Assessing an indirect health implication of a changing climate: Ross River Virus in a temperate island state

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Abstract

In Tasmania, a temperate island state of Australia, there is little understood about the human health implications of a changing climate. Here, we investigate the hypothesis that human populations in Tasmania might become more vulnerable to Ross River virus (RRV) under climate change, Australia’s most significant vector-borne disease. Importantly, our study considers the complex social-ecological systems based setting that this virus represents, with our approach being underpinned by systems thinking. Specifically, we undertake an integrated and participatory assessment of potential human vulnerability to RRV in a changing climate, and taking account of other parallel, non-climate regional-scale change considerations. We show that projected moderate changes in Tasmania’s climate will have implications for the State’s human health, whereby Tasmania is likely to become more vulnerable to RRV as the 21st Century progresses, shifting this health issue from a relatively low public health risk to one that will become more concerning and costly. The study assists us to contemplate how we frame human health questions as we move into a climatically changing world and reminds us that health impacts will not always be linear or obvious. It demonstrates an approach for scoping indirect and potentially insidious implications of climate change, even in the face of uncertainty, imperfect systems understanding, and limited resources, to inform a range of decision makers.

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Introduction

In Tasmania, a temperate island state and the most southern and smallest state of Australia, the impacts of climate change on human health and wellbeing remain largely unstudied. Consequently there have been few developments in climate change adaptation research and praxis for the human health sector in Tasmania (Lyth et al., 2015). Climate change assessments suggest that Tasmania will experience relatively modest climatic changes through the 21st Century compared with other parts of Australia (Hughes and McMichael, 2011). In particular projected extreme heat indicators point to Hobart’s much lower projected increase in extreme heat days compared to other Australian capital cities in turn tending to imply...
low or moderate impacts of climate change on human health for Tasmania overall (Hughes and McMichael, 2011; Steffen and Hughes, 2012).

While physically-based climate indicators, such as the number of hot days per year, may help guide research and decision making on the possible intensity and/or frequency of climatic stressors, they tell us little about the broader spectrum of indirect human health responses associated with climate change through regional socio-ecological system change. Human health vulnerability to exposure from climatic stress is also influenced or exacerbated by established poor socio-health (Bell, 2011), socio-economic adaptive capacity, and/or sensitivity and tolerance of differing populations to changing regional environmental conditions. These mediating factors are particularly pertinent to issues of disease, such as vector-borne diseases, which are influenced by changes in ecological environments in which communities are located (McMichael et al., 2006).

Ross River virus (RRV) represents a relevant example of a significant health concern that is influenced by complex ecological, environmental, and socio-economic interactions. It is the most common vector-borne disease affecting Australia (Russell, 1998), accounting for some 63% of all reported mosquito-borne disease notifications in 2011 (DoHA, 2012; Yu et al., 2014). While a number of significant RRV outbreaks have been reported in Tasmania, and the factors enabling outbreaks of this disease are indeed prevalent, RRV occurrences in this State are historically lower than for northern Australian states.

In the climate change context, however, there is consensus within the scientific community that climate change will affect the incidence and extent of vector-borne diseases globally (IPCC, 2014), though there is relatively poor regional understanding of the complexity that tends to underpin future impacts of climate change on vector-borne diseases. In its most recent Fifth Assessment Report, Working Group II of the Intergovernmental Panel on Climate Change (IPCC) concludes, with medium confidence, that the effects of climate change combined with other factors, such as global travel, could expand the geographic range of vector-borne diseases such as Ross River virus in the Australasia region specifically (Reisinger et al., 2014). Hence, given these conclusions, it seems reasonable to hypothesise that Tasmania’s human population might become more exposed to RRV in the future – and specifically, more vulnerable to this disease under future climate change scenarios. Additionally, based on the exploration of key environmental drivers, Werner et al. (2012) suggest that RRV is likely to pose an increased public health threat in southeastern Tasmania. While important, this research does not account strongly for the social contributions to vulnerability.

Here, we investigate the hypothesis that human populations in Tasmania might become more vulnerable to RRV under climate change. Importantly, our study considers the complex social-ecological systems based setting, underpinned by systems thinking (Rittel and Webber, 1973; Ison, 2010). We apply established qualitative methods to analyse the direct exposure and indirect social-ecological factors that contribute to disease occurrences and human health vulnerability. We assess emerging and future vulnerability to RRV in the context of regional climate change projections by synthesising: (1) published knowledge of the important system factors affecting RRV incidence in human populations, reinforced by local stakeholder knowledge; (2) ecological and geographic knowledge of RRV vectors, reservoir hosts, and habitats in Tasmania; (3) indicators of social sensitivity and adaptive capacity in Tasmania; and (4) physical climate information from downscaled (to 10 km scale) climate change projections provided by Climate Futures for Tasmania (Grose et al., 2010). This integrated assessment aims to provide first-order guidance for risk management of RRV in a changing climate at the local to regional scale.

Ross River virus in the Tasmanian setting

Ross River virus is a notifiable disease in Australia under state and territory public health legislation with notifications via the National Notifiable Diseases Surveillance System (NNDSS). The disease is evident in vastly different geographic and climatic regions across the country and is transmitted by a broad range of mosquito vectors (Harley et al., 2001; Russell, 2002). Historically, Tasmania experiences relatively low numbers of RRV cases. Some 583 cases of RRV were confirmed between 1993 and 2012 (NNDSS, n.d.b.), but substantially increased rates of infection above the long-term Tasmanian annual average have been noted during certain ‘event years’. Werner et al. (2012) point to annual RRV cases ranging from 4 to 117 between 1994 and 2008.

The largest outbreaks present heightened stress and economic costs for local communities and local and state governments responsible for monitoring, environmental health hazard management, and health service delivery. While there are no published estimates of the economic costs specific to Tasmania, the total cost for Australia was estimated to be between AUS$4.3 and AUS$4.9 million in 2007 (Woodruff and Bambrik, 2008; Yu et al., 2014). Further there are indirect economic impacts on local tourism, industry, and communities that are more difficult to quantify (Westley-Wise et al., 1996; Yu et al., 2014).

