governments that control both saltwater *and* freshwater mosquitoes have lower annual Ross River virus disease rates and more stable disease rates across years than those that focus only on controlling saltwater mosquitoes.[11]

Expanding monitoring of mosquitoes in regions that are currently epidemic—and particularly at the borders of these regions—may provide evidence of early changes in the breeding patterns of vector species and their hosts when they occur.

Improve urban control programs

Community progress with vector and virus surveillance and control will be a key factor in determining future Ross River virus activity in local areas.[21] The main hosts for the virus in urban environments are native species (marsupials and flying foxes) or livestock (horses).[28] Eradicating protected species to reduce the risk of Ross River virus transmission is not a sensible option, and the only practical solution is to reduce the number of mosquitoes involved in circulating the virus. Mosquitoes such as *Ae. notoscriptus* are a significant domestic pest that breed in containers in sub-tropical urban backyards. Government programs can reduce the number of available breeding sites for other species, but public motivation is needed to reduce the level of *Ae. notoscriptus* larvae in natural and artificial containers around houses (buckets, ponds, poor drainage leading to pooled water).[28]

Water management

Some involuntary adaptations to climate change, such as those changes now occurring in the irrigated agriculture industry in the Murray-Darling Basin of south-eastern Australia, may have unintended benefits by reducing mosquito breeding environments. Other adaptations to climate change could increase mosquito habitat and the risk of Ross River virus infection. Water storage for residential use (such as tanks) and some grey water treatment facilities could provide environments for mosquito breeding in some regions unless managed. Policy responses to drought periods should consider the risk of inadvertently increasing mosquito sites.

6 Strategy and policy implications

The issues raised in this paper in relation to Ross River virus are in many respects transferable to other infectious pathogens affected by climate.[29] In particular, Barmah Forest virus seems to inhabit a related ecology to Ross River, although we know less about the specifics of which mosquitoes and animal hosts are involved. Similar policy approaches could be adopted for other mosquito-borne infectious diseases (such as dengue, Murray Valley encephalitis) and food-borne infections (such as *Campylobacter*, *Salmonella*, *E. coli*).

The complexity of most infectious disease transmission processes, coupled with our uncertainty about how these will be affected by climate change and the manner in which the social environment will mediate transmission, means policy responses at and between the three levels of government are required.

This increasingly unpredictable risk environment requires information sharing and vigilance to reduce the risk of large outbreaks of infectious diseases in future. Local governments are responsible for specific planning actions (such as managing wetland developments and water storage) and for mosquito control. State governments are responsible for coordinating the surveillance of cases, mosquito monitoring and public education. At the federal level, the best support for regional adaptation will be a funding and policy environment that is sympathetic to promoting coordination between jurisdictions and research into advance warning mechanisms.

Some key priorities for future research and activity are:

1. The impact of climate change on the transmission of infectious diseases at local and regional scales is likely to be slow to observe at first, and then to become increasingly noticeable as temperature and rainfall differences are amplified, relative to current patterns. The predictive power of current observations will diminish over time. *Ongoing research of the relationship between climate and Ross River virus transmission at the regional level* is necessary to keep pace with changing patterns of disease.

2. *Focus surveillance and monitoring activities* to regions bordering the edges of current Ross River virus endemic regions to be alert for whether changes in climate influence changes in the incidence and timing of Ross River virus notifications.

