CoastAdapt

Climate change impacts on human health in the coastal zone

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Impact Sheet 5

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Contents

Summary of Australia's climate trends and projections

Temperatures in Australia are increasing, and rainfall is becoming more variable.

Mean surface air temperatures in Australia have warmed by 0.9°C over the last 100 years. Nights have become relatively warmer; overnight minimum temperatures have increased more (1.1°C) than daily maximum temperatures (0.8°C). Rainfall has increased in the north-west but declined in the south-west (winter) and south-east (autumn and winter), and the fire season has increased in length and intensity (CSIRO and Bureau of Meteorology 2015).

Temperatures will continue to increase over coming decades, with increasing frequency of extreme hot days and decreasing frequency of extreme cold days. There remains some uncertainty about how rainfall will be affected, but it will most likely decrease in the south and especially south-west of Australia (Reisinger et al. 2014). Tropical cyclones in the north will increase in intensity, and fire-risk weather in the south will increase (Reisinger et al. 2014).

Sea-level rise associated with climate change contributes to shoreline instability and temporary inundation and, in the longer term, permanent loss of land, buildings and infrastructure. Storm surges, also likely to increase with climate change, augment the effects of a rise in sea level and contribute to temporary inundation and erosion. By 2030, sea level around Australia's coastline will have increased 13–20 cm relative to 1990 levels, depending on global greenhouse gas (GHG) emissions (Department of Climate Change and Energy Efficiency 2015). By 2100, the increase will be between approximately 0.5 m (low emissions scenario) and 1.1 m (high emissions scenario). A medium emissions scenario will have added about 0.8 m to sea level by 2100 (Department of Climate Change and Energy Efficiency 2015).

Coastal zone vulnerability to health impacts

Australia's population is increasing in size, becoming older and moving to the coast.

Australia has a population of approximately 24 million (ABS 2016); this is expected to almost double over the next 50 years. A mid-estimate of Australia's future population based on current trends is 42 million in 2061 and 54 million in 2101 (ABS 2013a).

The median age in Australia is currently 37 years, but the average age of the population is rising. In 2031, for example, the median ages in New South Wales, South Australia and Tasmania are projected to be around 40, 42 and 45 respectively; by 2061, on current trends, these will have increased to 43, 44 and 48 (ABS 2013b). People aged 65 years and over currently make up about 14% of the population, increasing to 22% in 2061 and 25% in 2101; those 85 years and older are approximately 2% of the current population, increasing to 5% and 6% in 2061 and 2101 (ABS 2013c).

Australia's population is highly urban (approximately 90%), and, with the exception of Canberra, all of its capital cities are located in the coastal zone. Other major population centres in the coastal zone are Wollongong, Newcastle, Gold Coast and Tweed Heads, Sunshine Coast, Townsville and Cairns. The fastest growing regional major cities – those that have increased in size by more than 20% over a decade – are all located on the coast (Department of Infrastructure and Regional Development 2015). Altogether, more than 80% of the population lives in the coastal zone, and coastal populations are growing more rapidly than non-coastal populations as an increasing number of people live in major cities (ABS 2013b).

In Australia – with the exception of Canberra and a few inland regional centres – coastal zone vulnerability to climate change is closely aligned to urban vulnerability, but the coastal zone has the added impacts from sea-level rise. While smaller coastal communities may escape some of the explicitly urban impacts (urban heat island contributions to extreme heat days, for example), they may also lack the services and infrastructure to best manage or avoid the impacts (public transport, air-conditioned public spaces or public swimming pools).

As the Australian population grows and ages, more people – both proportionately and in absolute numbers – are at increased vulnerability to the effects of climate change and, in particular, increased exposure to heat.

Categories of health impacts from climate change

The health consequences of climate change are complex and interrelated. They can be usefully thought of as falling into three categories: primary, secondary and tertiary (Butler and Harley 2010).

Primary impacts are most familiar and are the direct effects, often readily observable and fairly immediate, of a particular event. These include injury, illness and death resulting directly from an extreme event, such as a flood or a heatwave.

Secondary impacts are outcomes that have climate as a mediator. They are more difficult to observe and to measure than primary effects. There may be a longer period of time between an event and its impact, and there may be a number of other factors contributing. For example, humidity enhances the survival time and the feeding rate of a disease-carrying mosquito and hence increases transmission potential of diseases such as Ross River virus and dengue; a warmer spring may increase the density of allergenic pollens that can trigger asthma.