While RRV infection occurs in all age groups, it is most frequently reported in middle-aged adults, male and female (NNDSS, n.d.a). Symptoms and their duration vary from person to person, but the virus can cause persistent and debilitating arthritic symptoms or symptoms resembling chronic fatigue syndrome. In most cases symptoms disappear within a few months, although they can continue beyond a year (Mackenzie and Smith, 1996; Mylonas et al., 2002). There is no treatment for the virus and prevention remains the sole public health strategy in the absence of a vaccine (McMichael, 2003). Consequently, surveillance monitoring and adaptation strategies for protection of people from mosquito bites continue to be important hazard mitigation responses.
The ecology of RRV involves the interaction of the vector, reservoir host\(^1\), virus and a number of environmental factors (Harley et al., 2001; Russell, 2002). The abundance and activity of both the vector and the reservoir host is dependent on climatic factors such as temperature and rainfall and other environmental conditions. Spill over to humans completes the ecological chain of interaction, which may lead to an epidemic (Russell, 2002; Carver et al., 2010). Following the Tasmanian 2002 outbreak (117 reported cases), clear seasonal patterns in the monthly RRV case data were identified for areas in Tasmania’s southeast, with peak incidences occurring in autumn tending to follow a wetter than average spring and summer (Robertson et al., 2004; Werner et al., 2012). Of the 32 mosquito species in Tasmania, some seven species have been identified as vectors of RRV (Russell, 1993). The saltmarsh mosquito, Aedes camptorhynchus found in coastal areas in southern Australia, is by far the most important RRV vector in Tasmania and has been the focus of studies into RRV in Tasmania to date (e.g. McManus et al., 1992; Robertson et al., 2004; Carver et al., 2011). Saltmarshes, and areas where there are brackish waters, are important breeding habitats for this species. There are a large number and diversity of saltmarsh habitats in Tasmania (Prahallad and Jones, 2013). Many are located near growing human settlements or popular tourist and recreation areas.

When considering the implications of climate change on regional scenarios of RRV, it is important to also consider future changes to the vector and its habitat, reservoir host animals, and human population behaviour, as all of these factors contribute to human vulnerability to the disease. Regional environmental change due to human settlement expansion, land use change, and/or changes in saltmarsh environmental health, is also a complicating factor that is expected to play an important role in future RRV human health risk.

The main island of Tasmania is separated from continental Australia by Bass Strait – a distance of ~250 km. It lies between 40°S and 44°S and has a wide range of landscapes, including a combined coastline of more than 3000 km, and a cool temperate climate subject to regional and inter-annual variation (Lyth et al., 2015). Tasmania has a human population of approximately 513,000 (ABS, 2014). In the north the demographic is focused across a number of small and larger towns of which Launceston is the largest – located at the foot of the Tamar estuary along which there are a number of saltmarsh habitats, peri-urban and rural settlements (approximate population of Launceston greater urban area is 107,000 (ABS, 2012)). The northeast coast comprises popular towns and settlements, attractive to tourists and lifestyle residents. The population in southeast Tasmania is predominantly concentrated in the greater urban region of Hobart, Tasmania’s capital city (approximate population of greater Hobart is 217,000 (ABS, 2013)) with peri-urban areas to the east, north and south of Hobart representing some of the fastest growing areas in the state (ABS, 2014). The region has many estuaries, coastal waterways and rural landscapes around which saltmarshes, human settlements and attractive tourist destinations are located.

Methodology

Vulnerability is broadly defined as the ‘propensity or predisposition to be adversely affected’ by something such as climate change or other environmental changes (IPCC, 2014: 21). In the climate change context, understanding vulnerability is an important step in minimizing the regional impacts of climate change on linked social-ecological systems (Adger, 2006). It provides the basis for judging the context and level of risk, in order to assist the development of appropriate responses. Despite the growing number of approaches to assessing vulnerability and risk (Jones and Preston, 2011; IPCC, 2014), and steady progress in our understanding of different dimensions of vulnerability and the characterization of risk (Patwardhan et al., 2009), there remain limited examples where the specific components of vulnerability have been considered within linked biophysical and social system frameworks (Marshall et al., 2013). In the scope of indirect regional implications of climate change on human health these lack of examples are particularly apparent (Barnett et al., 2015). Patwardhan et al. (2009) point to opportunities in risk assessment research that explores multiple and interacting stresses or change drivers for localities, sectors and populations, where climate change is not the only driver of change. This type of work is particularly important in understanding the indirect implications of climate change where other parallel and interacting drivers of global and local change are also important considerations. In this context climate factors are important in vulnerability studies, but other drivers such as demographic, socio-economic, and governance processes are also given attention (Patwardhan et al., 2009). We extend this to include interrelated socio-ecological system change perspectives (such as socio-economic, land use, and ecological change interactions) essential for our RRV inquiry.

Jones and Preston (2011) explain that risk assessment and management should be an iterative and learning endeavour and that the entry risk assessment point can be quite simple (such as scoping work), becoming more complex as required over time. This should also involve stakeholders who play a part in sharing local and specialist knowledge about the problem framing, the system components, and risk management possibilities. Hence, an approach that focuses on scoping vulnerability in an integrated way, sensitivity analysis of the socio-ecological system components supported by regional scale climate scenarios, and stakeholder participation in the research process, is deemed appropriate to our study.

The assessment framework and input methods

We applied a well established, albeit slightly modified, participatory vulnerability assessment framework taking account of the co-dependence of the social and ecological systems. The framework is adapted from the IPCC definition of

\(^1\) A host (in this case an animal) that serves as a source of infection of humans, sustaining a parasite when it is not infecting humans (definition abridged from The Free Medical Dictionary http://medical-dictionary.thefreedictionary.com/reservoir+host accessed 17 Feb 2015).
vulnerability as a function of exposure, sensitivity and adaptive capacity (IPCC, 2007). The framework is modified into a co-dependency version, following the approach of Marshall et al. (2013) for a fisheries sector vulnerability assessment. Their co-dependency framework recognises the need, in some contexts, to assess vulnerability according to different, but interlinked, ecological and socio-economic systems. Importantly the assessment process includes stakeholder participation.

Smit and Wandell (2006) describe participatory vulnerability assessment approaches citing a number of pioneering projects (e.g. Ford and Smit, 2004; Lim et al., 2004). Researchers begin with an assessment of current exposures, sensitivities and adaptive capacity drawing from a range of tools and information. They incorporate insights from decision-makers, practitioners, natural resource managers, scientists, as well as published and unpublished literature, and other available sources of information (Smit and Wandell, 2006). The aim is to identify the conditions or risks including current and past exposures and sensitivities, how the social system deals with these, and how these elements might be affected with changing regional climatic conditions and other regional change drivers.

Fig. 1 schematically outlines the co-dependency assessment framework and summarises the mixed methods employed to establish the status of each component within the framework. The input methods employed include: a comprehensive review of the body of literature on RRV in Australasia to identify the important ecological, environmental, and social factors relevant to the Tasmanian situation; collection of critical indicators of ecological, environmental and social factors, such as the location and extent of saltmarshes, local social sensitivity and adaptive capacity indicators, and the location of human settlements; identification of relevant scenarios of future societal development for Tasmania based on projections of demographic change and plans for human settlement and land use change; the application of regional climate projections through to 2100 based on Climate Futures for Tasmania modelling (Grose et al., 2010); and the involvement of 22 Tasmanian stakeholders to verify the RRV background research and vulnerability assessment conclusions, and to qualitatively explore baseline adaptive capacity of Tasmanian professional communities of practice involved in managing RRV incidence and risk (stakeholders included health service professionals, natural resource managers, environmental health officers, land use planners, and local RRV and ecology scientists). Based on these inputs we undertook a qualitative assessment (again with the involvement of stakeholders) of the relationships, robustness and confidence of conclusions in the literature, employing approaches that draw upon calibrated language similar to the IPCC (Mastrandrea et al., 2010) and other Australian assessments (e.g. Poloczanska et al., 2012).

