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Climate and communicable disease

Discussion paper

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Executive summary

This report

Climate changes such as rising temperatures, changing rainfall patterns and extreme weather events are driving a shift in the types and geographic spread of communicable disease in Australia. This report explores the differences in climate sensitivity across communicable diseases, provides a framework for assessing priority communicable disease risks for Australia in 2050, and outlines research and analyses that will support Australia in further understanding priority risks. The insights presented in this report were compiled through desktop research and engagement with 57 experts across research, industry and government.

CSIRO has undertaken this project as part of the National Climate Risk Assessment, in partnership with the Department of Climate Change, Energy, the Environment and Water.

Mosquito borne diseases are the most climate sensitive.

Mosquito borne diseases are the most climate sensitive transmission type of communicable disease in Australia, with other vector borne diseases, food and water borne diseases, zoonotic diseases and environmental diseases also aggravated by multiple climate conditions (Figure 1).

Projected warming, rainfall and flooding changes are expected to aid the proliferation of mosquito borne diseases through shortened pathogen incubation periods, additional geographies with suitable habitats, and longer seasons for mosquito survival and reproduction. These changes will be experienced most in Australia's tropical (Northern Territory, northern Western Australia, and Queensland) and subtropical (northern New South Wales and southern Queensland) regions to 2050. Projected decreases in rainfall and increases in temperature in southern Australia (South Australia, southern New South Wales, southern Western Australia and Victoria) may also alter mosquito breeding and survival.

Figure 1: Summary of climate condition impacts on communicable disease transmission categories in Australia.

	CLIMATE CONDITION						
	Warming	**Rainfall**	**Flooding**	**Drought**	**Extreme storms, winds and cyclones**	**Bushfires and grassfires**	**Coastal erosion, shoreline change and ocean warming**
Vector borne – mosquito	Strongly aggravating	Strongly aggravating	Strongly aggravating	Moderately aggravating	Moderately aggravating	Moderately diminishing	Low/little climate sensitivity
Vector borne – other	Strongly aggravating	Moderately aggravating	Moderately diminishing	Moderately diminishing	Moderately diminishing	Moderately diminishing	Low/little climate sensitivity
Food and water borne	Strongly aggravating	Strongly aggravating	Moderately aggravating	Low/little climate sensitivity	Moderately aggravating	Low/little climate sensitivity	Moderately aggravating
Zoonotic	Moderately aggravating	Moderately aggravating	Moderately aggravating	Moderately aggravating	Moderately aggravating	Moderately aggravating	Moderately aggravating
Soil borne	Moderately aggravating	Strongly aggravating	Strongly aggravating	Low/little climate sensitivity	Strongly aggravating	Low/little climate sensitivity	Low/little climate sensitivity
Air borne	Moderately aggravating	No published climate-link	No published climate-link	Low/little climate sensitivity	Moderately aggravating	Low/little climate sensitivity	No published climate-link
Blood borne	No published climate-link	No published climate-link	No published climate-link	No published climate-link	No published climate-link	No published climate-link	No published climate-link
Sexually transmitted	No published climate-link	No published climate-link	No published climate-link	No published climate-link	No published climate-link	No published climate-link	No published climate-link

CLIMATE CONDITION IMPACT

No published climate-link	Moderately diminishing	Low/little climate sensitivity	Moderately aggravating	Strongly aggravating

Prioritising national investments in communicable disease resilience should consider climate sensitivity, disease severity, and the degree to which Australia's health systems are prepared to respond to outbreaks.

While surveillance and investment should remain focused on high incidence diseases, considering other criteria may help to direct additional investment and policy support towards communicable diseases that are currently under-monitored and under-evaluated based on their future risk profile.

Figure 2 presents a set of criteria that could be used to comprehensively assess future communicable disease risk in Australia. Preliminary assessments were made for 93 communicable diseases considered to be potential national health risks by 2050. By considering diseases that rate high or moderate across most criteria in the framework, and those most frequently raised as national 2050 risks of concern by engaged stakeholders, five were selected as example priority diseases. These were avian influenza, dengue, Japanese encephalitis, melioidosis and salmonellosis.

Figure 2: Criteria for assessing future communicable disease risks in Australia.

Climate sensitivity

Which diseases are most likely to increase in incidence or impact due to climate projections?

Transmissibility

Which diseases have high transmissibility and have the potential to rapidly spread?

Vaccine availability risk

Which diseases do not have effective vaccines that are available in Australia?

Disease severity

Which diseases result in severe illness or death in an infected person?

Impact on Indigenous health

To what extent do diseases disproportionately impact Aboriginal and Torres Strait Islander peoples?

Novelty in Australia

To what extent does Australia lack experience with responding to outbreaks of the disease?

Further research and analyses are required to sufficiently understand climate impacts on future communicable disease risks.

These needs fall under four broad objectives: understanding climate sensitivity, predicting disease incidence, projecting health and health system impacts, and monitoring, detection and surveillance (Figure 3). Activities that target these objectives can inform each other, ideally forming an ongoing cycle of data collection and insight gathering that ensures the nation's prioritisation of communicable disease risk is responsive to the ever-evolving global context.

Efforts in these areas will need to be tailored for key variables including disease, climate projections, epidemiology, and geography, and consider cultural, behavioural, economic, and genetic differences across communities. They should be undertaken with a One Health approach, and consider indirect factors like food security, mental wellbeing, social and environmental determinants of health, socioeconomic impacts, ecology, and population demographics.

While each of the examples presented in Figure 3 are important for informing comprehensive national risk assessments, those most frequently raised in stakeholder consultations, and with the potential to provide valuable short-term insights, fall under the monitoring, detection and surveillance objective. These could be considered nearer term priorities for establishing a strong foundation for the other activities.

Figure 3: Summary of further research and analysis needs grouped by objective.

Understanding climate sensitivity

- Pathogen sensitivity
- Vector sensitivity
- Zoonotic sensitivity
- Host sensitivity

Predicting disease incidence

- Modelling changing climate and disease

Projecting health and health system impacts

- Disease burdens
- Healthcare demand
- Economic costs

Monitoring, detection and surveillance

- Prioritisation framework rating validation
- Preliminary scoping of a national vulnerability, capacity and adaption assessment
- Early warning detection system needs assessment

Glossary

TERM	DEFINITION
Air borne disease	A disease transmitted through the air by droplets or dust particles. Within the context of this report, only communicable air borne diseases were considered.
Blood borne disease	A disease transmitted through contact with infected blood, blood products or body fluids.
Bushfires and grassfires	Uncontrolled fire event that occurs in vegetation, including forests, grasslands and shrublands.
Climate condition	Climate events and trends which have been derived from the climate hazard categories defined in the National Climate Risk Assessment Methodology.[1] For example, warming, rainfall and flooding.
Climate variables	Physical, chemical or biological variables that contribute to climate conditions. For example, land surface temperature, precipitation and sea surface temperature.
Coastal erosion, shoreline change and ocean warming	Includes impacts from sea level rise, changing tides, wave action, storm surge, high winds, marine heatwaves, coral bleaching, changes in biogeochemical cycles, ocean acidification, changes in ocean productivity, currents and overturning.
Communicable disease	An infectious disease that can be transmitted from one person, animal, or vector to a person.
Congenital disease	A disease that is transmitted from birthing parent to child during pregnancy, birth or breastfeeding.
Drought	A prolonged period of abnormally low rainfall. Includes broadscale changes in atmospheric circulation resulting in short (years) and long (decades) term drought, increases in aridity, and flash drought associated with high evapotranspiration.
Endemic	The consistent presence or usual prevalence of a disease within a specific population or geographic area, without significant fluctuation in its occurrence over time.
Epidemic	The widespread occurrence of a disease within a specific population or geographical area.
Extreme storms, winds and cyclones	Intense weather events characterised by high winds, heavy rainfall (and flash flooding), thunderstorms, storm surges and cold fronts.
Flooding	The overflow of water onto land caused by abnormally heavy rainfall. Includes pluvial (flash) and fluvial (riverine) floods, soil moisture and river/dam levels.
Food borne disease	A disease caused by the ingestion of contaminated food. Within the context of this report, only communicable food borne diseases were considered.
Infectious disease	A disease caused by an infectious agent or pathogen.
One Health	An integrated multi-sector and transdisciplinary approach to health that considers the interconnected relationships between human, animal, plant and environmental health.
Pathogen	An organism that causes disease in its host (e.g., bacteria, virus, parasite, fungi).
Sexually transmitted disease	A disease transmitted through sexual contact.
Soil borne disease	A disease acquired through exposure to a pathogen that lives in soil or passes through soil. Within the context of this report, only communicable soil borne diseases were considered.
Vectorial capacity	A measure of the potential of an insect population to transmit disease, similar to the daily reproductive number (R_0 value) of other infectious diseases.
Vector borne disease	A disease transmitted to humans or other animals by vectors (insects that can transmit infectious pathogens, e.g., mosquitoes and ticks). Many vector borne diseases are also zoonotic as they originate in animals or involve animals as intermediate hosts.
Water borne disease	A disease caused by the ingestion of contaminated water. Within the context of this report, only communicable water borne diseases were considered.
Zoonotic disease	A disease caused by a pathogen that has crossed species from an animal to a human. Zoonotic diseases can be transmitted directly through animals or indirectly through contaminated sources. Within the context of this report, zoonotic diseases that rely on vectors for transmission to humans are considered vector borne diseases.
Zoonotic spillover	A cross-species transmission event where a pathogen, which originated in an animal, moves from an animal to a human. Spillover generally involves a source host, intermediate host and recipient host.[2]

1 Australia Government Department of Climate Change, Energy, the Environment, and Water (2023) National Climate Risk Assessment Methodology. <https://www.dcceew.gov.au/sites/default/files/documents/national-climate-risk-assessment-methodology.pdf> (accessed 16 May 2024).

2 Ellwanger JH, Chies JA (2021) Zoonotic spillover: Understanding basic aspects for better prevention. Genetics and Molecular Biology 44(1 Suppl), 1–18.

1 Introduction

Communicable diseases cause significant impacts on individual health, public health and health systems in Australia. For example, the total health system spending in response to COVID-19 in Australia from 2019 to 2022 was $47.9 billion, and campylobacteriosis is estimated to cost Australia $365 million per year.[3] Aside from the direct costs associated with mortality, morbidity, and disease prevention and treatment, communicable diseases also cause productivity loss and can lead to the onset of chronic disease.[4]

Economic and social costs associated with communicable disease are disproportionately felt by priority populations including Aboriginal and Torres Strait Islander people, rural and remote communities, young children, pregnant people, the elderly and immunocompromised people.[5] The spread and incidence of communicable diseases also differ by geography, season and climate in Australia, further contributing to their varied impacts.[6]

Climate changes have the potential to exacerbate the impacts of communicable diseases by creating more favourable conditions that increase pathogen virulency, change human behaviour, and increase the geographic range, seasonality and intensity of disease transmission.[7] By 2050, changes in Australia's climates are projected to increase the incidence and severity of communicable diseases.[8]

There are limited Australian-specific analyses exploring the link between climate and communicable diseases and comparing the future risks that these relationships could pose. This discussion paper examines climate sensitivity of communicable disease, proposes criteria that could be used to prioritise and assess communicable disease risks in Australia, and outlines research and analyses that will support Australia in further understanding priority risks.