Tertiary impacts are more complex still, more stretched out in time and more difficult to attribute to a particular event or exposure. They include malnutrition arising from food insecurity, as well as increased physical and mental trauma associated with forced migration, social disruption and conflict.

A single climate driver or event, such as an extreme heatwave, can have multiple population health impacts at different levels. For example, extreme heat may cause deaths directly (primary effect), as well as driving bushfire weather and contributing to asthma (secondary effect) within the nearby communities. Flooding may cause immediate drownings (primary effect) as well as provide additional mosquito breeding habitat in the following days or weeks (secondary effect). A prolonged drought may trigger poor mental health in response to loss of livelihood for farmers (secondary effect) as well as cause food shortages and force population displacement (tertiary effect).

Previous efforts to examine the impact on human health of climate change impacts include the National Climate Change Adaptation Research Plan for Human Health. In that document, nine themes were identified as a means to provide focused areas for research (McMichael et al. 2009): heat, extreme weather events, vector-borne disease, food safety and quality, air quality, water quality, mental health, community and Indigenous health, and health services and infrastructure. These nine themes do not map readily to the categories of primary, secondary and tertiary that describe the range of impacts, but instead include drivers (such as weather events), outcomes (vector-borne disease) and moderators (infrastructure), as well as specific population groups (Indigenous communities). As this paper is concerned with impacts it is therefore structured using expected health outcomes (primary, secondary and tertiary), and discusses the drivers, moderators and specific populations at risk.

Primary health impacts

Primary health effects of climate change are those that are directly and readily linked to climate events. The most readily discernible and measureable of these are injuries and deaths linked to a particular extreme weather event: heat, storms and bushfires. Prolonged drought is an extreme event but differs from the others in that it unfolds more slowly. Illness, injuries and deaths from droughts are less immediate and less direct than those from heatwaves and storms, with drought serving as a trigger for poor mental health and suicide in rural areas (secondary effects), and compromising water security and food security (tertiary effect) (Nicholls et al. 2006). Extreme weather is predicted to continue to increase in frequency and intensity with climate change in Australia (Hughes et al. 2015; Steffen 2015).

Extreme heat

Extreme heat, especially when it occurs over several consecutive days in the form of a heatwave, increases hospital admissions, emergency department visits, ambulance call-outs and mortality (Hansen et al. 2008a; Vaneckova and Bambrick 2013). The people most affected tend to be older and to have underlying chronic health conditions such as cardiovascular or respiratory disease (Hansen et al. 2008a; Vaneckova and Bambrick 2013). They are also more likely to be poor or socially isolated and to be undertaking physical work outdoors and in non-air-conditioned indoor environments (Bi et al. 2011; Kjellstrom et al. 2009). Young children are also at increased risk (Xu et al. 2012). It is not only how high the daytime maximum temperatures reach that matters for health, but also for how long they are high. The worst heatwaves in terms of health outcomes are those where the night-time minimum temperatures do not drop sufficiently to provide relief from the high daytime temperatures. Heat builds up over a period of days, and people who are less well able to regulate their body temperature because of age or underlying disease may become ill (Vaneckova and Bambrick 2013).

Urban areas in the coastal zone are hotter than climate-comparable rural areas due to the urban heat island effect, where heat is absorbed by the concrete and bitumen and builds up over time, increasing local daytime maximum temperatures and maintaining higher night-time minimum temperatures.

People living closest to the sea may be somewhat protected from the effects of extreme heat, relative to those further inland, as the ocean moderates the higher temperatures, and cooler sea breezes may be more accessible.

People in different areas have different responses to temperature. For example, age-specific mortality increases at relatively low temperature thresholds in some locations in comparison with others (Bambrick et al. 2008). The lag time between high temperatures and health effects is also affected by how heat-adapted a population is, with people who are used to higher temperatures experiencing a longer delay before experiencing apparent health effects from heat (Nairn and Fawcett 2015). This variation is most likely due to physiological acclimatisation to usual temperatures in the population, as well as to more or less adaptive behavioural responses and environmental and social characteristics.

The duration as well as the intensity of warmer temperatures affects human health outcomes. Defining a heatwave most usefully in a particular location is thus dependent on both temperature and duration. The excessive heat factor, derived from averaged mean temperatures over three days (allowing the capture of both maximum and minimum temperatures), has been developed to provide a consistent standard for forecasting heatwaves in Australia (Nairn and Fawcett 2015).