Regional climatic changes can contribute to alterations in regional ecological systems that, in turn, can present issues for human populations. This social-ecological change context is also mediated by human activities and socio-economic circumstances. Our assessment involves the consideration of exposure and sensitivity of the ecological system (the vector, vector habitats, terrestrial host reservoirs) to present and changing climatic conditions. A further linked assessment of the social vulnerability to RRV is then made that considers the social exposure and sensitivity to the ecological condition at present and under changing climatic conditions, and scopes social adaptive capacity (of local communities, professional communities of practice, agency resources and responses). External linked systems largely refer to the likely increased prevalence of vector-borne diseases such as RRV in other communities outside Tasmania, such as through human migration and the movement of transient populations impacting on virus exposure and extension, or the introduction of other mosquito vectors.

**Application of climate change projections**

In order to determine the exposure and sensitivity of the ecological and social systems to changing climatic conditions in Tasmania, the study used climate change projections and impact statements primarily from the Climate Futures for Tasmania (CFT) program (Grose et al., 2010). Vulnerability assessment at regional and local scales is most relevant to society, and the environmental factors that influence vector-borne disease in human populations are well aligned with the relatively high resolution (~10 km in space) dynamically downscaled CFT simulations of Tasmania’s climate under future climate change projections. These simulations represent the best currently available estimates of climate change for the state of Tasmania that are most useful for climate change impact, risk and vulnerability studies – including for bushfire (Fox-Hughes et al., 2014), water and catchments (Bennett et al., 2012), and extreme events (White et al., 2013).

The CFT modeling adopted two scenarios of anthropogenic emissions of greenhouse gases and aerosols through the 21st century from the Special Report of Emissions Scenarios (SRES) of the IPCC (IPCC, 2000; Grose et al., 2010) – high end (A2) and low end (B1) emissions pathways. These SRES scenarios have been used to force global climate model simulations of future climates, after which they have been dynamically downscaled to the Tasmanian region model (for a review of downscaling methods and limitations, see Wilby and Wigley, 1997). A physically-based high-resolution numerical regional climate model that includes the complex Tasmanian topography is used to dynamically downscale the global climate model projections, in order to better quantify spatial and temporal variations in the physical impacts of climate change (Corney et al., 2014). This provides a range of relatively high-resolution climate futures for the region (Grose et al., 2010). International Energy Agency (IEA) emission trend data shows that anthropogenic greenhouse gas and aerosol emissions over the previous decade, have been tracking a little above the A2 emissions scenario (IEA, 2013), suggesting the CFT modeling results might be conservative at least in their projected impacts (Grose et al., 2010). This context was considered in our assessment.

The climate change projections from CFT important to this study are summarised in Table 1. These climate change exposure factors include projected changes to temperature and rainfall, in particular, and also humidity and wind projected to occur in the Tasmanian coastal zone, since this is where both the vector habitats and human settlements are predominantly located. The sea level projections applied to our study are those adopted from the technical literature prepared for the
Tasmanian Government in development of sea level rise planning allowances for 2050–2100, for application in land-use planning instruments (TCCO, 2012), and have been derived using an approach developed by Hunter et al. (2013).

Qualitative confidence assessments

Based on detailed knowledge from the literature, and taking account of the amount and quality of evidence, and amount of agreement between studies, we used collective expert and stakeholder judgments to provide a qualitative confidence assessment of the relationships between social and environmental factors and their conduciveness to RRV incidences. This follows an IPCC-style of assessment using calibrated language (Mastrandrea et al., 2010) and other Australian assessment approaches (e.g. Poloczanska et al., 2012). This approach is further applied to assess the likely changes in RRV incidence in the State of Tasmania under projected future climate change. Confidence in the relationships identified between biophysical factors and RRV incidences is assessed based on a three-point scale taking account of the amount of evidence and amount of agreement between studies that present the evidence. The selected ‘low’, ‘medium’ or ‘high’ confidence levels are based on the authors’ assessment of this information, grounded by their climate and health expertise, and verified by stakeholder knowledge via the stakeholder workshop. The confidence assessment of future changes is based on the Climate Futures for Tasmania downscaled projections of changes in the relevant environmental factors to RRV, contextualised against the literature on, and our knowledge of, projected climate change and other expected significant regional changes.

Study limitations

This study is concerned with synthesizing the science and qualitatively assessing the current knowledge base to develop decision support tools for assessment and planning rather than quantifying predictions or probabilities of future RRV incidence. It does this via the use and modification of a relatively simple assessment framework that attempts to embrace the complex-system setting. As Jones and Preston (2011) point out tensions about the application of risk management are often between simplicity and complexity, and predictability and uncertainty. On the one hand there is a need for cost effective and relatively simple methods for vulnerability assessment in order to be able to move forward timely and cost effective.

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Fig. 1. Co-dependency framework (left) for assessing vulnerability to RRV and the mixed methods inputs (right). Co-dependency framework on left is adapted from Marshall et al. (2013).

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The sea level rise planning allowance for Tasmania is 0.8 m for 2100, relative to 2010. The allowance is based on: the statistical distribution of the IPCC Fourth Assessment Report which adjusts the Third Assessment Report projections for the 21st century for the A1FI (SRES A1 ‘fossil intensive’) emissions scenario; and the variability of present local tides and storm surges (TCCO, 2012:13).
adaptation planning and response, but on the other there are calls for more comprehensive assessments that include quantified predictions, probabilities, and uncertainties. The latter approaches are often costly exercises. They are certainly important for understanding system components, but do not guarantee the accurate quantification of complex problems, nor necessarily provide any greater insight into the system responses than a conceptual framing involving more qualitative approaches. Approaches that scope vulnerability and risks but involve stakeholders in the process enable project participants to appreciate the complexity involved in assessing uncertain and contested futures and allow recognition of the need for more applied approaches (Jones and Preston, 2011). This was necessary in order to be able to prepare for, and mitigate, hazards and risks. Our approach scopes a health implication of climate change in Tasmania where there is already very little guidance for decision makers. Through the process itself the extent of uncertainty and the relative significance of this for decision makers, and gaps in crucial knowledge can be identified.

In terms of uncertainty, there is always uncertainty with futures planning tasks (Christensen, 1985), but planning is necessary in order to be able to prepare for, and mitigate, hazards and risks. Our approach scopes a health implication of climate change in Tasmania where there is already very little guidance for decision makers. Through the process itself the extent of uncertainty and the relative significance of this for decision makers, and gaps in crucial knowledge can be identified.

Our assessment of RRV potential in Tasmania’s human population in the future is based on a combined confidence assessment of the previously outlined relevant environmental and social factors influencing vulnerability together with the Climate Futures for Tasmania projected changes. The Climate Futures for Tasmania team have rigorously tested their methods and results. Corney et al. (2014) demonstrate that the fine-scale model output has been successfully used in a number of studies with only minimal bias adjustment.