3 Australian Institute of Health and Welfare (2023) Health system spending on the response to COVID-19 in Australia 2019–20 to 2021–22. <https://www.aihw.gov.au/reports/health-welfare-expenditure/health-system-spending-on-the-response-to-covid-19/contents/spending-by-area> (accessed 14 June 2024); Australia National University (2022) The annual cost of foodborne illness in Australia. <https://www.foodstandards.gov.au/sites/default/files/publications/Documents/ANU%20Foodborne%20Disease%20Final%20Report.pdf> (accessed 14 May 2024).

4 Crosland et al. (2019) The economic cost of preventable disease in Australia: a systematic review of estimates and methods. Australian and New Zealand Journal of Public Health 43 (5), 484–495; O'Connor et al. (2006) Emerging Infectious Determinants of Chronic Diseases. Emerging Infectious Diseases 12(7), 1051–1057.

5 Australian Institute of Health and Welfare (2021) Significant improvements in the burden of disease experienced by Aboriginal and Torres Strait Islander people. <https://www.aihw.gov.au/news-media/media-releases/2021-1/october/indigenous-burden-of-disease> (accessed 15 April 2024).

6 Australian Department of Health (2021) National Preventive Health Strategy. <https://www.health.gov.au/sites/default/files/documents/2021/12/national-preventive-health-strategy-2021-2030_1.pdf> (accessed 14 June 2024).

7 Semenza JC, Rocklov J, Ebi KL (2022) Climate Change and Cascading Risks from Infectious Disease. Infectious Diseases and Therapy 11(4), 1371–1390.

8 Mora et al. (2022) Over half of known human pathogenic diseases can be aggravated by climate change. Nature Climate Change 12, 869–875.

2 Climate sensitive communicable diseases

The mechanisms and magnitude of climate impacts on communicable disease (climate sensitivity) vary significantly across climate conditions, pathogens, geography and demography.

Given the large number of communicable disease pathogens and complex nature of their relationship to climate, Figure 4 attempts to summarise climate sensitivity to key climate conditions by grouping diseases by forms of transmission. The ratings in this figure were informed by Australian-relevant literature and stakeholder consultation. To reflect Australian-specific climate sensitivities as best as possible, the ratings also factored in Australia's infrastructure (including water supply and sanitation standards, and healthcare system) that reduce certain disease transmission risks compared to low- and middle-income countries.

These ratings did not consider the secondary impact of climate on disease, for example where a climate condition may exacerbate the symptoms of a communicable disease or where extreme weather events may cause infrastructure destruction that disrupt healthcare and emergency services.

Mosquito borne diseases are the most climate sensitive transmission type of communicable disease in Australia, with other vector borne diseases, food and water borne diseases, zoonotic diseases, and soil borne diseases also aggravated by multiple climate conditions. While air borne diseases are aggravated by some climate conditions, the impact is indirect. For example, multiple climate conditions can increase the spread of air borne disease due to increased congregation of people inside, poor ventilation and increased air conditioning use.[9] This section provides further discussion of the transmission types that were determined to have high and direct climate sensitivity through stakeholder consultation and literature review.

Figure 4: Summary of climate condition impacts on communicable disease transmission categories in Australia.

	CLIMATE CONDITION						
	Warming	Rainfall	Flooding	Drought	Extreme storms, winds and cyclones	Bushfires and grassfires	Coastal erosion, shoreline change and ocean warming
Vector borne – mosquito	Strongly aggravating	Strongly aggravating	Strongly aggravating	Moderately aggravating	Moderately aggravating	Moderately diminishing	Low/little climate sensitivity
Vector borne – other	Strongly aggravating	Moderately aggravating	Moderately diminishing	Moderately diminishing	Moderately diminishing	Moderately diminishing	Low/little climate sensitivity
Food and water borne	Strongly aggravating	Strongly aggravating	Moderately aggravating	Low/little climate sensitivity	Moderately aggravating	Low/little climate sensitivity	Moderately aggravating
Zoonotic	Moderately aggravating	Moderately aggravating	Moderately aggravating	Moderately aggravating	Moderately aggravating	Moderately aggravating	Moderately aggravating
Soil borne	Moderately aggravating	Strongly aggravating	Strongly aggravating	Low/little climate sensitivity	Strongly aggravating	Low/little climate sensitivity	Low/little climate sensitivity
Air borne	Moderately aggravating	No published climate-link	No published climate-link	Low/little climate sensitivity	Moderately aggravating	Low/little climate sensitivity	No published climate-link
Blood borne	No published climate-link	No published climate-link	No published climate-link	No published climate-link	No published climate-link	No published climate-link	No published climate-link
Sexually transmitted	No published climate-link	No published climate-link	No published climate-link	No published climate-link	No published climate-link	No published climate-link	No published climate-link

CLIMATE CONDITION IMPACT

No published climate-link	Moderately diminishing	Low/little climate sensitivity	Moderately aggravating	Strongly aggravating

9 He et al. (2023) Viral respiratory infections in a rapidly changing climate: the need to prepare for the next pandemic. EBioMedicine 93(104593); Huan Minh Tran et al. (2023) The impact of air pollution on respiratory diseases in an era of climate change: A review of the current evidence. Science of The Total Environment 898, 1–7.

Vector borne diseases

The most climate sensitive communicable diseases in Australia are vector borne; with warming, rainfall and flooding the main aggravating climate conditions for vectors (e.g., mosquitoes and ticks).[10] The relationship between climate variables and mosquito borne disease is particularly complex because disease incidence is impacted by species-specific factors, such as vector seasonality, geographic distribution, survival rates, biting rates, pathogen incubation periods and vectorial capacity.[11]

Warming can have significant impacts on mosquitoes, including extended transmission seasons and geographical range expansion.[12] Warming can also impact the survival of mosquitoes and the pathogens they transmit, as they have specific temperature ranges for development. Meta-analysis of the transmission of 10 viruses (including Ross River, Murray Valley encephalitis and dengue) in 15 mosquito species (including *Culex*, *Anopheles* and *Aedes* species, all found in Australia) show precise temperature boundaries. Transmission peaks at 23–29°C and drops to zero above 32–38°C, with malaria and Ross River virus peaking at lower optimal temperatures (25–26°C) than Zika or dengue (29°C).[13]

Warmer climates also impact specific vector-pathogen mechanisms. For example, increased temperature can shorten the time between a vector's exposure to a pathogen and becoming infectious (extrinsic incubation period). In *Aedes aegypti* and *albopictus* mosquitoes (species that carry dengue), this extrinsic incubation period reduces from 15 days to 6.5 days as mean temperature increases from 25°C to 30°C.[14] General temperature related increases in dengue incidence is greater in tropical monsoon climate zones and humid subtropical climate zones; conditions found predominantly in Queensland.[15] By 2050, Australia's tropical monsoon zones are projected to expand by 50%, which may increase dengue risk over greater geographical areas.[16]

Predicted increases in the frequency of heavy rainfall and flooding events is likely to increase the incidence of some vector borne diseases by increasing the extent and longevity of larval mosquito habitats, expanding geographical range and boosting populations.[17] The Western Australian government releases warnings most years regarding the heightened risk of mosquito borne diseases, including Ross River virus, Murray Valley encephalitis and Barmah Forest virus, due to periods of non-seasonal and increased rainfall and flooding creating ideal mosquito breeding conditions and lengthening disease risk periods.[18]

10 Rocklov J, Dubrow R (2020) Climate change: an enduring challenge for vector-borne disease prevention and control. Nature Immunology 21, 479–483.

11 Colón-González et al. (2021) Projecting the risk of mosquito-borne diseases in a warmer and more populated world: a multi-model, multi-scenario intercomparison modelling study. The Lancet Planetary Health 5(7), e404–e414.

12 Colón-González et al. (2021) Projecting the risk of mosquito-borne diseases in a warmer and more populated world: a multi-model, multi-scenario intercomparison modelling study. The Lancet Planetary Health 5(7), e404-e414.; Russell RC (2009) Mosquito-borne disease and climate change in Australia: time for a reality check. Australian Journal of Entomology 48(1), 1–7.

13 Mordecai et al. (2019) Thermal biology of mosquito-borne disease. Ecology Letters 22(10), 1690–1708.

14 Chan M, Johansson MA (2012) The incubation periods of dengue viruses. Public Library of Science One 7(11), e50972.

15 Australian Bureau of Meteorology (2005) Climate classification maps. <http://www.bom.gov.au/climate/maps/averages/climate-classification/?maptype=kpngrp> (accessed 16 May 2024).

16 Crosbie et al. (2012) Changes in Koppen-Geiger climate types under a future climate. Hydrology and Earth Systems Science Discussions 9(6), 7415–7440.

17 Harley et al. (2011) Climate change and infectious diseases in Australia: Future prospects, adaptation options, and research priorities. Asia Pacific Journal of Public Health 23(2 suppl), 54S–66S.

18 WA Department of Health (2023) New Murray Valley encephalitis case prompts mosquito warning for the Kimberley <https://www.health.wa.gov.au/Media-releases/2023/July/New-Murray-Valley-encephalitis-case-prompts-mosquito-warning-for-the-Kimberley> (accessed 17 May 2024).

For many mosquito species, high temperatures combined with increased rainfall (i.e., high humidity) typically increase mosquito population development, survival, and biting rates; expanding their suitable habitats, extending reproductive seasons, and altering migration patterns.[19] The 2023 Intergovernmental Panel on Climate Change Sixth Assessment Report reported increasing global average temperatures, relative humidity, and rainfall, are making larger geographic areas more suitable for the increased transmission and vectorial capacity of mosquito borne diseases.[20] This is likely to be most relevant to mosquito borne disease transmissions in northern Australia (Northern Territory, northern Queensland and northern Western Australia). In these areas, expected temperature increases and changes to rainfall patterns are likely to extend seasonal wetlands (impacting diseases like Murray Valley encephalitis) and create longer seasons of peak vector activity (impacting diseases like Ross River virus).[21] In contrast, areas of southern Australia (South Australia, southern New South Wales and northern Victoria) are projected to see a decrease in average rainfall and increase in temperature, which may see a decrease in transmission due to a reduction in suitable larval habitats and higher temperatures compromising adult mosquito survival.[22]

Less literature exists around the climate sensitivity of other vectors. However, it has been proposed that long periods of moderate rainfall significantly increase tick survival, spread and population size; and high severity in rainfall can wash away ticks, eggs and larvae, thereby reducing their population.[23] While this indicates a strong aggravating impact for some climate conditions, especially in tropical settings, Australian health systems are comparatively well equipped to manage common tick diseases (predominantly rickettsial infections).[24]

19 Rocklov J, Dubrow R (2020) Climate change: an enduring challenge for vector-borne disease prevention and control. Nature Immunology 21, 479–483.