Extreme heat not only has a direct physiological effect; it can also damage services and infrastructure that serve to protect health and facilitate social and economic functioning. The Melbourne heatwave in 2009, for example, caused disruption to public transport, with the buckling of railway tracks (Ham 2009), and blackouts occur when electricity grids are overloaded due to increased air-conditioner use (ABC News 2014), for example. Such failures of broader infrastructure can increase mortality and serious illness in a number of ways: rendering home medical equipment inoperable, slowing ambulance response times, disrupting the mobile phone network, triggering power loss at hospitals, causing overcrowding in emergency rooms, increasing physiological stress from being trapped in lifts and subways, causing isolation in high-rise apartments without potable water, leading to stranding on roads and public transport without air-conditioning or adequate water, and requiring unusual physical exertion (using stairs instead of the lift) (Anderson and Bell 2012).

Severe storms

Heavy rainfall during severe storms can cause local flooding, sudden rise in levels and increased flow of rivers and storm water, and overflow and breaking of dams. Associated storm surges along the coastline can pose immediate danger and cause local flooding. The latter is particularly a problem with low-lying coastal communities, especially those with poorer housing quality.

Direct (primary) risks to human health are from drowning (being swept away while crossing floodwaters or from coastal rocks) or being injured by falling trees, loose material such as metal sheeting being blown about in the strong winds, or downed electricity wires.

During extreme rainfall, infrastructure and services may be affected through damage to transport (road, rail and ferry), interrupted power supply, damage to water supply and sewerage treatment, as well as damage to public buildings through flooding or structural loss (Steffen and Hughes 2012). These effects may compound direct health impacts in a similar way to extreme heat, with, for example, slower response times for emergency vehicles. Flooding can also have a number of secondary effects, leading to increased risk of infection, such as melioidosis and leptospirosis, as well as food-, water- and vector-borne disease.

Bushfires

The primary health effects of bushfires are injury and loss of life directly associated with the event. Bushfires also lead to secondary effects of respiratory illness (Johnston et al. 2011) and mental health impacts – especially post-traumatic stress disorder – associated with loss of life and properties in the affected communities (Bryant 2009).

With each of these extreme events, the people most vulnerable to the primary health effects are those who are elderly, homeless or socially isolated or who have some other disadvantage. Seeking shelter in temporary accommodation due to an extreme event such as a flood or a bushfire, may put people – especially women and children – at increased risk of violence (Klein 2008).

Secondary health impacts

Secondary health effects are those where there is a discernible intermediary step on the causal pathway between climate and health. For example, humidity affects survival of mosquitoes, and this affects dynamics of disease transmission; warmer temperatures cause allergenic plant species to produce more pollen, and this affects hospitalisations for allergic asthma.

Vector-borne disease

A number of vector-borne diseases are relevant to Australia. Barmah Forest virus, chikungunya, Japanese encephalitis, Kunjin virus, Murray Valley encephalitis, Ross River virus, malaria and dengue (National Notifiable Diseases Surveillance System 2012). Cases of malaria are imported on an ad hoc basis, with (currently) no local transmission, while dengue outbreaks occur annually in north Queensland through local transmission following the introduction of an imported case. Coastal zones are at risk from saltwater breeding mosquitoes, while urban areas (also in the coastal zone) are home to *Aedes aegypti*, Australia's dengue-transmitting mosquito. *Aedes aegypti* is very well adapted to human settlements, with artificial containers (such as garden pots) providing suitable breeding habitats, and is therefore of particular importance in urban areas.

Climate change may alter the geographic distribution of vectors and increase transmission potential in some areas. Warmer temperatures speed up mosquito development so that they reach adulthood more quickly, increase mosquito activity and biting rate, and (to a point) enhance mosquito survival. Warmer temperatures can also speed up the incubation period of a virus within the mosquito (the time between when a mosquito ingests infected blood and when it is able to transmit the infection), so that a mosquito becomes infectious more quickly and is more likely to transmit the virus on subsequent feeds. Increased humidity enhances mosquito survival, while rainfall provides breeding pools. Modelling the dynamics of mosquito-borne disease with climate is complicated because so much depends on the microhabitat (the availability of shade and breeding sites in a small area, such as the corner of a backyard). Very heavy rainfall may flush out mosquito eggs from breeding pools and cause an initial decline in numbers, while the pools left consequent to flooding may provide ample new breeding areas.

The transmission cycle of some vector-borne diseases, such as Ross River virus and Barmah Forest virus, is especially complex. It involves alternative host populations, primarily native marsupials, and the risk of infection is highly dependent on the dynamics of host populations and local environmental and social factors (Tong et al. 2008).