Limitations in this study are associated with the current knowledge of social-ecological factors contributing to RRV in the context of Tasmania and assumptions about future development scenarios, such as human settlement development. We considered some key social adaptive capacity factors contributing to regional vulnerability in this study, and applied a relatively simple indicator metric for relative scaling of adaptive capacity across local government areas. Any future local assessments, however, would benefit from a more detailed exploration of social adaptive capacity.

Assessment of relevant biophysical and social vulnerability factors

The following summarises the synthesis of literature on how: climate factors, particularly temperature and rainfall, influence the ecological conditions conducive to RRV prevalence; and any changes in the ecological condition, teamed with other parallel regional environmental changes, might impact on the social (human) vulnerability in terms of the sensitivity and adaptive capacity of the Tasmanian population into the future. From this, relevant information is gleaned about the state of current knowledge and our confidence in it, the key climate exposure factors most relevant to RRV, and how sensitive and adaptable the socio-ecological system components important for RRV might be to a change in the key climate exposure factors.

Biophysical assessment factors

The comprehensive literature review of the biophysical factors important to RRV incidence in Australia broadly, and Tasmania specifically, revealed three biophysical factors most significant in contributing to RRV incidences in Tasmania over
time: (1) the impact of climate change on the adaptability, health and extent of saltmarshes; (2) the impact on vector breeding, seasonality, extension and survivorship; and (3) the impact on reservoir hosts (macropod) population health and immunity. These three factors form the focus of the ecological vulnerability assessment where ecological sensitivity and adaptive capacity is assessed for both present and future climatic conditions.

**Climate exposure factors**

The literature synthesis revealed that temperature and rainfall are probably the two most important climate factors influencing RRV. Temperature exposure plays a direct role in the potential impact on abundance, activity and distribution of RRV vector and reservoir hosts, as well as having an indirect effect on the habitat of the vector and reservoir host (Hearnden, 1999). Year-to-year temperature and rainfall variability across Australia tends to be driven by various large-scale modes of climate variability (e.g. Risbey et al., 2009). El Niño – Southern Oscillation (ENSO), a natural mode of large-scale climate variability due to the coupling of the atmosphere and tropical Pacific Ocean, is the most significant driver of Australia’s climate variability on this time scale, with ENSO events playing a significant role in RRV incidences across the country (Done, 1998; Hu et al., 2007; Bi et al., 2009). Interestingly, RRV incidences in Queensland are also consistent with quasi-biennial east–west wind variations along the equator, connecting the middle-upper atmosphere (stratosphere) with the surface, associated with the Quasi-Biennial Oscillation (Done et al., 2002).

No previous studies in Tasmania make any note of the role of wind in extending mosquito range. Further, the CFT model results point to lower wind speeds in warmer months (Grose et al., 2010). Consequently, wind was not considered as a significant factor here in this particular study.

In temperate Australia, RRV outbreaks are highly seasonal, coinciding with the warmest months of the year, typically October to March (Kelly-Hope et al., 2004a). Much of the variation in vector activity focuses around fluctuations in minimum and maximum temperatures, with minimum temperatures apparently most important for *Ae. camptorhynchus* (Dhileepan et al., 1997; Barton et al., 2004). Temperature fluctuations are believed to affect RRV in a number of ways. Warmer temperatures affect vectors and their pathogens by altering their metabolic processes (Barton et al., 2004), increasing the rate of vector population growth by decreasing the incubation period, and increasing the breeding rate allowing for more generations to fit into a finite period (Hearnden, 1999; Harley et al., 2001). Increased temperatures also promote host-seeking behaviour in adult mosquitoes (Hill et al., 2009), reduce the incubation period for viral infections, and increase host contact by shifting geographic range and distribution (Patz et al., 2008; Bi et al., 2009; Hu et al., 2010). This allows vector populations to reach higher levels faster and be maintained, which increases opportunities for viral transmission. Higher minimum temperatures may also assist larval survival through winter (Bi et al., 2009), which might be particularly significant in Tasmania.

Mean maximum temperatures in southeast Tasmania have been highly influential in outbreaks to date. Werner et al. (2012) found this factor to be conducive to (i.e. positive relationship with) RRV across a number of time lags, claiming a 23% increase in notifications with a rise of 1°C over the long-term average. These results are consistent with other Australian studies (e.g. Tong et al., 2002; Hu et al., 2010). Very hot temperatures coinciding with dry conditions in southern Tasmania, however, are thought to impede mosquito abundance (Carver et al., 2011). Ultimately, the role that maximum temperatures play in vector abundance is dependent on interactions with other climatic variables, such as rainfall and humidity (Woodruff et al., 2006).

Climate and temperature also directly affect the reservoir hosts. In years where higher rainfall is accompanied by increased temperatures, the vegetation upon which reservoir hosts feed tends to flourish, increasing the population of young and non-immune hosts and expanding the reservoir for RRV both spatially and temporally (Hearnden, 1999). Climate also increases the human-vector interface, as warmer temperatures in a temperate climate encourage greater levels of human activity outdoors.

Rainfall, and its ability to create water bodies, is a significant predictor of RRV notifications across Australia (Kelly-Hope et al., 2004a; Bi et al., 2009; Carver et al., 2011; Werner et al., 2012). This relationship is strongest in Australian temperate climates (Kelly-Hope et al., 2004b). Non-linear relationships are thought to exist between rainfall and vector abundance, with small amounts of rainfall instigating breeding, but too much potentially inhibiting it (Dhileepan et al., 1997), although heavy rain events and associated flooding may help to establish ephemeral habitats which are known to support the larval and pupal stages of vector development (Bi et al., 2009; Carver et al., 2009a).

Significant correlations are found amongst studies that examine the relationships between total amount of monthly rainfall and abundance of *Ae. camptorhynchus* for up to a three month time lag (Barton et al., 2004; Tong et al., 2005; Hu et al., 2006; Bi et al., 2009) – including in southeast Tasmania (Werner et al., 2012). This timeframe allows drainage to occur from surrounding catchments and inundation of breeding habitat, the hatching of eggs, and facilitation of adult emergence (Barton et al., 2004). Outbreaks of RRV in Tasmania have been linked to un-seasonally wet conditions in summer and autumn in the past (McManus et al., 1992), and an analysis by Werner et al. (2012) links an increase in rainfall of 1 mm in southeast Tasmania to an increased risk of RRV being contracted.

**Adaptability, health and extent of saltmarshes**

Incidences of RRV are spatially associated with certain vegetation types, and mostly associated with mosquito breeding. In Tasmania, saltmarshes are particularly favoured habitats and breeding environments for *Ae. camptorhynchus* (Carver et al., 2011). Besides saltmarshes, Tasmania also supports considerable areas of tidally influenced freshwater wetlands – notably in the Derwent, Huon (south) and Tamar (north) estuaries, which are also environments of significant human settlements.