20 IPCC (2023) Summary for Policymakers. Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Geneva, Switzerland.

21 Russell RC (2009) Mosquito-borne disease and climate change in Australia: time for a reality check. Australian Journal of Entomology (48)1, 1–7.

22 Russell RC (2009) Mosquito-borne disease and climate change in Australia: time for a reality check. Australian Journal of Entomology (48)1, 1–7.

23 Ma et al. (2022) Climate change drives the transmission and spread of vector-borne diseases: An ecological perspective. Biology 11(11), 1628.

24 Stewart et al. (2019) The epidemiology and clinical features of rickettsial diseases in North Queensland, Australia: Implications for patient identification and management. Public Library of Science Neglected Tropical Diseases 13(7).

Food and water borne diseases

Several climate conditions increase the risk of food and water borne diseases in Australia. Warming can increase the growth, virulence and survival of food and water borne pathogens. For example, warming is associated with the virulence of water borne *vibrio parahaemolyticus* bacteria that causes gastroenteritis,[25] and increases in food borne salmonellosis incidence.[26] Positive correlations have been found in most Australian States and Territories regarding temperature and salmonellosis notifications, with a 1°C mean temperature increase associated with a 3.4% increase in salmonellosis cases the following month.[27] In contrast, some food and water borne diseases survive best in cooler conditions, like rotavirus. For each 1°C rise in mean temperature, rotavirus hospital admissions decrease by 2–5%.[28]

Recreational exposure to water borne disease, which is the most common cause of Australian outbreaks (as opposed to exposure from drinking water), is also correlated with warming.[29] Both salmonellosis and campylobacteriosis cases peak in spring and summer, due to higher ambient temperatures and higher rates of recreational water activities.[30]

Rainfall also significantly impacts the transmission of several food and water borne diseases. Outbreaks of cryptosporidiosis, salmonellosis and campylobacteriosis have strong correlations with seasonal rainfall.[31] Further, heavy rainfall facilitates the leaching of pathogens into water bodies and the contamination of water supplies.[32] Rainfall in combination with other climate variables also changes pathogen dynamics. For example, heavy rainfall and ocean warming reduces coastal water salinity, facilitating rapid growth and virulent mutations of *vibrio parahaemolyticus* in oysters and mussels.[33] Further, the 2018 Australian rockmelon listeriosis outbreak (resulting in 22 cases and 7 deaths) has been attributed to heavy rainfall and dust storms, which enabled disease-causing levels of bacteria despite above-average sanitation practices.[34]

Extreme weather events can also increase pathogen presence in water and agricultural systems. In recent years, storms and bushfires have damaged water infrastructure causing widespread contamination.[35] Fire related vegetation loss in water catchments also makes soil vulnerable to erosion, increasing the long-term possibility of contaminated runoff entering water supplies.[36] Further, floodwater can transport bacteria to growing crops and processing facilities and has been implicated in *Escherichia coli* and *Salmonella* contamination of vegetable crops.[37]

25 Zhang et al. (2023) The impact of global warming on the signature virulence gene, thermolabile hemolysin, of Vibrio parahaemolyticus. Microbiology Spectrum 11(6), e01502–01523.

26 Davis et al. (2022) Climate variability and change are drivers of salmonellosis in Australia: 1991 to 2019. Science of The Total Environment 843(156980).

27 David et al. (2022) Climate variability and change drivers of salmonellosis in Australia: 1991 to 2019. Science of The Total Environment 843(15), 156980.

28 Harley et al. (2011) Climate change and infectious diseases in Australia: Future prospects, adaptation options, and research priorities. Asia Pacific Journal of Public Health 23(2 suppl), 54S–66S.

29 Dale et al. (2010) Reported waterborne outbreaks of gastrointestinal disease in Australia are predominantly associated with recreational exposure. Australian and New Zealand Journal of Public Health 34(5), 527–530.

30 Harley et al. (2011) Climate change and infectious diseases in Australia: Future prospects, adaptation options, and research priorities. Asia Pacific Journal of Public Health 23(2 suppl), 54S–66S.

31 Harley et al. (2011) Climate change and infectious diseases in Australia: Future prospects, adaptation options, and research priorities. Asia Pacific Journal of Public Health 23(2 suppl), 54S-66S; Semenza et al. (2012) Climate Change Impact Assessment of Food- and Waterborne Diseases. Critical Review Environmental Science and Technology 42(8), 857–890.

32 Ghazani et al. (2018) Temperature variability and gastrointestinal infections: A review of impacts and future perspectives. International Journal of Environmental Research and Public Health 15(4), 766.

33 Burge et al. (2014) Climate Change influences on marine infectious diseases: implications for management and society. Annual Review of Marine Science 6, 249–277; Scanes et al. (2023) Emerging diseases in Australian oysters and the challenges of climate change and uncertain futures. Australian Zoologist 15.

34 NSW Government Department of Primary Industries (2018) Biosecurity and Food Safety: Listeria Outbreak Investigation. NSW Government Department of Primary Industries, Biosecurity and Food Safety. <https://www.foodauthority.nsw.gov.au/sites/default/files/_Documents/foodsafetyandyou/listeria_outbreak_investigation.pdf> (accessed 12 June 2024).

35 Calyton R (2020) Melbourne suburbs served by Yarra Valley Water, South East Water warned to boil water after wild weather. ABC News, 28 August.

36 Landow S (2020) Drinking water under threat: water contamination risks this bushfire season. UNSW Sydney, Newsroom.

37 Singh SP (2023) Flooding adversely affects fresh produce safety. Microbiology Australia 44(4), 185–189.

Zoonotic diseases

Zoonotic pathogens have the potential to be aggravated by all climate conditions. A major driver of zoonotic disease in Australia is the reduction in habitable conditions for wildlife species and biodiversity loss, which alters interaction patterns with humans and other animals. For example, in subtropical Australia, climate-driven food shortages have driven bats to migrate and feed in agricultural areas, potentially infecting horses and pigs that come into contact with humans.[38] This mechanism has facilitated Hendra virus transmission in Queensland and New South Wales.[39] As an indication of how these drivers are spreading south; Hendra virus was reported for the first time during 2019 in southern New South Wales, despite its endemicity in Queensland.[40]

Animals that act as intermediary pathogen hosts for vector borne diseases will also be impacted by climate change, demonstrating the interaction between different disease transmission types and ecology. Seasons of high temperatures and rainfall boost vegetation for the animal hosts of Ross River virus and Barmah Forest virus (marsupials such as possums, kangaroos and wallabies).[41] In contrast, longer and more intense fire seasons will instead limit the food sources of animal hosts, lead to biodiversity loss, and reduce the ability of mosquito vectors to spread the pathogen.[42] For example, Japanese encephalitis is thought to have emerged in Australia because of drought conditions in 2015–2019 followed by flooding events in 2020; drought conditions brought together wetland bird populations (the amplifying host) with mosquito vectors around shrinking water reserves, and subsequent flooding events created optimal breeding conditions for both species.[43]

Soil borne diseases

Rainfall and flooding events strongly aggravate the transmission of soil borne diseases. Up to 25% of the bacteria emitted from soil globally are attributed to rain and floods, with excess water bringing bacteria to the surface for increased exposure.[44] In Australia, 81% of melioidosis cases occur during the wet season and more severe symptoms are associated with heavier rainfall.[45] Increases in melioidosis cases are also associated with storms and cyclone events, which may disperse pathogens to previously unaffected regions.[46]

Warming also aggravates soil borne diseases, with higher temperatures providing a more favourable environment for the survival of anthrax spores in soil.[47] Incidence of soil-transmitted helminthiases and strongyloidiasis are also expected to increase with warming, as higher temperatures accelerate the development of parasitic worms that cause these diseases.[48]

38 Eby et al. (2023) Pathogen spillover driven by rapid changes in bat ecology. Nature 613, 340–344.

39 Australian Government Department of Agriculture, Fisheries and Forestry (2023). Hendra virus. < https://www.agriculture.gov.au/biosecurity-trade/pests-diseases-weeds/animal/hendra-virus#:~:text=Since%201994%2C%20Hendra%20virus%20(HeV,New%20South%20Wales%20(NSW)> (accessed 17 June 2024).

40 Yuen et al. (2021) Hendra virus: Epidemiology dynamics in relation to climate change, diagnostic tests and control measures. One Health 12, 100207.

41 Kain MP et al. (2021) Physiology and ecology combine to determine host and vector importance for Ross River virus. eLife 10(e67018), 1–40.

42 Harley et al. (2011) Climate change and infectious diseases in Australia: Future prospects, adaptation options, and research priorities. Asia Pacific Journal of Public Health 23(2 suppl), 54S–66S.

43 Purnell, C (2022) The role of waterbirds in Australia's 2022 Japanese Encephalitis outbreak Unpublished – a rapid synthesis. Birdlife Australia, Carlton.

44 Joung YS, Ge Z, Buie CR (2017) Bioaerosol generation by raindrops on soil. Nature Communications 14668.

45 Chakravorty A, Heath CH (2019) Melioidosis: An updated review. Australian Journal of General Practice 48(5); Currie et al. (2000) Endemic Melioidosis in Tropical Northern Australia: A 10-year prospective study and review of the literature. Clinical Infectious Diseases 31(4), 981–986; Currie BJ, Jacups SP (2003) Intensity of Rainfall and Severity of Melioidosis, Australia. Emerging Infectious Diseases 9(12), 1538–1542.

46 NT Health Department (2021) Melioidosis Fact Sheet. <https://health.nt.gov.au/__data/assets/pdf_file/0006/1303386/melioidosis-nt-health-factsheet.pdf> (accessed 30 April 2024).

47 Walsh MG, Smalen AW, Mor SM (2018) Climatic influence on anthrax suitability in warming northern latitudes. Nature Scientific Reports 8(9269).

48 Weaver HJ, Hawdon JM, Hoberg EP (2010) Soil-transmitted helminthiases: implications of climate change and human behaviour. Trends in Parasitology 26(12), 574–581.

3 Assessing priority communicable disease risks in 2050

Australian surveillance systems

Australia has a range of existing national, state and territory surveillance programs for tracking communicable diseases across human, animal and environmental health.[49] The National Notifiable Disease Surveillance System (NNDSS) coordinates national surveillance by collecting and tracking incidence, trends, and several impact metrics for diseases that present risks to public health.[50] In 2023, the most frequently reported cases of communicable diseases in Australia were for COVID-19 (864,564 reports), influenza (288,989), and respiratory syncytial virus (128,013).[51] While the specific pathogens may vary, it is likely that these types of respiratory viruses will continue to cause seasonal epidemics and be among the most frequently reported diseases in Australia by 2050.