Dengue is of particular concern in Australia, given the severity of the disease and its sometimes intractable annual outbreaks in urban coastal regions of North Queensland. The virus is transmitted by the urban-dwelling mosquito, *Aedes aegypt*i, with annual outbreaks currently restricted to north Queensland. Unlike some other mosquito-borne diseases, the transmission cycle of dengue is relatively simple as it does not involve alternative hosts; its vector is somewhat geographically limited; and outbreaks are thus potentially much easier to limit. As the climate changes, the populations at risk from dengue may increase as transmission becomes more likely over a broader geographic area, particularly extending south from its current distribution in Queensland along the coast and into New South Wales (Bambrick et al. 2008). However, of more immediate concern to Australia is the potential establishment of another competent dengue vector, *Aedes albopictus*, which is a more aggressive biter and tolerates a much cooler climate. *Aedes albopictus* occurs throughout Asia and would pose a major threat to coastal and other communities should it ever become established in Australia. Both *Aedes* species are also competent vectors of chikungunya virus, a major health concern elsewhere.

While climate sets the parameters for vector distribution and virus transmission, of considerable importance are systems of vector surveillance and control and behaviours that affect the availability of breeding sites (Russell et al. 2009; van Kleef et al. 2011). Urban-dwelling *Aedes aegypti,* for example, relies on artificial containers (garden pots, old tyres, discarded plastic) to breed in, and clearing household gardens is a major control measure for dengue.

All else being equal, higher temperatures and increased rainfall and humidity will facilitate geographic spread of vectors and their diseases, resulting in increased numbers of people at risk, and will promote longer disease transmission seasons and higher seasonal peaks (Bambrick et al. 2008). Areas where rainfall and humidity increase alongside temperature are those where risk of vector-borne disease will increase the most (Woodruff and Bambrick 2008). While both the seasonal timing and intensity of rainfall affect mosquito breeding habitat and survival, it may be that the risk of transmission of vector-borne diseases such as Ross River virus in the south-east of Australia declines in coming years if the region experiences an overall decline in rainfall (Woodruff and Bambrick 2008). Coastal areas, even in regions where there is decreasing rainfall, may be at increased risk with rising temperatures and tidal inundation.

It should also be noted that warmer overnight minimum temperatures – the trend that is already occurring – could prolong mosquito seasons as it is minimum temperatures that set the limits on mosquito activity and virus replication (Jetten and Focks 1997).

Respiratory disease, asthma and allergy

Air pollution is associated with hospitalisations (Morgan et al. 1998a) and mortality (Morgan el al. 1998b). Exposure to air pollutants leading to hospitalisations may increase with climate change (Confalonieri et al. 2007) as ozone density increases with warmer temperatures (Cope et al. 2008). Air quality concerns under climate change are compounded by potential for increasing urban pollution with population growth and urban expansion in coastal regions and increasing ambient temperatures. The combined effects of heat and air pollution may contribute to increasing mortality and ill health in hot weather (Vaneckova et al. 2008).

People at increased health risk from air pollutants are those with underlying respiratory illness such as asthma, chronic obstructive pulmonary disease and lung cancer (Hughes and McMichael 2011).

Air quality can be affected by bushfire smoke and dust storms (arising from drought). The frequency and intensity of both of these may increase with climate change. Bushfire risk will most likely increase across south-eastern Australia alongside increasing drought, and wind speeds may increase (CSIRO 2007).

Pollutants are not the only concern regarding air quality. Exposure to aeroallergens may change, potentially increasing ill health from asthma and hay fever. In Australia, 10–15% of people are affected by asthma (ACAM 2008), while 'wheeze' occurs in up to 30% of children (Lai et al. 2009). Causing about 400 deaths a year, asthma is associated with reduced quality of life, poorer overall health, and reduced productivity and school time (ACAM 2011). Hay fever contributes to impaired quality of life and is Australia's third most common long-term condition, affecting around 15% of the population, with prevalence increasing with age (ABS 2009), reducing work productivity (Vandenplas et al. 2008).

Up to 80% of asthma cases may be related to allergy (Grossman 1997), and exposure to allergens causes initial sensitisation as well as serving as the trigger for asthma episodes (Sublett 2005). Climate sets the parameters for outdoor aeroallergens such as pollens (Dales et al. 2004; Gioulekas et al. 2004) and fungal spores (Beggs and Curson 1995; Burge and Rogers 2000) and to indoor aeroallergens from moulds, cockroaches, house dust mites and rodents (Beggs and Curson 1995; Burge and Rogers 2000), all of which are associated with increased sensitivity (Huss et al. 2001) and severity of asthma and allergy (Stelmach et al. 2002). Sensitivity to house dust mites is more prevalent in coastal areas than inland (Peat et al. 1993), and people living near the coast are more likely to experience asthma (Muscatello 2003).