Temperature and rainfall are clearly two important factors influencing RRV via influencing vector breeding and survival and reservoir host abundance. We conclude that based on Climate Futures for Tasmania projections (projected increase in mean temperature of at least 1.6–2.9 °C and a steadily emerging pattern of increasing rainfall over coastal regions as outlined in Table 1), even a small increase in minimum and maximum mean temperatures and emerging wetter coastal regions in the northeast and southeast of the State will likely enhance the ecological conditions for RRV vectors and hosts at least through to the mid 21st century.

Social assessment factors

For RRV outbreak potential, a human population must be in close proximity to vector and reservoir populations. One of the key factors in the emergence of infectious disease is human expansion and encroachment into natural habitats, such as urbanisation, and agricultural development (Derraik and Slaney, 2007; Patz et al., 2008). The following social factors were identified from the literature as being important contributors to Tasmanian human population vulnerability to RRV: (1) the level of human exposure and proximity of the human population to mosquito habitats; (2) the level of relative non-immunity in the human population; and (3) specific social indicators including measures of socio-economic disadvantage and adaptive capacity.

Exposure and proximity of the human population to mosquito habitats

People are susceptible to RRV infection if they have not previously been exposed to the virus (Hearnden, 1999). In coastal regions across Australia, expanding residential development is increasing the contact between people and mosquito vectors. Many migrants relocating to these areas do not have immunity to RRV, increasing the risk of infection (Russell, 2002; Patz...
et al., 2004). In addition to permanent migration, coastal areas are also popular destinations for tourists and seasonal residents, providing a regular supply of non-immune individuals to exposure (Lyth et al., 2005; Carver et al., 2009b). Transient populations may also assist in the wider spread of the disease (Hearnden, 1999; Carver et al., 2009b).

The majority of outbreaks in Australia to date have been reported in residential areas in close proximity to vector and reservoir breeding sites, such as towns on the coast or adjacent to rivers or wetlands also frequented by non-immune tourists or seasonal work (Kelly-Hope et al., 2004a). This is true in Tasmania too, with a large proportion of human infections of RRV in the 2002 outbreak in people who had either visited, or were permanent residents of, coastal communities in southeast Tasmania (Russell and Kay, 2004). There appears to be no consensus on the distance that the Ae. camptorhynchus vector is capable of travelling. The vast majority of mosquito dispersal is said to likely take place within a relatively small area (~1 km), although there is some evidence of the species travelling significant distances beyond 5 km (Lee et al., 1984; Hearnden, 1999; Barton et al., 2004).

In Tasmania there are sizeable suburban, rural, and coastal communities living amongst and very near to (within 1–5 km of) significant saltmarsh and brackish water environments (based on reference to Tasmanian human settlement planning documents and environmental land use and resource databases e.g. STCA, 2011; DPIPWE, 2005). Fig. 2 outlines the major urban footprints and smaller urban settlements of particular interest relative to estuary and saltmarsh areas for the north and south of the state. Based on population trends and urban and economic development growth projections and plans, it is expected that permanent and transient populations will continue to expand in Tasmanian coastal environments, particularly along the southeast and east coast (STCA, 2011; ABS, 2014). In addition to human settlement expansion, tourism and agricultural activities are important and growing sectors of the regional economy (West et al., 2012). Tourism brings transient immunologically naïve populations, while rural activities proximate and interspersed with human settlements and saltmarsh environments, may assist human and vector interface with reservoir hosts.

**Immunity and sensitivity in the human population**

Apart from new arrivals or transient populations visiting areas in the vicinity of vector habitats, there is little known about the relative immunity levels in the resident Tasmanian population. It is plausible that the Tasmanian population is relatively immunologically naïve due largely to its lower historical exposure to RRV to date. Determining relative immunity in the medium and longer term is an important topic for further research inquiry that would assist in understanding the existing and future relative sensitivity of the Tasmanian population. Certainly, it can be assumed that the projected increase in warm spells for Tasmania, from spring through summer and autumn this century, will bring more people outdoors presenting opportunities for exposure. Increased outdoor recreation in summer months is linked to increased incidence of RRV when more people are exposed to RRV vectors (Bi et al., 2009).

**Social adaptive capacity**

There is some, albeit slim, evidence to suggest socio-economic factors play a direct role in the probability of infections (Weinstein and Cameron, 1991; Hu et al., 2007). Previous studies show a connection between RRV incidences and people with lower levels of education, which may be related to lower levels of awareness about the disease and measures for prevention (Weinstein and Cameron, 1991), or related to poor quality housing connected to lower incomes (Hu et al., 2007), although, these results have not been replicated (Hu et al., 2010). It is suggested, however, that occupation (or the type of activities people undertake) may be relevant. For example, Hu et al. (2010) found that the incidence of RRV was lower amongst individuals employed as labourers, which may be due to higher levels of immunity present in people who frequently worked outdoors.

While the Australian literature does not point to a direct link between socio-economic factors and heightened RRV risk, there is wide acknowledgment that population health inequities globally and within nations are strongly linked to social determinants (e.g. Blas et al., 2008; CSDH, 2008). Similarly it is recognised that risk associated with a changing climate is not shared equally between, or within, communities and those with pre-existing disadvantage (such as unemployment, low incomes, pre-existing poor health and disability) tend to a disproportionate vulnerability (Adger, 2006; Heltberg et al., 2009; Clemens et al., 2013). In the study of other vector borne diseases, such as Dengue and Malaria, there is acknowledgment that socio-economic factors are indeed important contributors to health risk and management (e.g. Manh et al., 2011; Arauz et al., 2015), although much of the evidence base is for countries where social disadvantage is more stark than in Australia. Nevertheless, compared to other states within Australia, Tasmania is known for its relatively poor and worsening social health indicators (DHHS, 2013: 17; RPDC, 2003), justifying the need to scope potential social vulnerability factors further for this case study.

A community’s capacity to understand, respond to, and prepare for RRV as a hazard, whether now or into the future, will depend on a range of factors. These factors may include a community’s socio-economic and social health characteristics, the availability and capacity of health services, and adaptation or hazard mitigation response options. Adaptation responses may involve: programs that monitor, predict and warn of RRV outbreak; educating health service providers, the community and tourists about local risks and community risk management options; and land use planning, building, and natural resource management guidelines. We scoped both the strength of social indicators that might heighten vulnerability in some areas of Tasmania and the adaptive capacity of key professional communities of practice to be able to prepare for, and respond to, increased RRV incidences in the future.
In a sample of Tasmanian local government areas (LGAs), where the ecological and human settlement conditions are present for RRV transmission (human settlements proximate to significant saltmarsh habitats), we find that many of these areas also demonstrate socio-economic disadvantage. To understand this a bit better, we considered three social indicators — education, income, and availability of health services — that contribute to adaptive capacity in each LGA (see Table 2). For each social indicator, a relevant metric is considered a guide to its contribution. The metrics considered across the LGAs include: for education — percentage of the population having completed Year 12; for income — percentage of the population not receiving government allowances; and for the availability of health services — the estimated fraction of full-time equivalent (FTE) general practitioners per 100 people. For each LGA, the social indicator metric \( I_i \) represents the standardised (by the sample standard deviation across all LGAs) social indicator value differences from the sample mean (across all LGAs). The adaptive capacity indicator \( AC \) is simply the unweighted sum of the three social indicator metrics. Positive values for \( I_i \) indicate that the social factor for that LGA is above the State average. Conversely negative values for \( I_i \) indicate that the social factor for the LGA is below the State average. A similar logic applies to the adaptive capacity \( AC \), where positive values are indicative of above State-average adaptive capacity based on the three social indicators, while negative values are indicative of below-average adaptive capacity based on these social indicators.