Diseases tracked by the NNDSS are determined using an established decision-making protocol,[52] however, this process is not designed to be used as a risk assessment tool. In the context of building national resilience to future communicable disease risks, pairing surveillance system insights with information on climate impacts, disease severity, and health system preparedness for both notifiable and non-notifiable diseases is required.

Prioritisation framework

This section introduces a framework that investigates a range of criteria for determining future communicable disease risks (Table 1). This may help to direct additional investment and policy support towards communicable diseases that are under-monitored and under-evaluated based on their future risk profile. The framework may also support the early assessment of emerging diseases and pathogens that have not previously been encountered globally.

The proposed framework builds on existing national and international prioritisation frameworks,[53] by (i) focussing on communicable diseases, (ii) considering a future (2050) state rather than exclusively looking at present day risks, and (iii) incorporating Australian-specific criteria. Each criterion is assessed independently of the others to highlight their influence on potential priority diseases; however, it would be reasonable to combine and weight them based on the prioritisation objectives of a given stakeholder group.

A total of 93 communicable diseases were assessed through the framework (see Appendix A.2). These diseases were identified by combining national, state and territory notifiable disease registers, notable climate health literature, and stakeholder insights, to arrive at a comprehensive list of potential risks to Australia in 2050. These preliminary assessments focus on the direct health and health system impacts of each disease and were developed to aid discussion. More comprehensive analysis (as outlined in Section 4) for each disease-criterion combination would be required to support government decision making.

49 Australian Government (2024) National Notifiable Diseases Surveillance System. <https://www.health.gov.au/our-work/nndss#about-the-nndss;%20https://nahis.animalhealthaustralia.com.au/public.php;%20https://www.agriculture.gov.au/abares/research-topics/social-sciences/making-general-surveillance-work/listing-stocktake-general-surveillance-initiatives> (accessed 17 May 2024); Wildlife Health Australia (2024) Our work: Surveillance. <https://wildlifehealthaustralia.com.au/Our-Work/Surveillance> (accessed 11 June 2024).

50 Australian Government Department of Health and Aged Care (2023) National Communicable Disease Surveillance Dashboard. <https://nindss.health.gov.au/pbi-dashboard/> (accessed 11 June 2024).

51 Australian Government Department of Health and Aged Care (2023) National Communicable Disease Surveillance Dashboard. <https://nindss.health.gov.au/pbi-dashboard/> (accessed 11 June 2024).

52 Australian Government Department of Health and Aged Care (2015) Protocol for making a change to the National Notifiable Diseases List (NNDL) in Australia. <https://www.health.gov.au/sites/default/files/documents/2022/06/protocol-for-making-a-change-to-the-national-notifiable-diseases-list-in-australia.pdf> (accessed 11 June 2024).

53 Australian Government Department of Health and Aged Care (2015) Protocol for making a change to the National Notifiable Diseases List in Australia. Canberra, Australia; United Nations Framework Convention on Climate Change (2021) Handbook on Vulnerability and Adaptation Assessment, Chapter 8: Human Health. Bon, Germany; World Health Organisation (2017) Methodology for Prioritizing Severe Emerging Diseases for Research and Development. Geneva, Switzerland; World Health Organisation (2021) Climate Change and Health Vulnerability and Adaptation Assessment. Geneva, Switzerland.

Table 1: Criteria for identifying priority communicable disease risks for further analysis.

CRITERIA	ASSESSMENT CATEGORIES	COUNT OF DISEASES RATED 'HIGH'	EXAMPLES OF DISEASES RATED 'HIGH'
Climate sensitivity Which diseases are most likely to increase in incidence or impact due to climate projections?	**Low**: No evidence or a diminishing/protective link **Moderate**: Low to moderate aggravating link **High**: Moderate to strong aggravating link	60	Dengue Japanese encephalitis Melioidosis Ross River virus Salmonellosis
Transmissibility Which diseases have high transmissibility and have the potential to rapidly spread?	**Low**: No or low potential for disease to cause widespread transmission **Moderate**: Disease has previously caused, or has the potential to cause, an epidemic **High**: Disease has previously caused multiple epidemics or a pandemic	23	COVID-19 Cryptosporidiosis Dengue Influenza Salmonellosis
Vaccine availability risk Which diseases do not have effective vaccines that are available in Australia?	**Low**: Effective vaccine available and a national program dedicated to access in Australia **Moderate**: Vaccine available but ineffective or low acceptability/uptake in Australia **High**: No vaccine available either on the market or approved for use in Australia	63	Avian influenza Barmah Forest virus Hendra virus Murray Valley encephalitis Ross River virus
Disease severity Which diseases result in severe illness or death in an infected person?	**Low**: Short-term illness, complete recovery in most cases, or case-fatality <1% **Moderate**: Long-term illness requiring treatment, long-term disability likely, or case-fatality 1-10% **High**: Severe and long-term illness or case fatality 10-100%	22	Australian bat lyssavirus Avian influenza Hendra virus Murray Valley encephalitis Viral haemorrhagic fevers (e.g., Ebola, Lassa and Marburg viruses)
Impact on Indigenous health To what extent do diseases disproportionately impact Aboriginal and Torres Strait Islander peoples?	**Low:** Disease severity or disease rates for Aboriginal and Torres Strait Islander peoples are similar to disease severity or rates for non-Indigenous Australians **Moderate:** Disease severity or disease rates are somewhat higher for Aboriginal and Torres Strait Islander peoples **High**: Disease severity or disease rates are significantly higher, or the disease nearly exclusively impacts Aboriginal and Torres Strait Islander peoples	12	Chlamydial trachomatis infection (trachoma) HTLV-1 Melioidosis Pneumococcal disease (*Streptococcus pneumoniae*) Soil-transmitted helminthiases and strongyloidiasis
Novelty in Australia To what extent does Australia lack experience with responding to outbreaks of the disease?	**Low**: Disease is endemic in Australia or Australia has experience with addressing widespread outbreaks of this disease **Moderate**: Australia has experience with addressing small outbreaks of this disease (or very localised experience) **High**: Australia does not have experience dealing with widespread outbreaks of this disease	12	Chikungunya Middle East respiratory syndrome (MERS) infection Viral haemorrhagic fevers (e.g., Ebola, Lassa and Marburg viruses) West Nile/Kunjin virus Yellow fever

Example priority diseases

Five example priority diseases were selected by considering diseases that rate high or moderate across most criteria in the framework (see Table 2). These diseases were also the most frequently raised as 2050 disease risks of national concern by consulted stakeholders. The following summaries seek to outline the drivers, impacts and magnitude of these potential priority disease risks for 2050.

Table 2: Prioritisation framework assessment ratings for example priority diseases

	CLIMATE SENSITIVITY	TRANSMISSIBILITY	VACCINE AVAILABILITY RISK	DISEASE SEVERITY	IMPACT ON INDIGENOUS HEALTH	NOVELTY IN AUSTRALIA
Avian influenza (HPAI H5N1)	High	Moderate	High	High	Low	High
Dengue	High	High	Moderate	Moderate	Moderate	Moderate
Japanese encephalitis	High	Moderate	Moderate	High	Moderate	Moderate
Melioidosis	High	Moderate	High	Moderate	High	Moderate
Salmonellosis	High	High	High	Low	Moderate	Low

Avian influenza (HPAI H5N1)

Avian influenza is a zoonotic disease caused by strains of type A influenza. The Highly Pathogenic Avian Influenza (HPAI) H5N1 strain is transmitted by birds, for which it is highly contagious and deadly. HPAI H5N1 can infect a range of species including humans, pigs, cats and dairy cattle. While transmission from birds to humans is rare and relies on close contact, it can cause serious viral pneumonia.[54]

Between 1 January 2003 and 3 May 2024, 889 human cases of HPAI H5N1 were reported to the World Health Organization; these incidents span 23 countries and had a 52% fatality rate.[55] In March 2024, the first human case of H5N1 was detected in Australia, relating to a returned traveller who acquired the infection in India.[56] In April 2024, the first case of cattle-to-human transmission was recorded in the United States of America, further demonstrating the virus' changing epidemiology.[57]

Recent global surges of HPAI pandemics in bird populations have paralleled climate change patterns.[58] In Australia, wild waterbirds – the natural reservoir for avian influenza – move according to drought and rain cycles and transmit the virus to domesticated birds in the industrialised poultry sector.[59] As a result, avian influenza has been linked to irregular, non-seasonal rainfall, which causes shifts in waterbird breeding and creates temporary wetlands.[60] For example, poultry outbreaks of non-H5N1 avian influenza surge after periods of high rainfall in southeastern Australia (the Murray-Darling Basin and southern Queensland).[61]

No human vaccines are available for HPAI H5N1 (or other avian influenza strains). While the public health risk in Australia is low, occupational groups like poultry workers have a higher risk of exposure.[62]

54 New South Wales Government (2023) Avian Influenza ("bird flu") fact sheet. New South Wales Health. <https://www.health.nsw.gov.au/Infectious/factsheets/Pages/avian-influenza.aspx> (accessed 15 May 2024).

55 Food and Agriculture Organisation of the United Nations (2024) Global avian influenza viruses with zoonotic potential situation update. United Nations, Rome <https://www.fao.org/animal-health/situation-updates/global-aiv-with-zoonotic-potential/en> (accessed 15 May 2024); World Health Organisation (2024) Cumulative number of confirmed human cases for avian influenza A(H5N1) reported to WHO, 2003-2024, 3 May 2024. <https://www.who.int/publications/m/item/cumulative-number-of-confirmed-human-cases-for-avian-influenza-a(h5n1)-reported-to-who--2003-2024-3-may-2024> (accessed 23 May 2024).

56 Victoria Department of Health (2024) Human case of avian influenza (bird flu) detected in returned traveller to Victoria. <https://www.health.vic.gov.au/health-advisories/human-case-of-avian-influenza-bird-flu-detected-in-returned-traveller-to-victoria?utm_source=social&utm_medium=twitter&utm_campaign=CHO_Advisory&utm_content=Bird_Flu> (accessed 23 May 2024).

57 World Health Organisation, Disease Outbreak News (2024) Avian Influenza A(H5N1) - United States of America, 28 March 2024. World Health Organisation. <https://www.who.int/emergencies/disease-outbreak-news/item/2024-DON512> (accessed 15 May 2024).

58 Prosser et al. (2023) Climate change impacts on bird migration and highly pathogenic avian influenza. Nature Microbiology 8, 2223–2225.

59 CSIRO (2022) Understanding bird flu dynamics in Australia. CSIRO, Australia. <https://www.csiro.au/en/news/all/articles/2022/september/understanding-bird-flu-dynamics-in-australia> (accessed 12 June 2024); Gilbert M, Slingenbergh J, Xiao X (2009) Climate change and avian influenza. Revue scientifique et technique 27(2), 459-466.