While seasonal trends in morbidity are apparent (Laforest et al. 2005; Xirasagar et al. 2006), how climate change may affect these patterns is not well understood. There are peaks for asthma hospitalisations and emergency department visits in Australia in late autumn to winter (ACAM 2008) for adults and in late summer and autumn for children (ACAM 2008; Bambrick et al. 2006), and there is also inter-annual variability in asthma morbidity (ACAM 2008). It is possible that climate change may increase ill health due to asthma and hay fever (Beggs and Bambrick 2005), but very little is known about the impacts of climate change on specific outdoor or indoor allergens, such as important allergenic weeds (e.g. *Parietaria judaica* and *Plantago lanceolata*, both common in coastal regions) or on house dust mites and indoor mould spores. Temperature may independently contribute to emergency department visits for asthma among children, with both heat and cold increasing attendance (Xu et al. 2013).

The Indigenous population may be the most sensitive group to any effects on asthma drivers arising from climate change; as a group, Indigenous people are 50% more likely to have asthma, twice as likely to be hospitalised from it and three times as likely to die (ACAM 2008). A study of the effects of bushfire smoke on respiratory outcomes found Indigenous people to be more likely to be hospitalised than non-Indigenous people (Hanigan et al. 2008).

Mental health

The mental health impacts of climate change is a relatively new area of research. As demonstrated by the 2009 Victorian fires and the 2011 Queensland floods, extreme and acute events may have long-lasting impacts on community mental health and social wellbeing (Hanna et al. 2012). Poor mental health has also been associated with prolonged drought, with an increase in suicide linked to periods of low rainfall (Nicholls et al. 2006), hot weather and low humidity (Hansen et al. 2008b; Toro et al. 2009). Depression and suicide may increase with climate change in places where rainfall is reduced (Nicholls et al. 2006), as may occur across southern Australia with projected rainfall declines of 0–40%. Hospitalisations for mental health-related diagnoses increase significantly during hot weather (Hansen et al. 2008b), but this may be related to medication as some antidepressants and antipsychotics interfere with the body's ability to regulate temperature, such as through decreasing sweating (Kaiser et al. 2001). There may be an increased risk to emergency response and hospital staff from patients presenting with mental health conditions in response to an extreme event (Cusack et al. 2011).

Gastroenteric disease (water, food)

Water security is a growing concern in much of Australia, with the adoption of permanent water restrictions in recent years (Steffen and Hughes 2012). Under climate change, the south of Australia may experience increasingly constrained water resources, while at the same time requiring enhanced strategies to deal with greater acute flooding potential.

Droughts and rainy periods may become more frequent and more severe, and both types of event can affect water quality. Flooding associated with an intense rainfall event can overload storm water pipes and sewers and cause heavy run-off from farms, contaminating water supplies with protozoa (e.g. *Giardia* and *Cryptosporidium*), bacteria (e.g. *Escherichia coli*, *Campylobacter*), viruses and agricultural chemicals and contributing to toxic algal blooms from high nutrient levels (McCarthy et al. 2012; McMichael et al. 2009). Heavy rainfall also promotes contamination by non-volatile organic compounds washed from roads (Mahbub et al. 2012). Drought can reduce water quality by increasing the concentration of pathogens, heavy metals and major ions (e.g. chloride, sodium, fluoride) and by depleting oxygen levels (Zwolsman and van Bokhoven 2007).

Some water-borne pathogens are also affected by changing temperature, with increased giardiasis notifications occurring with both higher temperature and rainfall, while cryptosporidiosis increases with higher rainfall but decreases with higher temperature (Britton et al. 2010a). Higher ambient temperatures promote the growth of toxic algae (Kjellstrom and Weaver 2009). Population growth further increases pressure on already stressed water resources.

Food production is affected by climate change, as it is vulnerable to seasonal conditions and extreme events (Stadler et al. 2011), which can diminish supply, increase prices and even lead to increasing reliance on imports over exports for dominant food crops such as wheat (Butler 2009). Floods damage plant crops and cause livestock losses (Steffen and Hughes 2012), while climate change may reduce the long-term viability of agriculture in some areas. Even if overall quantity remains sufficient, access to nutritionally healthy foods may be reduced with climate change (Friel 2010).