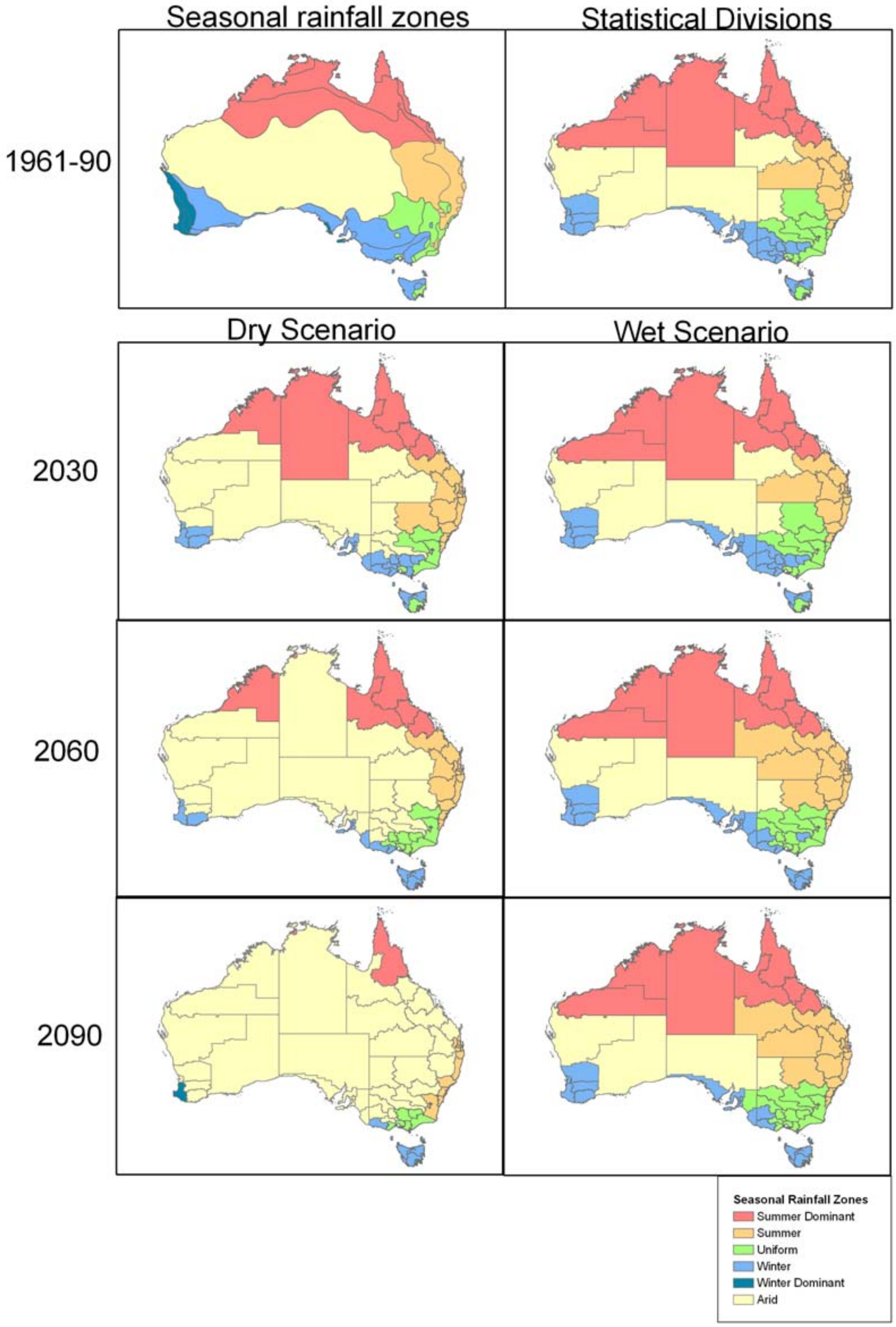
3. *Develop links between health, urban planning, and environment departments* to explore how climate change adaptations (such as water storage and management, housing development, protection of native wildlife) will affect Ross River virus disease risk.

4. *Improve understanding of regional-level Ross River virus activity*. (a) Maintain existing ongoing collections of mosquito data, and expand trap sites to include regions that are vulnerable to changing patterns of disease in future. (b) Identify the influence of climate on the breeding cycles, abundance and immunity level of host animals.