60 Ferenczi M, Beckmann C, Klaassen M (2021) Rainfall driven and wild-bird mediated avian influenza virus outbreaks in Australian poultry. BMC Veterinary Research 17(1), 306.

61 Queensland Government, Department of Agriculture and Fisheries (2022) Outbreaks of avian influenza. <https://www.daf.qld.gov.au/business-priorities/biosecurity/animal-biosecurity-welfare/animal-health-pests-diseases/notifiable/outbreaks> (accessed 12 June 2024); South Australia Department of Primary Industries and Regions (2024) Avian influenza. <https://pir.sa.gov.au/biosecurity/animal_health/animal_species/poultry/avian_influenza> (accessed 12 June 2024).

62 Communicable Disease Network Australia (2016) Avian influenza in humans: CDNA national guidelines for public health units. Communicable Disease Network Australia. <https://www.health.gov.au/sites/default/files/2023-08/avian-influenza-in-humans-cdna-national-guidelines-for-public-health-units_1.pdf> (accessed 15 May 2024).

Dengue

Dengue is a vector borne disease transmitted by *Aedes* species mosquitoes, which can also spread Zika and chikungunya. Dengue is endemic in more than 100 countries, and the World Health Organization reported a ten-fold surge from 2000–2019 amounting to approximately 5.2 million cases per year.[63] In April 2024, Brazil classified dengue as a public health emergency, with 3 million cases occurring due to rising temperatures and El Niño-associated heatwaves and rainfall.[64]

Australia reports around 1,000 notifications of dengue annually, however, 95% of these cases are acquired overseas.[65] Locally acquired cases (confined to Far North Queensland) have decreased from 236 in 2013 to zero in 2021 and 2022 following widespread *Wolbachia* rollouts.[66]

The future rates of dengue vector and virus distribution in Australia are difficult to project and will be influenced by many factors including warming, increased domestic water storage (due to regional drying) and human population growth. While some research implies these drivers are likely to see an increased risk of dengue into more southern and inland regions of Australia,[67] other modelled scenarios indicate a reduced risk is possible.[68] Further adding to the uncertainty of future risk is the potential for the dengue-transmitting *Aedes albopictus* species to enter mainland Australia (currently found in the Torres Strait as well as North and South America, Africa, Europe and the Middle East).

Between 2020 and 2050, public health costs of dengue are estimated to rise from $1.35m to $1.87m per year, with an additional 900 lost workdays per year.[69] While controls like the *Wolbachia* bacteria are demonstrating effectiveness in some contexts, there are no licensed antivirals for dengue treatment and limited vaccines for prevention.[70] The development of effective universal therapeutics is complicated by the existence of four distinct dengue variants; with therapies for one variant impacting the safety and efficacy of therapies for others. This presents additional challenges for regions where more than one variant establishes.

63 World Health Organization (2023) Disease Outbreak News; Dengue – Global situation. <https://www.who.int/emergencies/disease-outbreak-news/item/2023-DON498> (accessed 9 May 2024).

64 Glatter RD, Ferreira JSD (2024) An Escalation of Dengue in Brazil Echoes a Global Crisis. <https://www.medscape.com/viewarticle/escalation-dengue-brazil-echoes-global-crisis-2024a10006js?form=fpf> (accessed 10 May 2024).

65 Sohail A et al. (2024) The epidemiology of imported and locally acquired dengue in Australia, 2012-2022. Journal of Travel Medicine 31(2).

66 Sohail A et al. (2024) The epidemiology of imported and locally acquired dengue in Australia, 2012-2022. Journal of Travel Medicine 31(2).

67 Russell RC et al. (2009) Dengue and climate change in Australia: predictions for the future should incorporate knowledge from the past. Medical Journal of Australia 190(5), 265–268.

68 Williams et al. (2016) Projections of increased and decreased dengue incidence under climate change. Epidemiology and Infection 144(14), 3091-3100.

69 Bambrick HJ, Woodruff RE, Hanigan IC (2009) Climate change could threaten blood supply by altering the distribution of vector-borne disease: an Australian case-study. Global health action 2(1).

70 Kwek SS, Ooi EE (2024) Race against dengue. Elife 13(e96018), 1–2.

Japanese encephalitis

Japanese encephalitis is a vector borne disease most commonly transmitted by *Culex* species mosquitoes. The virus is endemic in 24 countries in the Western Pacific and South-East Asia, with an estimated 70,000 annual cases.[71] Less than 1% of cases experience severe symptoms. However, of those that do, roughly one-third are fatal, and another third are left with permanent injury to the brain and nervous system.[72]

In 2022, mainland Australia experienced its first ever Japanese encephalitis outbreak. There were 45 reported cases associated with this outbreak including 7 fatalities.[73] The outbreak followed months of intense rainfall that resulted in the creation of inland wetlands, the migration of wading birds (disease hosts) to the south, and a surge in mosquito populations. Viral amplification in pig populations also facilitated virus spread to southern Australia. Japanese encephalitis was identified in more than 80 piggeries in Queensland, New South Wales, Victoria and South Australia.[74] With the establishment of Japanese encephalitis in mainland Australia, there is a high likelihood of endemic circulation and future outbreaks.[75]

The emergence of Japanese encephalitis in mainland Australia underscores the need for One Health approaches to tackle zoonotic diseases, coordinating human, animal and environmental health sectors. In 2022, the Australian Government recognised these risks and committed $69 million to control Japanese encephalitis spread including vaccines, mosquito surveillance and control, and agricultural support.[76]

71 World Health Organization (2019) Japanese encephalitis. World Health Organisation. <https://www.who.int/news-room/fact-sheets/detail/japanese-encephalitis> (accessed 14 May 2024).

72 Queensland Government (2024) Japanese encephalitis. Queensland Health, Australia. <https://www.qld.gov.au/health/condition/infections-and-parasites/viral-infections/japanese-encephalitis> (accessed 14 May 2024).

73 Australian Government, Department of Health and Aged Care (2023) Statement on the end of Japanese encephalitis virus emergency response. <https://www.health.gov.au/news/statement-on-the-end-of-japanese-encephalitis-virus-emergency-response> (accessed 15 May 2024).

74 Australian Government, Department of Agriculture, Fisheries and Forestry (2023) Japanese encephalitis virus. Department of Agriculture, Fisheries and Forestry, Australia. <https://www.agriculture.gov.au/biosecurity-trade/pests-diseases-weeds/animal/japanese-encephalitis> (accessed 14 May 2024).

75 Australian Government, Department of Agriculture, Fisheries and Forestry (2023) Japanese encephalitis virus. <https://www.agriculture.gov.au/biosecurity-trade/pests-diseases-weeds/animal/japanese-encephalitis> (accessed 12 June 2024); McGuinness SL, Lau CL, Leder K (2023) The evolving Japanese encephalitis situation in Australia and implications for travel medicine. Journal of Travel Medicine 30(2), 1–4; Pendrey CG, Martin GE (2023) Japanese encephalitis clinical update: Changing diseases under a changing climate. Australian Journal of General Practice 52(5).

76 Australian Government, Department of Health and Aged Care (2022) $69 million for Japanese encephalitis virus (JEV) response. <https://www.health.gov.au/ministers/the-hon-greg-hunt-mp/media/69-million-for-japanese-encephalitis-virus-jev-response> (accessed 15 May 2024).

Melioidosis

Melioidosis is caused by exposure to the *Burkholderia pseudomallei* bacteria in contaminated soil or water, or more rarely, by direct contact with an infected person. The disease is endemic in the tropical north of Australia including the Kimberly region of Western Australia, Northern Territory and North Queensland; however, sporadic cases have been reported in other states.[77] Approximately 400 cases of human infection have been reported in Queensland between 2019 and 2023,[78] with the majority of infected individuals having one or more associated risk factors such as diabetes, cancer, chronic lung or kidney disease.[79] Fatality rates vary but are as high as 50% in Far North Queensland.[80] With early diagnosis and treatment, fatality can be reduced to less than 10%, but fatality remains high in regional areas where there is reduced access to health services.[81]

Melioidosis disproportionately affects Aboriginal and Torres Strait Islander peoples. Between 2012–2016, there was an average of 5.7 cases per 100,000 Aboriginal and Torres Strait Islander peoples. For non-Indigenous Australians the rate was 0.4 cases per 100,000 people.[82]

Climate conditions strongly aggravate the transmission of melioidosis, with increased incidences and severity associated with heavy rainfall and extreme weather events like windstorms and cyclones, all of which are expected to become more frequent and intense by 2050.

Salmonellosis

Salmonellosis is caused by the ingestion of food or water contaminated with *Salmonella* bacteria, or less commonly, by direct contact with an infected person or animal. Salmonellosis is the most common cause of food borne disease outbreaks in Australia.[83] Each year there are around 55,000 cases of non-typhoidal salmonellosis in Australia, amounting to an estimated $140 million in total public health costs.[84]

Warming is likely to increase the incidence of salmonellosis in Australia. A 1°C increase in mean temperature is associated with an up to 15% increase in incidences of salmonellosis.[85]

77 Inglish TJ (2021) Melioidosis in Australia. Microbiology Australia 42(2), 96–99.

78 Queensland Government (2024) Notifiable conditions annual reporting <https://www.health.qld.gov.au/clinical-practice/guidelines-procedures/diseases-infection/surveillance/reports/notifiable/annual> (accessed 12 June 2024).

79 Currie et al. (2021) The Darwin Prospective Melioidosis Study: a 30–year prospective, observational investigation. Lancet Infectious Disease 21(12), 1737–1746.

80 Smith S, Hanson J, Currie BJ (2018) Melioidosis: An Australian Perspective. Tropical Medicine and Infectious Disease 3(1), 27.

81 Currie et al. (2021) The Darwin Prospective Melioidosis Study: a 30–year prospective, observational investigation. Lancet Infectious Disease 21(12), 1737–1746.

82 Queensland Department of Health (2017) Melioidosis in Queensland 2012–2016. <https://www.health.qld.gov.au/__data/assets/pdf_file/0026/671183/melioidosis-qld-2012-2016.pdf> (accessed 17 May 2024).

83 OzFoodNet Working Group (2021) Monitoring the incidence and causes of diseases potentially transmitted by food in Australia: Annual report of the OzFoodNet network, 2013–2015. Communicable diseases Intelligence (45); OzFood Working Group (2022) Monitoring the incidence and causes of disease potentially transmitted by food in Australia: Annual report of the OzFoodNet network, 2017. Communicable Disease Intelligence (46).