Climate change combines with competing pressures on land (urban development, tourism and agriculture), especially with population growth occurring in some of the otherwise more productive regions (Mason et al. 2011).

Food safety may also be compromised under climate change, as warmer ambient temperatures enhance replication of harmful bacteria and are associated with more cases of gastroenteritis (Bambrick et al. 2008; Britton et al. 2010b; Hall et al. 2011). Salmonella and other bacterial gastrointestinal infections are predicted to increase in Australia overall by 3% by 2020 and 14% by 2050 (compared to 2000 rates) due to climate change, with usual summer peaks in case numbers becoming higher and more prolonged (Bambrick et al. 2008). The relationship between temperature and gastroenteritis may be altered by humidity, with higher rainfall associated with fewer cases (Zhang et al. 2008).

How climate change affects food-borne disease may be a particular concern for people already at increased risk: those with underlying chronic disease and, in particular, residents in aged-care facilities or people receiving treatment in hospitals (Bambrick et al. 2008).

Obesity and chronic disease

Prevalence of overweight and obesity in Australia is already one of the highest in the world, and is increasing among adults and children (AIHW 2016a, 2016b). Obesity contributes to a number of chronic diseases, such as diabetes and cardiovascular and renal disease (Korda et al. 2013). The groups most at risk from obesity and related chronic disease are those that are more socioeconomically disadvantaged (Brennan et al. 2009; Glover et al. 2004).

In addition to these underlying chronic conditions putting people at increased risk from extreme heat associated with climate change (Hansen et al. 2008b), climate change itself may contribute to increasing overweight and obesity in the population. This could happen through changes to food consumption and physical activity patterns. If food quality declines and fresh produce becomes more expensive, an increased quantity of lower quality (cheap, energy dense) food may be consumed (Friel et al. 2011; Tapsell et al. 2011). As the temperatures increase, physical exertion becomes more difficult and people may further limit their physical activity (Townsend et al. 2003).

Tertiary health impacts

Climate change may have a number of tertiary health impacts in the Australian coastal zone. Rising sea levels and increasing coastal inundation will lead to forced relocation and the associated costs and social disruption through loss of housing, productive land and infrastructure. Increasingly frequent acute events such as floods and bushfires may cause loss of life in the short term and ongoing mental trauma in the long term, as well as increasing costs of repairs and disruption from relocation. Loss of property and relocation negatively affect family assets, community economy and social functioning and has lasting detrimental effects on people's wellbeing. Forced relocation and communal accommodation may put some people at increased risk of violence and mental trauma (Klein 2008). Climate change may bring about the collapse of some communities (Hanna et al. 2011).

Sea-level rise is happening in the region at around 3 cm per decade, with a tripling in the number of high sea-level events over recent decades (Steffen and Hughes 2013). Managing coastal erosion that threatens properties will most likely become a community-wide issue in a number of regions in coming years, unless there is urgent emissions reduction and a subsequent slowing of sea-level rise.

Economic impacts of changed land and sea ecology through climate change can have long-term flow-on effects to mental and physical health. Where coastal communities receive much of their income from fishing, local income may be especially vulnerable to the effects that climate change has on local fish populations – changing abundance and distribution of certain species, for example (Steffen and Hughes 2013).

Table 1 brings together a summary narrative of the primary, secondary and tertiary health impacts in coastal zones of Australia under different emissions scenarios. It lists the most vulnerable groups and describes the size of the problem in terms of numbers of people affected and how immediate these threats are. Three emissions scenarios are considered: a business-as-usual (BAU) scenario, where emissions remain high and there is little to no global effort to reduce them, approximating the IPCC RCP 8.5 scenario; a medium emissions scenario, where there is some global effort to curtail emissions, approximately equivalent to the IPCC RCP 4.5 scenario; and a low emissions scenario, where early and concerted global effort is made to minimise emissions, approximating the IPCC RCP 2.6 scenario (IPCC 2013).

The table shows estimated (relative) likely contribution of climate change to case numbers now and in 20 years, 50 years and 100 years, with a range from 0 (no contribution) to 3 (considerable contribution), with 1 and 2 representing, respectively, some and significant contribution from climate change. The delays in the climate system between human carbon emissions and their effects on climate mean that even with heavily curtailed emissions from strong global action beginning today, in 20 years' time we will still be experiencing increased global warming based on past and present-day GHG emissions. In 50 years, the effects of today's emissions will be apparent. As the pathways become more complex and with increasing temporal delays between, say, an event and a likely outcome, it becomes more difficult to attribute an outcome to a particular climate exposure. Hence the estimates of the contribution from climate change to case numbers are less certain and probably overly diminished, the less direct the connection between climate and health outcome (secondary and tertiary effects).