Table 2 shows that of the ecologically vulnerable LGAs assessed, coastal towns in Tasmania’s northeast, southeast and northwest (Break O’Day, Glamorgan Spring Bay, and Circular Head LGAs, respectively), and peri-urban growth areas on Hobart’s fringe (Brighton and Sorell LGAs), scored the lowest in terms of overall adaptive capacity based on readily available standardized education, income and health service access indicators. Thus, in the case of raising awareness about RRV and considering adaptation response options (such as education, access to information and alerts, purchase of insurances, and the ability to alter living conditions), socio-economic circumstances are likely to influence the capacity to adapt and so should not be discounted in the overall assessment of regional vulnerability and hazard mitigation responses.

In addition to considering socio-economic indicators for local areas, we qualitatively assessed the adaptive capacity of the community at large, validated by practitioners who have a role to play in hazard mitigation. Some 22 Tasmanian professionals from a variety of relevant communities of practice participated in a one-day workshop. The workshop provided the opportunity to share and consider the complex factors contributing to the problem in a succinct way, and verify the findings of the first draft socio-ecological vulnerability assessment which in turn helped inform participants to consider the adaptive capacity issues. A number of findings emerged from the workshop that are important considerations for determining social vulnerability and the baseline capacity for hazard mitigation and adaptation planning. These are summarised in Table 3 as examples of societal adaptive capacity issues, they particularly revolve around: the variable levels of awareness amongst differing practitioner groups responsible for RRV response and mitigation; competing and limited resources of government agencies for assessment work and adaptation planning; information limitations (such as the lack of knowledge about Tasmanian saltmarshes in a changing climate); and the condition of building stock.

Social assessment conclusions

The Tasmanian population is exposed to RRV risk through proximity and interaction with natural environments and ecological system components favorable to RRV, such as saltmarsh habitats in estuarine/coastal areas and macropods. Further, changing climatic conditions point to more warm spells that will likely encourage greater outdoor activity potentially also enhancing exposure in those less immunologically naïve. In the north and southeast of the state in particular there are human settlements and economic growth activities (including tourism and agricultural) that are proximate to significant saltmarsh, estuarine, and macropod environments; while peri-urban areas east, north and south of Hobart are some of the fastest growing population settlements in the State. Vulnerability in these areas is also likely to be impacted by the relative adaptive capacity of communities, health services, and hazard mitigation agencies. Indicators of social adaptive capacity in key local government areas point to the reinforcement of vulnerability for peri-urban areas in Tasmania’s southeast, and northeast coastal communities in particular.

Integrated assessment results

Tables 4 and 5 provide summary report matrices that present the qualitative assessment of how the key biophysical and social factors contribute to current vulnerability and potential future vulnerability in a changing climate. The assessments were developed by the research team in reference to the literature synthesis with stakeholder input and verification via the workshop process. The matrices summarise: the historical knowledge around the contributing factors to RRV vulnerability and the relative evidence, agreement and confidence in these relationships; and the projected changes in the relevant contributing factors under climate change, how this is likely to translate to changed RRV vulnerability in Tasmanian coastal regions, and the relative level of confidence in our assessment (based on the quality of projected evidence and the robustness of relationships).

For example in Table 4 we highlight that based on the current state of knowledge there appears to be a positive correlation between saltmarsh habitat condition/extent and RRV incidence. However, evidence for this is limited and thereby the level of agreement and confidence in the robustness of this relationship is low pointing to the need for further research in this area. Similarly, the table points to a positive correlation between a change in mean minimum temperature and RRV incidence (an increase in incidence with an increase in mean minimum temperature). However, this time we can state this
with a high degree of confidence due to the availability of robust evidence and high levels of agreement in the literature. The logic applies to the other key factors listed in the table.

In Table 5 we consider the potential changes in RRV incidence under climate change (according to the CFT projections outlined in Table 1) and other regional scale changes. This time we make assessments of the projected change in the state of each factor, whether it will increase or decrease in the future, what the implications for RRV incidence is likely to be and our confidence in this. For instance, we expect there to be an increase in human population density and proximity to ecological RRV risk areas into the century due to human settlement development plans (so a positive change in state). The population density factor then contributes to an increase in RRV incidence risk with a high level of confidence. Similar positive conclusions are made about mean minimum temperature, and heavy rainfall events in coastal regions (increases in these amplifying RRV incidence risk), while there is much more uncertainty about the role of wind, sea level rise and saltmarsh habitat condition/extent.

Collectively, our results suggest that climatic changes projected for coastal regions in Tasmania, together with trends in human settlement development, are likely to heighten the potential for RRV outbreaks in Tasmania towards the mid 21st century, after which the impacts of climatic changes on the biophysical environment become more uncertain. These conclusions, and the projected increased vulnerability in human populations across certain regions, are based largely on the anticipated changes in, and couplings between: mean minimum and maximum temperatures and coastal rainfall through the 21st century (as described by CFT in Table 1); the potential impacts of sea level rise on saltmarsh extent and coastal ecology;

### Table 2
Relative social adaptive capacity indicators in key local government areas.

<table>
<thead>
<tr>
<th>Social adaptive capacity indicators</th>
<th>Income</th>
<th>Availability of health services</th>
<th>Adaptive capacity indicator $\Sigma_i$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Education % of pop completed Year 12 (ABS, 2010)</td>
<td>Education Indicator ($I_1$)</td>
<td>Income Indicator ($I_2$)</td>
<td>Estimated FTE general practitioners per 100 people (Medicare local Tas 2012)</td>
</tr>
<tr>
<td>-----------------------------------</td>
<td>--------</td>
<td>--------------------------------</td>
<td>--------------------------------------</td>
</tr>
<tr>
<td>Kingborough (South Tas)</td>
<td>51</td>
<td>1.789</td>
<td>81</td>
</tr>
<tr>
<td>Clarence (South Tas)</td>
<td>42</td>
<td>0.984</td>
<td>77</td>
</tr>
<tr>
<td>Huon Valley (South Tas)</td>
<td>36</td>
<td>0.447</td>
<td>74</td>
</tr>
<tr>
<td>West Tamar (North Tas)</td>
<td>37</td>
<td>0.537</td>
<td>76</td>
</tr>
<tr>
<td>Sorell (South Tas)</td>
<td>24</td>
<td>−0.626</td>
<td>77</td>
</tr>
<tr>
<td>Glamorgan Spring Bay (South Tas)</td>
<td>28</td>
<td>−0.268</td>
<td>65</td>
</tr>
<tr>
<td>Circular Head (NW Tas)</td>
<td>17</td>
<td>−1.252</td>
<td>81</td>
</tr>
<tr>
<td>Brighton (South Tas)</td>
<td>23</td>
<td>−0.716</td>
<td>75</td>
</tr>
<tr>
<td>Break O’Day (North Tas)</td>
<td>21</td>
<td>−0.894</td>
<td>63</td>
</tr>
<tr>
<td>Sample Mean</td>
<td>31.0</td>
<td>74.3</td>
<td>6.344</td>
</tr>
</tbody>
</table>

The bold values indicate the ultimate indicator.