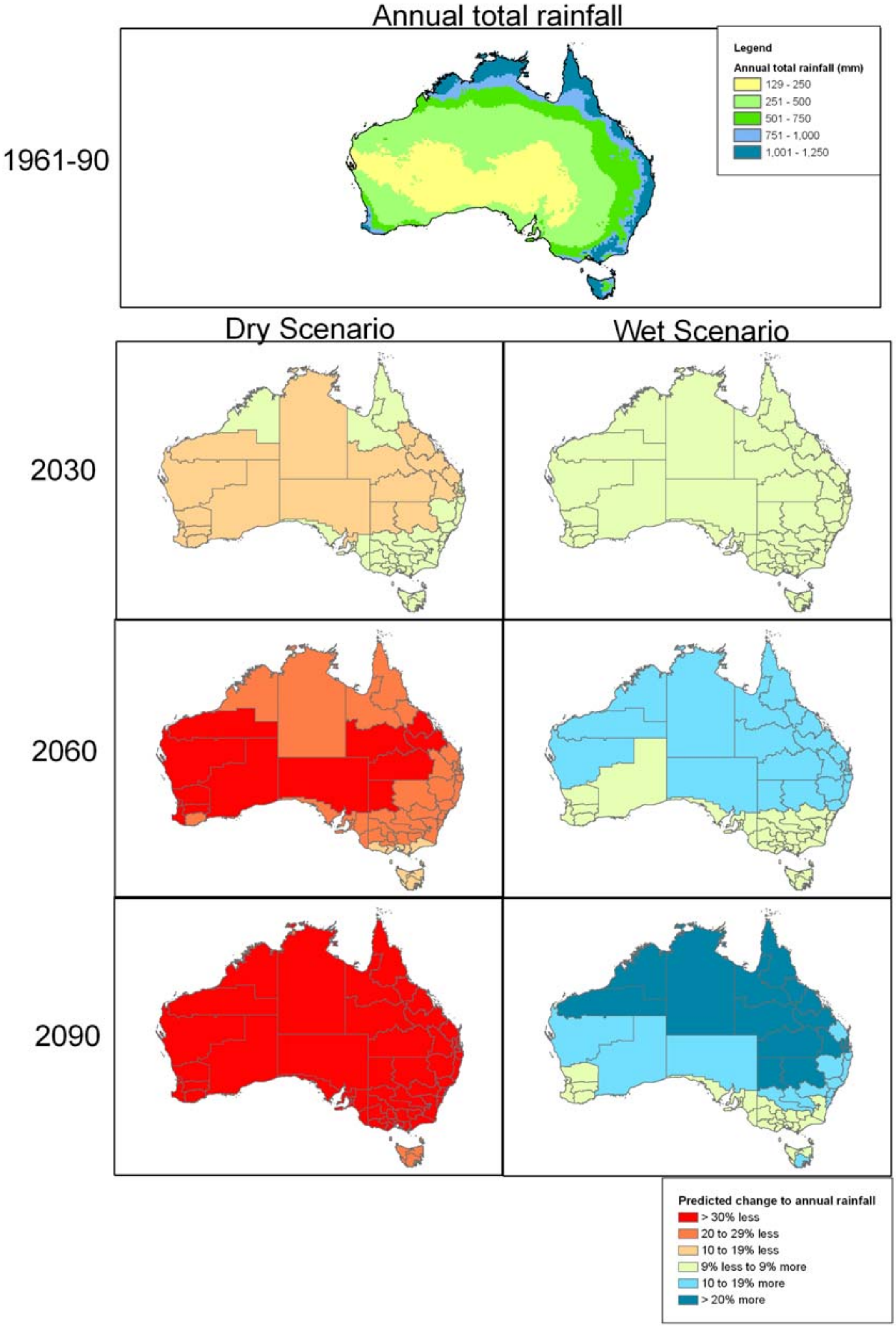
5. *Assess the cost-benefit ratio for Ross River virus surveillance and mosquito control* in states beyond Queensland. Explore the possibilities for improving this ratio through advance warning systems.

6. *Coordinate and standardise urban control methods* with a focus on freshwater and saltwater breeders.

The maps in **Figure 1** are modelled from the U1 (dry) and U3 (wet) scenarios. These show how the dominant season in which rain falls is projected to change throughout the century, compared to the period 1961–90. This has implications for mosquito breeding—dry summers will be less suitable for mosquito birth and survival than wet ones. A change in the dominant rainfall season in a region will also affect a range of other environmental factors that support or limit Ross River virus activity, such as human behaviours, plant growth to sustains kangaroo populations, etc.



The maps in **Figure 2** depict the probability of a change in total annual rainfall compared to the period 1961–90. The U1 (dry) scenario projects a 30% or more decrease in rainfall across almost the whole country (Tasmania is slightly less) by 2090. Under the U3 (wet) scenario, rainfall is expected to stay the same across the southern part of the continent, but would increase in total amount in tropical areas. The pattern of rainfall is expected to become more extreme (droughts and floods), regardless of whether increases or decreases in total amounts are predicted.


Annual total rainfall
1961-90
Legend
Annual total rainfall (mm)
129 - 250
251 - 500
501 - 750
751 - 1,000
1,001 - 1,250
Dry Scenario
Wet Scenario
2030
2060
2090
Predicted change to annual rainfall
> 30% less
20 to 29% less
10 to 19% less
9% less to 9% more
10 to 19% more
> 20% more

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