These estimates also assume little change to the social and economic context, for example, a health system that operates similarly to the present day, with similarly effective drug therapies being available (e.g. antibiotics to treat bacterial infections) and unchanged food-handling practices. Of course, this may not be the case. It is possible that the tertiary effects of climate change – social and economic collapse, loss of food systems – may occur much sooner and at lower levels of warming than anticipated, and that medicines become less effective. Under such circumstances, some other health outcomes not considered here would become more significant for Australia's coastal zone populations, including potential for widespread malnutrition and untreatable infections.

Qualitative estimates are also provided in the table for how avoidable these adverse health effects might be through taking adaptive action to cope with climate change (as opposed to simply reducing emissions). These range from relatively simple actions, for example, improved housing stock to reduce deaths during heatwaves, to more complex actions that might include relocating agricultural industries, developing modified food crops, transforming agricultural practices and overhauling entire food distribution systems.

Health systems

Most analyses of potential future health impacts by necessity assume that the status quo continues for everything that is not climate, including population behaviour, features of the health system, vaccine availability and vector surveillance. Such potential changes remain unknown, and therefore assumptions must be made about future environmental, social and economic systems of the time, as well as the state of future technology and medical care. Climate change may change how these systems function in the future, and this too will affect how well we are able to respond to its health challenges.

A key driver of successful adaptation will be the capacity of health systems and infrastructure to cope with sudden increased demand and physical challenges during extreme events and to be restructured to cope with the changing patterns and priorities of population ill health over time. To be best prepared for the impacts of climate change, the health system needs to be flexible (in location, response, types of services), strategic in resource allocation (builds on existing services, prioritises vulnerable populations, is equitable) and robust (resilient infrastructure, consistent, sustainable workforce) (Blashki et al. 2011). While the health impacts from climate change are not new, they may be novel for a particular location or service, or the service may experience unprecedented numbers of cases. Quality surveillance and monitoring systems are therefore necessary to enable, for example, early detection and management of mosquito-borne disease in new areas or out of season (Blashki et al. 2011). Greater awareness of the health impacts of climate change and a better prepared health system is required to best respond to the changing health needs of the population (Burton et al. 2014).

Table 1: Summary narrative of the health impacts of climate change in Australian coastal zones (see notes on following page).

Health risk		Main climate drivers	Most vulnerable groups	Emissions scenario[1]	Contribution from climate change to case numbers (0-3)[2]				Ease of avoidance through adaptation (1-3)[2]
					Now	20 years	50 years	100 years	
Primary	Heat	Temperature Humidity	Older people, people with underlying chronic conditions, the socially isolated, very young children,outdoor or manual workers	BAU Medium Low	1	2 2 2	3 2–3 2	3 3 2	1
Primary	Injury and deaths from severe storms, cyclones, flooding, bushfires	Temperature Humidity Rainfall Wind	The socially disadvantaged, people living in poorer quality housing, people in remote areas, women and children seeking shelter	BAU Medium Low	1	2 2 2	3 2 1–2	3 3 1–2	2
Secondary	Vector-borne disease	Temperature Humidity Rainfall Sea level	Depends on the particular disease (e.g. Ross River virus disease may be more mild in children), people working/ recreating outdoors (greater exposure to mosquitoes)	BAU Medium Low	1-2	2 2 2	3 2–3 2	3 3 2	2
Secondary	Respiratory disease (asthma and allergy	Temperature Humidity Rainfall Sea level	People sensitised to aeroallergens / at risk of being sensitised, people with asthma	BAU Medium Low	0-1	1-2 1-2 1-2	2 2 1–2	3 2 1–2	2
Secondary	Mental illness	Temperature Humidity Rainfall	People living in rural and remote communities subject to drought / other environmental pressure, people on some medications	BAU Medium Low	0-1	1-2 1-2 1-2	2 2 1–2	2–3 2 1–2	2
Secondary	Gastroenteric disease	Temperature Humidity Rainfall	Young children, older people, people accommodated in institutions (e.g. hospitals, aged-care facilities), people in drought-prone or flood-prone areas	BAU Medium Low	0-1	1-2 1-2 1-2	2 2 1–2	2–3 2 1	2
Secondary	Obesity and non-communicable diseases	Temperature Humidity Rainfall	People who are economically disadvantaged, people who are less active, people who are overweight, people living in areas with poor public transport	BAU Medium Low	0-1	0-1 0-1 0-1	1 1 0–1	1–2 1–2 1	2
Tertiary	Displacement and social disruption, food system collapse	Temperature Humidity Rainfall Sea level	People who are economically disadvantaged / less able to relocate, people in communities sustained by fishing, people in communities sustained by agriculture	BAU Medium Low	0-1	1 1 1	2 2 1–2	3 2–3 1–2	3