84 Australia National University (2022) The annual cost of foodborne illness in Australia. <https://www.foodstandards.gov.au/sites/default/files/publications/Documents/ANU%20Foodborne%20Disease%20Final%20Report.pdf> (accessed 14 May 2024); Hall et al. (2008) Estimating community incidence of Salmonella, Campylobacter, and Shiga toxin-producing Escherichia coli infections, Australia. Emerging Infectious Disease 14(10), 1601–1609. Queensland Health Department (2017) Foodborne disease outbreaks. <https://www.health.qld.gov.au/clinical-practice/guidelines-procedures/diseases-infection/diseases/foodborne/outbreaks> (accessed 14 May 2024).

85 Milazzo et al. (2015) The effect of temperature on different Salmonella serotypes during warm seasons in a Mediterranean climate city, Adelaide, Australia. Epidemiology and Infection 144(6) 1231–1240; Zhang Y, Bi P, Hiller JE (2010) Climate variations and Salmonella infection in Australian subtropical and tropical regions. Science of The Total Environment 408(3), 524–530.

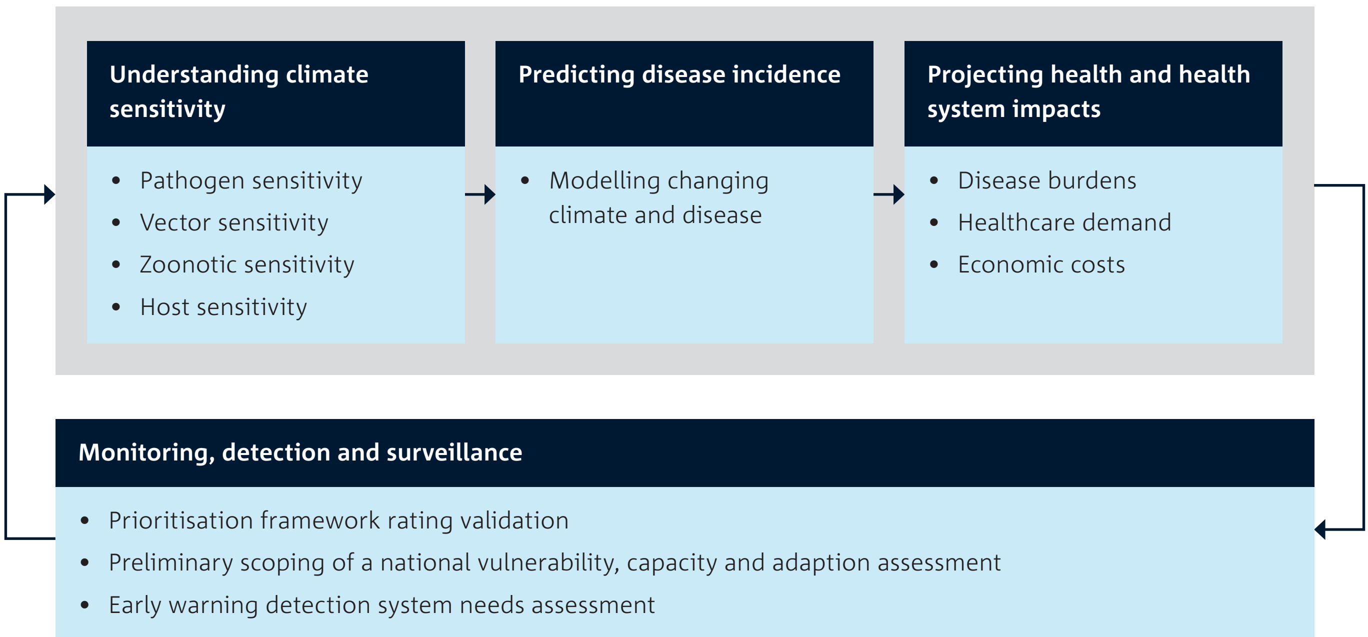
4 Priority needs for further analysis

A range of research activities and analyses are needed to better understand climate impacts on communicable diseases within the Australian context. Examples were developed in collaboration with consulted stakeholders and fall under four broad objectives: understanding climate sensitivity, predicting disease incidence, projecting health and health system impacts, and monitoring, detection and surveillance (see Figure 5).

Activities that target these objectives can inform each other, ideally forming an ongoing cycle of data collection and insight gathering that ensures the nation's prioritisation of communicable disease risk is responsive to the ever-evolving global context. Each of these activities can inform the structure, weightings, and ratings of the prioritisation framework presented in Section 3 and should link with upstream disease prevention activities and downstream outbreak response activities.

While these activities are all important for informing comprehensive national risk assessments, those most frequently raised in stakeholder consultations, and with the potential to provide valuable short-term insights, fall under the monitoring, detection and surveillance objective. These could be considered nearer term priorities for establishing a strong foundation for the other activities. This section provides an overview of three forms of analysis that were suggested within this context. Further research and analysis examples that map to the other objectives from Figure 5 can be found in Appendix A.3.

Figure 5: Summary of further research and analysis needs grouped by objective.



Prioritisation framework rating validation

While this discussion paper is a start, the assessment of 93 communicable diseases against the prioritisation framework in Section 3 was developed rapidly for discussion purposes only. More robust analysis and validation of the disease assessments against the criteria is needed to build a sufficient evidence base for the prioritisation of national policy and investment decisions.

Comprehensive assessment could help guide evidence-informed investments in health service delivery, adaption efforts, infrastructure, information systems, and workforce education and skills to support Australia's resilience against future communicable disease risks. The results of more robust analysis and validation could also inform a national vulnerability, capacity and adaptation assessment, and identify priority diseases for the development of early warning systems.

Rating validation could be undertaken by comprehensively assessing each criterion from Section 3 for each of the 93 communicable diseases through further desktop research and validation from Australian communicable disease experts. This validation process could also involve expanding the analysis to capture non-communicable infectious diseases (e.g., tetanus or legionellosis), as well as diseases that are not notifiable or frequently reported in notable climate health literature.

Preliminary scoping of a national vulnerability, capacity and adaptation assessment

The *National Health and Climate Strategy* notes the intent of the Australian Government to undertake a National Health Vulnerability, Capacity and Adaptation (VCA) Assessment, starting with an analysis of the Health and Social Support System within the National Climate Risk Assessment.[86] VCA assessments are a useful tool for holistically evaluating a nation's capacity to manage the impacts of climate change on health and wellbeing, and can be used to consolidate the outputs of a breadth of analyses into a single coherent national narrative and plan.

To inform the planning process of the National Health VCA Assessment, an initial piece of work could involve adapting existing frameworks and guidance to the Australian context. A particularly relevant example is the World Health Organization's Vulnerability and Adaptation Framework,[87] which several countries have used as a guide for assessing the impact of climate on all health conditions. The framework provides guidance on assessing the current burden of climate sensitive health outcomes, the capacity of health systems to manage these burdens, baseline analysis against which changes in disease risks and protective measures can be monitored, and pairs risk assessments with policy-relevant insights and actions for addressing current and future risks.

Adapting existing frameworks to the Australian context would require consideration of the geographic, demographic and climatic diversity of Australia, as well as the wide variation in health system capacity and capability. This Australian-specific VCA framework could then be tested and refined through the rapid assessment of a selection of priority communicable diseases, prior to national implementation. Outputs from the other analyses described in this report could also feed into this process. For example, there would be synergies (information flows, efficient stakeholder engagement) in conducting this analysis alongside the validation of ratings from the prioritisation framework.

86 Australian Government Department of Health and Aged Care (2023) National Health and Climate Strategy. Canberra, Australia.

87 World Health Organization (2021) Climate Change and Health Vulnerability and Adaptation Assessment. Geneva, Switzerland.

Early warning system needs assessment

Early warning systems provide essential information about the likelihood of disease outbreaks before they occur and allow for implementation of mitigating activities to reduce the impact of a potential outbreak or prevent an outbreak entirely.[88] The data collected through early warning systems can also inform ongoing analyses to ensure Australia's communicable disease risk prioritisation is responsive and reflective of evolving global contexts. Early warning systems are routinely used for predicting extreme weather events and have been adapted across Europe, Africa and the Asia-Pacific to anticipate the emergence of zoonotic and vector borne diseases,[89] and extreme weather-related food and water borne diseases.[90]

To identify the highest value early warning system needs for Australia, a gap analysis and needs assessment of Australia's surveillance systems could be conducted for the priority diseases identified through the other analyses described in this section. This could include evaluating existing systems across human, animal and environmental sectors, including the data collection and processing requirements of each.

88 Hassan OA, Balogh K, Winkler AS (2023) One Health early warning and response system for zoonotic diseases outbreaks: Emphasis on the involvement of grassroots actors. Veterinary Medicine and Science 9(4) 1881–1889; National Research Council (US) Committee on Climate, Ecosystems, and Infectious Disease (2001) Under the Weather: Climate, Ecosystems, and Infectious Disease. National Academies Press, Washington DC, United States.

89 European Climate Adapt (2023) Early warning systems for vector-borne diseases. <https://climate-adapt.eea.europa.eu/en/metadata/adaptation-options/early-warning-systems-for-vector-borne-diseases> (accessed 17 May 2024); Inter-American Institute for Global Change Research: IAI and Wellcome Trust (2022) Landscape mapping of software tools for climate-sensitive infectious disease modelling. <https://www.iai.int/admin/site/sites/default/files/Landscape_mapping_of_software_tools_for_climate_sensitvie_infectious_disease_modelling_0.pdf> (accessed 20 June 2024); Pley et al. (2021) Digital and technological innovation in vector-borne disease surveillance to predict, detect, and control climate-driven outbreaks. Lancet Planet Health 5, e739–756.

90 ENBEL Project (n.d.) Addressing Extreme Weather Related Diarrheal Disease Risks in the Asia Pacific Region Project Page <https://www.enbel-project.eu/projects-page/award-apr> (accessed 17 May 2024).

Appendices

A.1 Consulted organisations

CSIRO would like to thank the 57 experts from across the following organisations for their contributions to the project through interviews and reviews. The insights expressed throughout this report were developed by considering the collective views obtained alongside independent desktop research. Insights may not always align with the views of the consulted individuals or organisations. This list is not to be interpreted as an endorsement or promotion of this report.

- Australian Climate Service
- Australian Government Department of Agriculture, Fisheries and Forestry
- Australian Government Department of Climate Change, Energy, the Environment and Water
- Australian Government Department of Foreign Affairs and Trade
- Australian Government Department of Health and Aged Care
- Australian Partnership for Preparedness Research on Infectious Disease Emergencies
- Charles Darwin University
- Communicable Diseases Network Australia
- Commonwealth Scientific and Industrial Research Organisation
- Healthy Environments and Lives (HEAL) National Research Network
- Monash University
- NT Health
- OzFoodNet Central
- The Australian National University
- The Climate and Health Alliance
- The Kirby Institute Biosecurity Program
- The Public Health Association of Australia
- The Royal Australian College of Physicians
- The University of Adelaide
- The University of Canberra, HEAL Global Research Centre
- The University of Queensland
- The University of Sydney Infectious Diseases Institute
- The University of Sydney School of Public Health
- The University of Washington
- The University of Wisconsin-Madison

A.2 Assessed communicable diseases

By combining national, state and territory notifiable disease registers,[91] notable climate health literature,[92] and insights from consultation with communicable disease experts, a total of 93 communicable diseases were identified that represent a potential risk to Australia in 2050. These diseases were assessed in the Section 3 analysis.