We provide here an adaptive capacity (AC) indicator metric – which represents the sum of standardised (by the sample standard deviation) social indicator value differences from the sample mean, for three social indicators (Education, Income, Health Services) – for comparison of the relative adaptive capacities across the relevant Tasmanian local government areas (LGAs). The LGA with the lowest AC indicator value is deemed to have the lowest social AC in the sample, based on this assessment. Here, each of the indicators is weighted equally. However, future exploration of the relative importance of each of these indicators may change the weightings. The data were drawn from the following sources: ABS (2010) (Government allowances refers to various age pensions, Carers Payment, Disability Support pension, Newstart Allowance, Single Parenting Payment and various youth allowances); Medicare Local Tasmania, 2012: 23.
<table>
<thead>
<tr>
<th>Top 6 Ross River virus Stakeholder adaptive capacity issues and response considerations</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) Tasmania has limited experience with RRV outbreaks, and thus there are low levels of community awareness about determinants of risk and simple risk management options. This points to the value of awareness raising and educational strategies in areas of highest vulnerability.</td>
</tr>
<tr>
<td>(b) Local government areas where there are existing or emerging hazards tend to be resource stretched, contain some of the lowest socio-economic status communities and fastest growing populations in Tasmania. This presents challenges for prioritising public health issues, directing scarce resources, and designing adaptation strategies.</td>
</tr>
<tr>
<td>(c) Monitoring of mosquito habitats in areas of human settlement is currently limited, but seasonal risk prediction capability is improving with developments in the local ecological science associated with RRV. However, little is understood about the implications of climate change for saltmarsh habitats (particularly the impact of sea level rise), nor the significance of managing saltmarsh health as a risk mitigation strategy.</td>
</tr>
<tr>
<td>(d) Tasmanian buildings poorly protect from mosquitoes compared to other parts of Australia where fly screens on windows and doors and mosquito management in particular are commonplace. Addressing this through the design and location of buildings, amendment of building codes and/or land use planning schemes may be required in the medium term.</td>
</tr>
<tr>
<td>(e) The indirect health implications of climate change have not been widely discussed as an issue for Tasmania, and thereby integrated vulnerability assessment, risk mitigation, and adaptation are virtually non-existent – thus, assessment and response strategies are starting from a low base.</td>
</tr>
<tr>
<td>(f) Awareness of RRV amongst professional communities of practice is largely confined to health professionals and local environmental health officers in areas where there is a history of outbreak. Land use planners and natural resource managers have not considered RRV as a hazard they need to manage into the future (nor perhaps many other indirect health implications of climate change), despite the importance of managing the interface between human settlements and saltmarsh habitats.</td>
</tr>
</tbody>
</table>
trends in human settlement patterns; and relevant social factors and adaptive capacity indicators. Tables 4 and 5, however, help qualify our degree of confidence and certainty in key influencing factors.

Areas where there are clear and increasing interfaces between saltmarsh, human settlement (particularly earmarked urban growth areas or coastal towns likely to experience growth), agricultural activity, and host populations are assessed as being most vulnerable without intervention. Maps of indicative vulnerability areas for Tasmania are provided in Fig. 2. Because of the projected wetter coastal environments of the northeast and southeast of Tasmania and the potential for human settlement growth, these regions have been identified as becoming more vulnerable than northwest Tasmania where the population is smaller, growing slowly (and in some settlements is in decline); and where the future climate is anticipated to be drier. We overlay the scoping of social sensitivity and adaptive capacity elements in areas of particular ecological and human settlement sensitivity, and the spatial vulnerability is reinforced in east coast communities and peri-urban growth areas of greater Hobart, such as Sorell and Brighton. The broad areas marked on Fig. 2 point to the need for further exploration of finer scale risk assessment to inform regionally and locally appropriate hazard risk mitigation and adaptation response.

### Table 4
A qualitative assessment of the relationships between biophysical factors and RRV potential in Tasmania.

<table>
<thead>
<tr>
<th>Factors contributing to RR virus potential</th>
<th>Relationship to RR virus incidence</th>
<th>Amount of evidence of relationship</th>
<th>Amount of agreement of relationship</th>
<th>Confidence in robustness of relationship</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saltmarsh habitat: condition/extent</td>
<td>Positive</td>
<td>Limited</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Relevant proximate reservoir host population</td>
<td>Positive</td>
<td>Robust</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Human population density and proximity</td>
<td>Positive</td>
<td>Robust</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Change in mean minimum temperature</td>
<td>Positive</td>
<td>Robust</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Change in mean rainfall</td>
<td>Unclear</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Heavy rainfall events</td>
<td>Positive</td>
<td>Medium</td>
<td>High</td>
<td>Med-high</td>
</tr>
<tr>
<td>Effective wind strength</td>
<td>Unclear</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Humidity</td>
<td>Positive</td>
<td>Limited</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Sea level rise</td>
<td>Unclear</td>
<td>Limited</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Other vector species migration, establishment, or extension</td>
<td>Positive</td>
<td>Limited</td>
<td>Medium</td>
<td>Low-med</td>
</tr>
</tbody>
</table>

‘Positive’ in the table effectively means that the factor contributing to RRV is positively correlated with RRV incidence – i.e. a reduction in the factor makes a contribution to reduced likelihood of RRV. Alternatively, an increase in the factor makes a contribution to increased likelihood of RRV incidences.

### Table 5
Qualitative assessment of the potential changes in RRV incidence under climate change – assuming an A2 emissions scenario and focusing on the mid 21st century (based on interpretation of CFT projections for 2040-70).