Table 1 notes

[1] 'RCP' is the abbreviation for Representative Concentration Pathways, describing levels of radiative forcing used in climate change modelling (IPCC 2013). The emissions scenarios applied here are broadly representative of three scenarios depicted in the IPCC AR5 Report: RCP8.5 (business as usual), RCP4.5 (global mitigation, or the medium emissions scenario used here) and RCP2.6 (urgent, strong global mitigation, similar to what would be required following the Paris COP21 agreement to attempt to limit global warming to below 2 °C; the low emissions scenario given here).

[2] Contribution from climate change to case numbers is a relative qualitative assessment ranging from 0 (no contribution) to 3 (considerable contribution).

[3] Ease of avoidance through adaptation is a relative qualitative assessment ranging from 1 (easy) to 3 (difficult) and refers to both complexity and expense.

Vulnerable populations

Older people

The ageing of Australia's population not only has economic implications, but also affects population-wide vulnerability to many of the health impacts from climate change. Older people tend to be less mobile, and although they may be able to make some personal adjustments to their own behaviours to better cope with heat, they tend to have less personal capacity to escape from heat and other hazards (Banwell et al. 2012). This is particularly relevant to the communities in Australia where retirees are re-locating: the major regional cities on the coast. These cities are popular among older people as they can offer adequate health and other services. Increasing population and added health impacts on older people from climate change mean that these cities will come under increasing health pressure. Ageing populations in rural areas may be at particular risk due to inadequate and declining infrastructure (Horton et al. 2010).

Indigenous Australians

Indigenous people have lower life expectancy, higher child mortality, higher rates of chronic disease and higher rates of hospitalisation than non-Indigenous people (Centre for Epidemiology and Research 2012). Climate change may therefore have a disproportionately adverse effect on the health and wellbeing of Australia's Indigenous people, due to high rates of pre-existing chronic disease and social disadvantage. Some communities will be especially vulnerable because of their location (e.g. low-lying coastal areas in the tropics) and substandard infrastructure (e.g. drinking water, housing). Some communities that rely on traditional fisheries, such as in the Torres Strait, may have a primary food source put at risk through climate change impacts on species abundance and distribution and the associated damage to the health of coastal ecosystems. More generally, the impacts of climate change on the functioning and perceptions of and relationship to country could have detrimental effects on the mental and physical health of people in some communities (Green and Minchin 2014).

Extreme events, such as cyclones, may be more damaging in Indigenous communities in at-risk areas because of poorer quality housing and reduced transport and communications.

Other at risk groups

Other population groups may be at increased risk either because they are more marginalised, have an underlying chronic illness or because their employment or activities expose them to greater risk. More vulnerable and marginalised groups include people who are homeless or recent migrants or people who are poor or socially isolated. People who are already ill or less mobile or those who are very young are at heightened risk, while people who work outdoors and in some (non-air-conditioned) factories may be especially at risk as they undertake physical labour under increasing ambient temperatures. Emergency service personnel – as first responders to an extreme event such as a flood or a bushfire – are themselves at increased risk of harm from that event.

Conclusion

Coastal zones in Australia are especially vulnerable because of their rapidly growing (and ageing) urban populations, as well as their sometimes fragile environments.

Recent events have demonstrated that even in wealthy countries such as Australia, human health and wellbeing are vulnerable to climate change, and human systems can be severely affected. For example, during acute events such as the Melbourne heatwave in 2009 and the Queensland floods in 2011 there were immediate loss of life and damage to buildings and infrastructure, while 'slow burning' climate catastrophes such as drought can have a negative impact on long-term agricultural productivity and therefore on regional economies.

While increased capacity of health systems to cope with the rising pressures from climate change is needed for responding to health impacts at primary, secondary and tertiary categories, it is the capacity to respond to urgent primary effects that will be most obvious if insufficient.

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