- Amoebiasis
- Anthrax (cutaneous and pulmonary)
- Australian bat lyssavirus
- Avian Influenza in humans (HPAI H5N1)
- Barmah Forest virus
- Botulism
- Brucellosis
- Campylobacteriosis
- Candida auris
- Carbapenemase-producing enterobacterales
- Chancroid
- Chikungunya virus
- Chlamydial trachomatis infection (trachoma and non-trachoma)
- Cholera
- Coronavirus Disease 2019 (COVID-19/SARS-CoV-2)
- Creutzfeldt-Jakob disease (all forms)
- Cryptosporidiosis
- Dengue
- Diphtheria
- Donovanosis
- Echinococcosis (hydatid)
- Flavivirus infection (unspecified; including Alfuy, Kokobera, Edge Hill, Stratford, New Mapoon and Zika)
- Gan Gan virus
- Getah virus
- Giardiasis
- Gonococcal infection
- Haemophilus influenzae type b infection (Hib)
- Hendra virus
- Hepatitis A
- Hepatitis B
- Hepatitis C
- Hepatitis E
- HTLV-1
- Human African trypanosomiasis (sleeping sickness)
- Human immunodeficiency virus (HIV)
- Influenza
- Invasive group A streptococcal disease (iGAS)
- Japanese encephalitis
- Leishmaniasis
- Leprosy
- Leptospirosis
- Listeriosis
- Lymphogranuloma venereum (LGV)
- Malaria
- Mapputta virus
- Measles

91 ACT Health (2022) Disease surveillance and public health response. <https://www.act.gov.au/directorates-and-agencies/act-health/our-business-areas/population-health/disease-surveillance-unit> (accessed 17 May 2024); Australian Government Department of Health and Aged Care (2024) List of nationally notifiable diseases. <https://www.health.gov.au/topics/communicable-diseases/nationally-notifiable-diseases/list> (accessed 17 May 2024); QLD Health (2023) List of notifiable conditions. <https://www.health.qld.gov.au/clinical-practice/guidelines-procedures/diseases-infection/notifiable-conditions/list> (accessed 17 May 2024); NSW Health (2024) Disease notification. <https://www.health.nsw.gov.au/Infectious/Pages/notification.aspx> (accessed 17 May 2024); NT Health (2024) Surveillance and Response Unit. <https://health.nt.gov.au/professionals/centre-for-disease-control/surveillance-response-unit> (accessed 17 May 2024); SA Health (2023) Notifiable disease reporting <www.sahealth.sa.gov.au/wps/wcm/connect/public+content/sa+health+internet/clinical+resources/health+notifications/notifiable+disease+reporting/notifiable+disease+reporting > (accessed 17 May 2024); TAS Department of Health (2024) Infectious diseases guides and fact sheets. <https://www.health.tas.gov.au/health-topics/infectious-diseases/infectious-diseases-guides-and-fact-sheets> (accessed 17 May 2024); VIC Department of Health (2024) Notifiableinfectious diseases conditions and micro organisms. <https://www.health.vic.gov.au/infectious-diseases/notifiable-infectious-diseases-conditions-and-micro-organisms> (accessed 17 May 2024); WA Department of Health (2023) Notification of infectious diseases and related conditions. <https://www.health.wa.gov.au/Articles/N_R/Notification-of-infectious-diseases-and-related-conditions> (accessed 17 May 2024).

92 Australian Government Department of Health and Aged Care (2023) National Health and Climate Strategy. Canberra, Australia; Centre for Disease Control (2024) Climate and Infectious Diseases <https://www.cdc.gov/ncezid/priorities/climate-infectious-disease.html?CDC_AAref_Val=https://www.cdc.gov/ncezid/what-we-do/climate-change-and-infectious-diseases/index.html> (accessed 17 May 2024); European Centre for Disease Prevention and Control (2010) Climate change and communicable diseases in the EU Member States <https://www.ecdc.europa.eu/sites/default/files/media/en/publications/Publications/1003_TED_handbook_climatechange.pdf> (accessed 17 May 2024); Mora et al. (2022) Over half of known human pathogenic diseases can be aggravated by climate change. Nature Climate Change 12, 869–875; UK Health Security Agency (2023) Health Effects of Climate Change (HECC) in the UK: 2023 report. Chapter 7. Effect of climate change on infectious diseases in the UK <https://assets.publishing.service.gov.uk/media/657087777469300012488921/HECC-report-2023-chapter-7-infectious-diseases.pdf> (accessed 17 May 2024); World Health Organization (2024) Neglected tropical diseases <https://www.who.int/data/gho/data/themes/neglected-tropical-diseases> (accessed 17 May 2024).

- Melioidosis
- Meningococcal disease (invasive)
- Methicillin resistant *Staphylococcus aureus* (MRSA) infection/colonisation
- Middle East respiratory syndrome coronavirus (MERS-CoV)
- Mpox (Monkeypox virus)
- Mumps
- Murray Valley encephalitis
- Mycobacterium ulcerans (Buruli ulcer)
- Onchocerciasis (river blindness)
- Paratyphoid fever
- Pertussis (whooping cough)
- Plague
- Pneumococcal disease (*Streptococcus pneumoniae*)
- Poliovirus infection (poliomyelitis)
- Psittacosis (ornithosis)
- Q fever
- Rabies
- Respiratory syncytial virus (RSV)
- Rickettsia infection (including spotted fevers and all forms of typhus fever)
- Ross River virus
- Rotavirus infection
- Rubella
- Salmonellosis
- Scabies (crusted)
- Schistosomiasis (bilharzia)
- Severe acute respiratory syndrome (SARS)
- Shigatoxin and verotoxin producing *Escherichia coli*
- Shigellosis (shigella)
- Sindbis
- Smallpox
- Soil-transmitted helminthiases and strongyloidiasis
- Syphilis
- Taeniasis and cysticercosis
- Termeil virus
- Toxoplasmosis
- Trubanaman virus
- Tuberculosis
- Tularaemia
- Typhoid fever
- Vancomycin Resistant Enterococcus (VRE) infection/colonisation
- Varicella zoster infection (unspecified; including chickenpox and shingles)
- Vibrio parahaemolyticus
- Viral haemorrhagic fevers (all forms; including Crimean-Congo, Ebola, Lassa fever and Marburg viruses)
- West Nile/Kunjin virus
- Yaws (endemic treponematoses)
- Yellow fever
- Yersiniosis

A.3 Additional needs for further analysis

This appendix provides additional examples of research and analysis activities that can advance national understanding around the impact of climate on communicable disease risk. They were developed in collaboration with consulted stakeholders and are not intended to be an exhaustive list. They do not cover all concepts listed in Figure 5.

Planning discrete projects that map to these concepts will require tailoring for key variables including disease, climate projections, epidemiology, and geography, and consider cultural, behavioural, economic, and genetic differences across communities. Efforts should also draw on multisectoral and transdisciplinary expertise and utilise One Health approaches, recognising the interconnection of human, animal and environmental health. Additionally, indirect factors of climate change, like the social and environmental determinants of health, socioeconomic impacts, food security, population demographics and mental wellbeing should also be considered.

Understanding climate sensitivity

Pathogen climate sensitivity

Climate change can induce mutations in pathogens, affecting pathogen survival, replication and virulence. Conducting analyses to examine mutation rates, their location on the genome, and the resulting functional change is valuable to understand pathogen sensitivity in relation to different climate conditions.

One approach to exploring pathogen climate sensitivity could include utilising machine learning and statistical approaches to conduct genome sequence alignments of pathogen species from different climates around the world. Once correlations between pathogen mutations and climate conditions have been identified, these studies can then seek to understand the direction and degree to which they might impact pathogen survival, replication and virulence within the Australian context by focussing on Australian-relevant pathogen species, samples and climate variables.

For example, using these methods, CSIRO identified 340 mutations in the dengue virus that are associated with warmer climates (see Appendix A.4 for further detail). Of note, most of these observed mutations were in a gene previously implicated as temperature sensitive in laboratory settings. In contrast, the opposite was observed for *Salmonella* bacteria, where heat resistant mutations were not observed in real-world samples. These findings highlight the need for more research to better understand the mechanisms of how heat might drive mutations in pathogens as they may occur differently in laboratory settings compared to the real world.

Vector climate sensitivity – mosquitoes

Mosquito borne diseases are the most climate sensitive of all transmission types (see Section 2). Approximately 40 species in Australia are known to bite humans and can spread disease.[93] While some studies have explored the impact of climate on *Aedes* mosquitoes (dengue vector),[94] and *Anopheles* mosquitoes (malaria vector),[95] more Australian-specific insights are needed, including for *Culex* mosquitoes (Japanese encephalitis, Barmah Forest virus, Ross River virus and Murray Valley encephalitis vector). Understanding the impact of climate variables on different mosquito species, the diseases they have the potential to carry, and inter-species dynamics within the Australian context, will be critical for informing priority 2050 risk assessments.

A prioritisation framework for mosquito specific pathogens has been established within the African context,[96] and a similar method could be applied to the Australian context. These methods utilise expert elicitation to develop a ranking of priority pathogens based on a range of criteria to measure their risk and impact on socioeconomics and human health.

New analysis should integrate data from field surveillance, modelling and laboratory experiments on field-collected mosquitoes to assess the impact of climate changes on mosquito fitness, population abundance, and vectorial capacity. The resulting transmission models and data could then be used to validate the mosquito species that pose high risk to Australia, and the relevant diseases. This will help identify at-risk regions and inform early warning systems to support targeted surveillance and interventions.

93 Claflin SB, Webb CE (2015) Ross River Virus: Many Vectors and Unusual Hosts Make for an Unpredictable Pathogen. Public Library of Science Pathogen 11(9), e1005070.

94 Rezza G (2024) Climate change and the spread of Aedes mosquito-borne viruses in Europe. Pathogen Global Health. 1–2.

95 Siraj et al. (2013) Altitudinal Changes in Malaria Incidence in Highlands of Ethiopia and Colombia. Science 343(6171), 1154–1158.

96 Hayes et al. (2020) Structured prioritisation of human and animal pathogens for the purpose of scoping risk assessments of genetic control strategies for malaria vectors in sub-Saharan Africa. CSIRO, Hobart, Tasmania.

Zoonotic climate sensitivity

Over 60% of infectious diseases in humans have originated in animals,[97] and some recent outbreaks of diseases in Australia have been zoonotic in origin, such as COVID-19 and Mpox. Further, many vector borne diseases also rely on one or more intermediary animal hosts. Understanding the impact of climate on animal distribution, ecological change (including change in land use) and animal to human transmission is crucial for predicting the risk of current and novel zoonotic diseases.