<table>
<thead>
<tr>
<th>Factors contributing to RR virus potential towards mid 21st century</th>
<th>Projected change in state (i.e. increase or decrease)</th>
<th>Future impact on RR virus incidence (increase or decrease)</th>
<th>Confidence of future impact based on quality of projected evidence and robustness of relationship</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saltmarsh habitat: condition/extent</td>
<td>Regional variation</td>
<td>Unclear</td>
<td>Low</td>
</tr>
<tr>
<td>Relevant proximate reservoir host population</td>
<td>Increase</td>
<td>Increase</td>
<td>Medium</td>
</tr>
<tr>
<td>Human population density and proximity</td>
<td>Increase</td>
<td>Increase</td>
<td>High</td>
</tr>
<tr>
<td>Change in mean minimum temperature</td>
<td>Increase</td>
<td>Increase</td>
<td>High</td>
</tr>
<tr>
<td>Rainfall trend in coastal regions</td>
<td>Increase</td>
<td>Increase</td>
<td>Medium</td>
</tr>
<tr>
<td>Heavy rainfall events in coastal regions</td>
<td>Increase</td>
<td>Increase</td>
<td>Med-High</td>
</tr>
<tr>
<td>Effective wind change</td>
<td>Little change</td>
<td>Unclear</td>
<td>Low</td>
</tr>
<tr>
<td>Humidity in coastal regions</td>
<td>Increase</td>
<td>Increase</td>
<td>Low</td>
</tr>
<tr>
<td>Sea level rise</td>
<td>Increase</td>
<td>Unclear</td>
<td>Low</td>
</tr>
<tr>
<td>Other vector species migration, establishment, or extension</td>
<td>Increase (long term)</td>
<td>Increase (long term)</td>
<td>Low</td>
</tr>
<tr>
<td>Exposure of human population (outdoor activity)</td>
<td>Increase</td>
<td>Increase (med term)</td>
<td>Medium</td>
</tr>
<tr>
<td>Sensitivity (non-immunity) of human population</td>
<td>Increase (med term)</td>
<td>Increase (med term)</td>
<td>Low</td>
</tr>
</tbody>
</table>

Discussion and conclusions

This paper demonstrates the complexity of climate change influences on human health, and shows that even subtle climate changes can amplify or assist emergence of human health issues. It also provides an example of a relevant approach for considering key factors, and their interactions, within complex social-ecological systems. Our approach is ideal for studies at the regional scale and for informing policy, plans and program development – in particular for scoping the indirect and potentially insidious implications of climate change on human health despite uncertainties and imperfect knowledge.

In addition to demonstrating the complexity of climate change influences on human health, this paper highlights a range of issues and findings. First, it specifically demonstrates that the temperate island state of Tasmania is likely to become more vulnerable to RRV as the 21st Century progresses even though the relevant climate change factors (mean minimum and maximum temperatures, and rainfall) are projected to be only subtle. This moves this health issue from a relatively low public health risk into one that will likely become increasingly concerning and costly during this century. Second, we have shown that it is important to consider the social adaptive capacity and the factors that might contribute to this within professional groups and institutions, and communities. Whether as an individual, community, health worker, or risk manager, human vulnerability to RRV in a changing climate is likely to be amplified in areas, or amongst groups, where social adaptive capacity is poorest. This is determined through a range of factors such as socio-economic status and wellbeing, decision maker and practitioner awareness, and institutional or governance capacity factors. Finally, the study demonstrates that climate (and climate change) is only one factor, albeit a significant one, that can influence the present and future potential of RRV incidence in Tasmania. Ultimately, human vulnerability to the virus is a critical consideration, being affected by other local and global changes occurring at the local to regional scale, such as land use and demographic change, and human behaviour.

The integrated assessment approach employed in this Tasmanian study can also be usefully translated to numerous other indirect social-ecological system issues within and outside the health sector, while the RRV specific results and approaches
used might be relevant to other temperate place contexts. The IPCC (Reisinger et al., 2014) statement that the effects of climate change combined with other factors could expand the geographic range of vector-borne diseases such as Ross River virus in the Australasia region specifically, certainly adds relevance to this work where other temperate regional settings, such as New Zealand, might benefit from the integration of knowledge and the conclusions of this study.

Our engagement with stakeholders from differing professional communities of practice demonstrates the need for different professional groups and fields of science to come together from time to time to share their knowledge and reflect on their understanding and roles in responding to such inter-linked system problems. For evaluation purposes, stakeholder workshop participants were asked to rate their level of understanding of RRV in Tasmania as well as what they believed the relevance of the management of RRV risk was to their profession, both before and after the workshop. The evaluation indicates that the workshop increased their perception of the importance of considering RRV in their profession (no-one indicated that they thought it was ‘not relevant’ by the conclusion of the process compared to 42% before). The largest shifts in awareness were amongst land use planners and natural resource managers who seemingly developed an understanding of their role in RRV risk management through the process. Likewise, health service professionals, and scientists working on the ecological component factors associated with RRV in Tasmania, also benefited from face to face engagement with environmental planners and managers who provided insight into risk management governance and praxis barriers. Hence, we deem the participatory nature of this project highly valuable in elucidating complexities, risk management issues, and barriers to a range of different stakeholders responsible for different response aspects.

We acknowledge that this vulnerability assessment is bounded by limitations in knowledge inputs and uncertainties. Nevertheless, this is not dis-similar to a myriad of other complex or ‘wicked-problems’ requiring many inputs of knowledge and certainty (e.g. Davidson and Lyth, 2012; Davidson et al., 2013). The Climate Futures for Tasmania climate projections and sea level rise estimates for Tasmania through this century are based on best knowledge of the day and are important foundations for considering social-ecological future scenarios, but they are veiled with caveats, and planners and decision makers will need to be mindful of this, where possible factoring in periodical review of such inputs and adapting responses accordingly. As much as this study helps us direct our attentions to the complex and indirect human health implications of climate change alongside other local changes, our confidence matrices also expose the strengths and weaknesses of our knowledge base and should assist in the prioritization of future regionally relevant research.

In conclusion, by exploring this complex human health issue in the context of a changing climate, it has acted to raise the profile of regional health implications associated with ecological change in the State of Tasmania. It has been particularly valuable to do this in this temperate island setting, where it has been largely assumed as irrelevant to the climate change agenda in Australia. This study has helped us to contemplate how we frame human health questions as we move into a climatically changing world and reminds us that health impacts will not always be linear or obvious.

Acknowledgements

The authors wish to acknowledge the valuable contribution of the late Erica Bell to this project, a member of the initial research team. Erica was a determined advocate for the need to incorporate social factors and adaptive capacity considerations into public health and climate change policy, and is greatly missed. We also appreciate: the input of Scott Carver and Vishnu Prahalad who reviewed the public report from which this paper has been developed, and provided scientific advice and technical support to the study; Robyn Allchin for her research support; all participants in the professional communities of practice workshop; and support from the Local Government Association of Tasmania and NRM South Tasmania. We gratefully acknowledge funding from a Tasmanian Government Climate Connect Program Grant and the USC-UTAS-Griffith University Collaborative Research Network (CRN) ‘Research Futures’ Grant. We thank the anonymous reviewers for their helpful suggestions which improved the quality of this paper.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.crm.2015.06.004. These data include Google maps of the most important areas described in this article.

References