Analysis in this field involves integrating ecological, biological and climatic data to understand how climate changes influence the transmission dynamics of zoonotic diseases.[98] One method of analysis is ecological niche modelling, which models current habitat suitability based on several factors including climate data, to estimate the geographic distribution of animal species. Future geographic distributions can be determined based on current habitat suitability and projected climate changes.[99] Outcomes of this analysis can highlight regions in Australia that are expected to experience changes in animal populations and consequently the diseases they carry.

This analysis can be conducted in tandem with zoonotic spillover modelling to quantify the likelihood of spillover risk (when an infectious agent jumps from an animal host to a human) in high priority animal and disease ecology hotspots.[100] This method considers factors such as human population density and zoonotic virus diversity to estimate the spatial distribution of spillover risk. This spillover risk can be correlated with climatic variables and projected to various climate scenarios in 2050. Efforts could focus on high-risk pathogen families known to cross into humans, such as *coronaviridae*, *flaviviridae*, *orthomyxoviridae*, *paramyxoviridae* and *togaviridae*.[101] These approaches are critical to ensure Australia is well prepared for diseases that the nation is yet to have experienced.

Predicting disease incidence

Modelling changing climate and disease

Once robust climate sensitivity data exists for pathogens of interest and their vectors, hosts and reservoirs, disease projections will require consideration of Australia's unique geographic and climate variability, and how these factors change over time. Currently, literature in this field is limited to discrete regions in Australia and for limited diseases. Comprehensive analyses that encompass all Australian regions and address all priority diseases are needed to better inform national risk.

Statistical and process-based spatio-temporal models offer these forms of analyses. Spatio-temporal models use disease incidence and climate variables, while accounting for additional factors that influence disease transmission. These factors include geographic location, vectors and animal reservoirs distribution, intermediate hosts distribution, seasonality, lag time effects, the effects of existing medical countermeasures and mitigation strategies, herd immunity, socioeconomic status and demographic shifts. By modelling these variables to projected climate scenarios, spatio-temporal analyses can provide a more holistic and accurate projection of disease incidence and geographic spread across Australia to 2050.

97 Ellwanger JH, Chies JAB (2021) Zoonotic spillover: Understanding basic aspects for better prevention. Genetics and Molecular Biology 44(1 suppl), e20200355.

98 Gibb et al. (2020). Ecosystem perspectives are needed to manage zoonotic risks in a changing climate. BMJ 371:m3389, 1–7.

99 Graham et al. (2019). Climate change and biodiversity in Australia: a systematic modelling approach to nationwide species distributions. Australian Journal of Environmental Management 26(2), 112–123.

100 Golchin et al. (2024) Prediction of viral spillover risk based on the mass action principle. One Health 18 (100737); Plowright et al. (2024) Ecological countermeasures to prevent pathogen spillover and subsequent pandemics. Nature Communication 15 (2577).

101 CSIRO Futures (2022) Strengthening Australia's Pandemic Preparedness: Science and technology-enabled solutions. CSIRO, Canberra.

Projecting health and health system impacts

Projecting disease burdens

Many analyses focus on the correlation of climate and disease, but there is a gap in understanding how much of the burden of communicable diseases can be attributed to climate changes. By quantifying the burden of communicable disease due to key climate variables, health systems can more appropriately prioritise efforts based on projected climate conditions.

Future burden of disease analyses could focus on priority communicable diseases that lack burden of disease data (e.g., dengue, melioidosis, cryptosporidiosis), addressing the gaps as outlined in the Australian Institute of Health and Welfare's Climate and Environmental Health Report.[102] Inputs of this analyses could include climate risk factors as well as additional variables that influence burdens of disease such as acuteness, existing medical countermeasures, socioeconomic status, and demographic shifts. These analyses can model disability-adjusted-life-years (DALYs), years of life lost (YLLs) and years lived with disability (YLDs) data to different climate variables over time. Once a baseline relationship between burden of communicable disease and climate conditions is established, these models can project the associated burden of communicable diseases for different climate scenarios in 2050.

Projecting healthcare demand

Several forms of healthcare demand are linked to climate. One example being hospital and intensive care unit admissions for respiratory conditions which show a correlation with climate changes.[103] Understanding the climate variables that are linked to health care demand for communicable diseases can help to assess future healthcare demand and effectively prepare the Australian healthcare system for the challenges anticipated in 2050.

These analyses could involve using historical hospital admission and primary health care demand, climate forecast and climate projection data to model the relationship between climate variables and health system demand for various communicable diseases and potential outbreak scenarios. These analyses can be region, disease, and time specific, and can be applied to project the demand for a range of health services including primary healthcare, specialist and hospital services.

Projecting economic costs

Climate change will likely increase the incidence of many communicable diseases, increasing the associated economic cost in the future. There is a lack of modelling outputs on the current indirect economic costs of many communicable diseases, although there are comprehensive data on the direct health system spending for various diseases across Australia.[104] While previous studies assessed the economic costs of select diseases,[105] they have not covered the full spectrum of communicable diseases in Australia. Understanding the current economic cost to Australia for priority communicable diseases, their projected incidence in 2050 due to climate change, and the economic cost of different outbreak scenarios, is critical to helping prioritise investments and preventative measures.

The economic cost of communicable diseases under a baseline global warming scenario in 2050 could be estimated by applying the projected burden of communicable diseases (measured as DALYs, YLLs and YLDs) to the current economic cost of that disease. Costs should include direct costs (e.g., public health expenditures) and indirect costs (e.g., absenteeism, workplace productivity, government subsidies, the cost of DALYs and change in tourism). Future economic costs could then be estimated based on projected disease burdens for different scenarios.

102 Australian Institute of Health and Welfare (2024) Climate change and environmental health indicators: reporting framework. Australian Government, Canberra. <https://www.aihw.gov.au/reports/environment-and-health/climate-change-and-environmental-health-indicators/summary> (accessed 22 May 2024)

103 Poon et al. (2023) Projecting Future Climate Impact on National Australia Respiratory-Related Intensive Care Unit Demand. Heart Lung and Circulation 32(1), 95–104.

104 Australian Institute of Health and Welfare (2023) Health system spending on disease and injury in Australia, 2020-21. <https://www.aihw.gov.au/reports/health-welfare-expenditure/health-system-spending-on-disease-and-injury-in-au/contents/summary> (accessed 17 May 2024).

105 Crosland et al. (2019) The economic cost of preventable disease in Australia: a systematic review of estimates and methods. Australian and New Zealand Journal of Public Health. 43(5), 484–495; PwC (2015) Weighting the cost of obesity: A case for action.

A.4 Pathogen climate sensitivity – applied research findings

As outlined in Appendix A.3, analysing pathogen sensitivity to changing climate conditions will be valuable in informing the ongoing assessment and prioritisation of communicable disease risks in Australia. To demonstrate methodologies that could contribute to this form of analysis, CSIRO researchers studied the link between genetic mutations and temperature for influenza, dengue and *Salmonella*.

Two separate methodologies were explored: (i) machine learning to identify heat sensitive mutations, and (ii) statistical analysis for validating laboratory insights with Australian samples. The intent of these analyses was to better understand the suitability of these approaches and to identify challenges within the data or the approach that will need to be addressed to apply the methodologies to other diseases or conduct further analysis that can validate causal relationships.

Machine learning to identify heat sensitive mutations

Before studies can explore the transmission risk impacts of temperature and temperature related mutations, it is first necessary to identify temperature sensitive mutations. CSIRO researchers designed machine learning algorithms to identify temperature sensitive mutations from the genomes of influenza and dengue. This involved pairing global pathogen genomic data sets with global temperature data sets.

For dengue, 340 temperature sensitive mutations were identified that would be suitable candidates for causality and impact related analyses. Consistent with the literature, these are clustered in a specific genomic region (NS5), which was previously implicated in temperature sensitive mutations.[106] For influenza, similar patterns of mutation were found across regions with varied average temperatures. It is likely that considering average temperature alone is too simplistic for this disease. Previous research has indicated several other factors associated with influenza mutations that may need to be controlled for, including minimum temperature, precipitation, social development index, and population density.[107] However, more quality sample data is needed, especially from warmer climates (average temperatures above 25°C). Without more balanced sample data, it is difficult to identify statistically significant differences between hot and cold climates.

These results indicate that the machine learning algorithms are proficient at navigating vast data series to detect temperature sensitive mutations and can be used to identify promising candidates for further investigation across a wide range of diseases. These candidates may also be suitable for surveillance activities.

Researchers also attempted to examine *Salmonella* using this approach but were unable to do so due to the time taken to convert relevant data into its necessary form. Tools for converting assembly information to standard mutation data are needed to apply this machine learning approach to *Salmonella*.

The next step for the analysis would be to investigate the functional effects of the mutations. Understanding how the mutations impact the pathogen (e.g., strengthening the cell wall) can inform medical countermeasure development (e.g., developing antimicrobials that target these features).

106 Alcaraz-Estrada et al. (2010) Construction of a dengue virus type 4 reporter replicon and analysis of temperature-sensitive mutations in non-structural proteins 3 and 5. Journal of General Virology, 91(11), 2713–2718; Cheng et al. (2022) Impact of intrahost NS5 nucleotide variations on dengue virus replication. Frontiers in Microbiology 13, 894200.

107 Jiang et al. (2020) Could Environment Affect the Mutation of H1N1 Influenza Virus? International Journal of Environmental Research and Public Health 17(9), 3092.

Statistical analysis for validating laboratory insights with Australian samples

Validating laboratory derived hypotheses around temperature sensitivity requires detecting the phenomena in the wild. A 2024 study identified 14 mutations in *Salmonella* associated with increased growth at higher temperatures in a laboratory setting.[108] CSIRO researchers aimed to identify the presence of these mutations (or analogous mutations) in Australian *Salmonella* samples and evaluate whether their emergence correlated with environmental temperature changes.

Upon analysis, no direct link was observed between these specific mutations and the yearly average temperature of Australia. This suggests that if Australian *Salmonella* strains adapt to heat, they may achieve this through currently unreported mutations. One of the implicated genes, *dnaj*, was however found to accumulate mutations at a higher rate than comparative regions in the *Salmonella* genome. This may be indicative of increased selection pressure warranting further analysis. Future studies could aim to incorporate more fine grain temperature information and a more in-depth quantification of mutations; potentially expanding to global *Salmonella* samples.

One challenge experienced was that evolutionary speed makes it difficult to obtain a common reference genome and therefore difficult to compare the locations between strains. As such, a reference free approach may be more appropriate for *Salmonella* data.

108 Berdejo et al. (2024) Evolutionary trade-off between heat shock resistance, growth at high temperature, and virulence expression in Salmonella Typhimurium. American Society for Microbiology 15(3), e3105–3123.

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